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Performance Assessment and Licensing Issues for United States Commercial Near-Surface Low-Level Radioactive Waste Disposal Facilities

National Low-Level Waste Management Program

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Performance Assessment and Licensing Issues

Performance assessment contributes to many aspects of the licensing process. First, engineering and design of a disposal system should use performance assessment in the same manner that analysis is used in the design of any other system (i.e., as an inexpensive alternative to physical testing). Second, PA calculations should not be considered absolute predictions. Results should be used to demonstrate that expected doses within a range of uncertainty would be below specified requirements, as opposed to predicting that the dose will be a specific value.

The final objective of performance assessment for a near-surface LLW disposal facility is to demonstrate that potential radiological impacts for each of the human exposure pathways will not violate applicable standards. This involves determining potential pathways and specific receptor locations for human exposure to radionuclides; developing appropriate scenarios for each of the institutional phases of a disposal facility; and maintaining quality assurance and control of all data, computer codes, and documentation. The results of a performance assessment should be used to demonstrate that the expected impacts are expected to be less than the applicable standards. The results should not be used to try to predict the actual impact. This is an important distinction that results from the uncertainties inherent in performance assessment calculations.

Because of the large data requirements and uncertainties associated with subsurface processes, the process of performance assessment is typically not completed in one attempt. Performance assessment is an iterative process and designs, pathways, and models will typically be updated as new results and data are obtained. Defensible data and calculations contribute to an efficient siting and licensing program and are an essential element of a final license application for a LLW disposal facility (US NRC, 1988a).

Specific radiological performance objectives for commercial LLW facilities in the United States are promulgated in 10 CFR 61 to protect the public and inadvertent intruders (Case and Otis, 1988). The disposal site must be designed to minimize the contact of water with waste during storage, the contact of standing water with waste during disposal. Reasonable assurance must be provided that ongoing active maintenance of the site will not be required following closure. Technical analysis included in the original license application must characterize the long-term stability of the site (as stated in 10 CFR 61.13[d]). The primary emphasis in site suitability is waste isolation and disposal site features that ensure that long-term performance objectives of 10 CFR 61, Subpart C are met. These objectives are protection of the general population from release of radioactivity, protection of individuals from inadvertent intrusion, protection of individuals during operations, and stability of the disposal site after closure. While additional requirements may be promulgated in state and local regulations, the essence of all the regulatory requirements attempt to ensure that the site is capable of being characterized, modeled, analyzed, and monitored.

Performance Objectives

The lifetime of a LLW disposal facility can be divided into several phases: siting, design, construction, operations, final closure and stabilization, post-closure observation and maintenance, and long-term care (active and passive institutional control periods). The purpose of a LLW disposal facility is to isolate LLW for an extended period of time so that the established performance objectives for the facility are met. Each phase should be focused on this purpose.

The disposal site must be designed to minimize the contact of water with waste during storage, the contact of standing water with waste during disposal, and reasonable assurance must be provided that ongoing active maintenance of the site will not be required following closure. Technical analysis included in the original license application must characterize the long-term stability of the site (as stated in 10 CFR 61.13[d]). The primary emphasis in site suitability is waste isolation and disposal site features that ensure that long-term performance objectives of 10 CFR 61, Subpart C are met. These objectives are protection of the general population from release of radioactivity, protection of individuals from inadvertent intrusion, protection of individuals during operations, and stability of the disposal site after closure. The site must be capable of being characterized, modeled, analyzed, and monitored.

During disposal operations, each disposal unit is closed and stabilized as it is filled; closure involves placement of an engineered cover (made of earthen or structural material) over the waste. Final site closure and stabilization are required following completion of operations to prepare the disposal site for the post closure observation and maintenance phase and to assure that the site will remain stable and will not need ongoing active maintenance. During the active phase of facility closure, support buildings are dismantled, the closed disposal units are inspected, and monitoring data are evaluated. During the post-closure observation phase, observations are made to assess the stability of the disposal site and determine whether the site is prepared for institutional control.

Accurate, comprehensive information on facility design, waste classification, characterization, and disposal location is necessary to perform a performance assessment. The environmental monitoring program must be designed to detect the critical radionuclides and chemical constituents at the site. Remedial action alternatives will depend on the specific information on wastes located within a certain area or container. The absence of complete documentation may introduce significant uncertainties regarding potential long-term environmental risks and may dictate a more cautious and conservative approach to site closure and post-closure activities (U.S. NRC, 1982).

Performance Assessment Phases

In terms of performance assessment, the life of the LLW disposal facility can be divided into four phases: 1) pre-operational, 2) operational, 3) short-term post-operational, and 4) long-term post-operational. To adequately assess long-term facility performance, evaluation of monitoring and surveillance results should be performed throughout each of these phases. Also, certain elements of the physical monitoring and assessment program should continue into the long-term post-operational phase to confirm the closure decision. Activities and goals for each performance-monitoring phase are summarized below.

Pre-Operational Activities

Before operation of the LLW disposal facility, site-specific information must be collected as a basis for long-term data analysis. The data collected may be used to predict the behavior of the facility during the operational and post-operational phases.

Operational Activities

The purpose of assessing activities performed during facility construction and waste disposal operations is to verify that the containment system is behaving according to the design basis. This includes verification that waste receipt, handling, and disposal operations comply with the operational plans that are rooted in the design basis. Coupled to this operational assessment is the implementation of a quality control program to assure that waste received is substantially in compliance with projected source term. Lastly, comprehensive environmental monitoring and site surveillance monitoring is performed to verify that waste is effectively isolated from the biosphere.

Short-Term Post-Operational Activities.

Post-operational performance assessments are based on information obtained during the previous phases. Assessments performed during the short-term post-operational phase are used to satisfy the primary objective of interpreting the conditions to make decisions that permit or deny issuance of a closure license.

Long-Term Post-Operational Activities

Long-term post-operational performance assessments are based primarily on information gathered from long-term environmental monitoring and site surveillance programs. This information is compared to that collected during the earlier phases of the monitoring program.

A performance-monitoring program is designed to demonstrate long-term, post-closure performance of a LLW facility. The program provides data to determine whether the engineered confinement structures are effectively isolating the waste and will continue to isolate the waste by remaining structurally stable. The data obtained from this program improves the site operator's ability to plan for the closure of the LLW disposal facility, as well as enhance closure decisions made by the NRC or the licensing authority (INEL/EG&G Idaho, 1990).

Several important degradation processes, including erosion, biological intrusion, and differential settlement, are evaluated using data obtained during environmental surveillance activities. Surveillance involves visual inspection and monitoring at the surface to measure parameters associated with degradation mechanisms. Information collected from this surveillance is used to calibrate the models used for performance assessment.

Inadvertent Intrusion

The design of the facility, how waste was disposed of, and its inventory of radioactive waste must be taken into consideration when evaluating the effects of inadvertent intrusion or biotic transfer mechanisms. Limiting certain waste streams or enhancing the facility design can greatly reduce an intruder's level of exposure to radiation or radioactivity.

10 CFR 61, Subpart C requires protection of individuals from inadvertent intrusion as one of the four performance objectives. Specifically, the regulation states that, "design, operation, and closure of the facility must ensure protection of any individual who inadvertently enters or occupies the site or who comes in contact with the waste after the institutional control period ends." Assurances to deter intrusion must be incorporated into the design of the disposal units. Class C waste, for example must be disposed of so that the top of the waste is a minimum of 5 m below the top surface of the cover over the waste. Alternatively, Class C waste may be placed below intruder barriers which are designed to protect against an inadvertent intrusion for at least 500 years. Intrusion by plant roots and burrowing animals through the cover of a disposal unit promotes water infiltration and may provide a mechanism for the transport of waste constituents to the surface.

Scenario Selection

Development of potential exposure pathways and scenarios is an important part of modeling the disposal system considered during the site characterization phase. Detailed lists of exposure pathways that should be addressed by a performance assessment are included in the NRC methodology report. Typical scenarios are also presented in NUREG-1199, *Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility.* However, site-specific scenarios must also be considered. The most relevant exposure scenarios must then be expanded for each of the facility's institutional phases to form a simple descriptive representation (conceptual model) of the disposal facility (Starmer, 1988; Starmer et al., 1988). A typical example of how exposure scenarios can be expanded is illustrated by the many variations of inadvertent intrusion including mining, agriculture, or residential development.

The applicable requirements and establish performance objectives must then be identified. This information provides a guide for the modeler to begin identifying pathways and scenarios to be considered, which are necessary to construct the site conceptual model. Following this is collection and interpretation of site characterization data. The site characterization involves two-way interactions with a number of the other steps in the process indicating that data collection is a continuous and iterative activity influenced by results of other steps in the PA process.

Using the performance objectives and site characterization data, the next step involves developing the exposure scenarios. The exposure scenarios should include a set of pathways and processes through which an individual may be exposed to radioactivity or radiation from the disposed of wastes. As opposed to worst, or bounding, case, emphasis is placed on making the exposure scenarios realistic and credible. Conceptual models that represent the scenarios are then developed. It is important that the models can accept terms that are easily translated to appropriate modeling inputs which are typically derived from initial site characterization activities. The conceptual models need to be consistent with the level of detail of the available data and the capabilities of the computer codes. Typically, initial performance assessments will be performed using very simple models because of a lack of detailed data. During the development of exposure scenarios and conceptual models, a number of additional data needs are identified.

Mathematical Modeling and Computer Programs

Proper selection and integration of assessment models is essential when assessing exposure pathway consequences. Models are selected based on the ability to represent site-specific phenomena such as source-term release, groundwater flow and transport, airborne transport, surface water transport, uptake through the food chain, and dosimetry. A successful code implementation phase is one in which the computer codes are demonstrated to be capable of representing the site-specific conceptual model of the physical and chemical system.

In most cases, the final dose prediction is based on contributions from a few key radionuclides. Consequently, simple screening calculations such as comparing radioactivity decay times versus the length of the institutional control period can eliminate a majority of the radionuclides in the waste inventory from future consideration. Therefore, PA efforts can be focused initially on the limited number of radionuclides that actually contribute to the predicted dose.

After performing screening calculations, computer codes and modeling approaches that more closely approximate actual conditions are selected for use with the radionuclides that were not screened. Computer codes are selected for their capability to model conditions at the given site. In some cases, it is necessary to modify an existing code to model conditions at a site. Following PA calculations with selected models, the results are evaluated to identify dominant processes and areas where future data may be required, and compared with the objectives. The final step is to report the results, discuss deficiencies, and in some cases, consider the collection of additional data to further calibrate the conceptual model.

In general, the NRC has advocated the use of reasonably conservative and defensible models for a PA (Starmer, 1988; Starmer et al., 1988). Thus, when simplified models are adequate, analytical techniques are included among the analysis methods suggested in the methodology and are preferred over numerical approximations. Clearly some pathways, groundwater in particular, require more complex models. A two-stage modeling approach is used to overcome this challenge.

In the case of groundwater, a detailed characterization (process) model may be used to predict an aquifer flow velocity. The result is then input into a system model that considers multiple pathways to calculate the dose that would be attributable to radioactivity in groundwater. Such an approach allows the results to be reviewed at a higher level with documentation available upon request for the more detailed calculations.

The first iteration of a PA should be used to limit the amount of data that must be collected to conduct the PA. Relatively simple sensitivity and screening analyses can be used early in the PA process to demonstrate the significance of a given input parameter for a specific problem (Case and Otis 1988; Seitz et al. 1991). In this respect, sensitivity analyses identify the data that have a large impact on the predicted dose, and thus warrant the commitment of resources to obtain additional data. Likewise, data with an insignificant impact on the predicted dose can be identified, and efforts to obtain such data can be minimized.

Such calculations place the analyst in the position to respond to questions such as "How does the licensee assure that the generic value is representative actual site conditions?" Through the use of sensitivity analysis, rather than being forced to respond with a statement that the value was assumed to be appropriate, a more concrete response can be given. The modeler can explain that the predicted dose was insensitive to changes in the parameter over the expected range of values, rendering non-important the specific value selected for the parameter within that range.

An illustration of the iterative nature of PA is the use of increasingly complex analysis techniques for each stage of the calculations. In the initial stages, simple hand calculations may provide enough justification to eliminate some pathways and radionuclides from consideration. Such a screening approach minimizes the amount of analyses that would require more detailed modeling. The identified pathways, site-specific processes, quantity and quality of available data, and code capabilities, should ultimately govern code selection. The use of established codes, if applicable to a specific site, is generally recommended over the development of a new code for each disposal facility. Furthermore, a PA conducted with a highly sophisticated model is not necessarily considered better than a PA conducted with a simple model. In fact, it is preferable to maintain consistency between the modeling complexity and the quantity and quality of available data.

Evaluation of the conceptual model of the facility and site involves the use of appropriate computer codes and site-specific data. Code selection for a PA is based on the capability of a code to model site-specific conditions. Generally, a single code will not be capable of simulating all relevant scenarios. Compliance calculations may be conducted using a single, system-level code. However, supporting calculations to determine selected inputs to the system-level code (e.g., groundwater velocities) may be conducted using a process-level code. In this respect, various levels of modeling are typically necessary to fully evaluate the performance of each LLW disposal facility.

Performance assessment codes are often differentiated according to their specific capabilities (Starmer et al. 1988; Case et al. 1989). For example, PA codes can be classified as either characterization (process) or system-level codes (Starmer et al. 1988). Characterization (process) codes are specialized codes dealing with a particular component of the disposal system (e.g., groundwater flow and transport), while the more generalized system-level codes integrate several processes involved in the system (e.g., groundwater flow and transport, irrigation, plant uptake and consumption, and internal dosimetry).

System-level codes typically use more simplistic, and thus, generally more conservative representations of system behavior. Initially, a system-level approach can provide a conservative approximation of the performance of a proposed LLW disposal facility. Such modeling efforts are useful during the site characterization and screening phases of the PA process, when less site-specific data will be available. System-level models also provide a relatively straightforward set of calculations that provide a basis for the demonstration of compliance. Examples of system-level codes include PATHRAE (Rogers and Hung, 1987a), PRESTO-CPG (Rogers and Hung, 1987b), and GENII (Napier, 1988).

Final Results of Performance Assessments Submitted for License Application

Demonstration of regulatory compliance using performance assessment is the license applicant's responsibility that is necessarily performed during the entire life span of the facility. Two documents have been produced by the NRC regarding the contents and review criteria for a license application (NRC, 1988a; NRC, 1988b). NUREG-1199, *Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility*, provides a format for the material to be presented in a Safety Analysis Report. Section 6 of NUREG-1199 includes a detailed discussion of the information necessary to document a safety (performance) assessment.

The NRC or the appropriate Agreement State agency will review performance assessments to determine whether the proposed facility complies with specified regulations. The NRC provides guidance on their review process in *Standard Review Plan for Review of a License Application for a Low-Level Radioactive Waste Disposal Facility*, NUREG-1200, Rev. 1. Section 6 of NUREG-1200 outlines the review criteria for the different elements of a Safety Assessment. Examples of topics addressed in the review process include validity of assumptions; adequacy of conceptual models for representation of site-specific processes; justification, documentation, verification, and calibration of numerical models; and appropriateness of balance between conservatism and realism in the assessment calculations with respect to the performance objectives.

The goal is to demonstrate that a facility will perform within the performance objectives of 10 CFR 61 and any other applicable state or local regulations. Thus, it is more of a bounding analysis that should be conservative. Furthermore, it is important to recognize that PA is an integral part of an efficient site characterization and design process and not just a compliance tool. Through the use of sensitivity analyses, PA can help focus efforts on characterization and design parameters that have the most critical impacts on the final results. As with the design of any high-tech system, modeling is an inexpensive alternative to physical testing.

During site characterization, a lack of sufficient data forces the establishment of various assumptions. At this preliminary stage, system-level codes or even hand-calculations are useful for screening calculations to limit the number of radionuclides and pathways that must be considered in detail during later iterations of the PA process. As data collection progresses, more specific process-level codes may be used to provide greater understanding of specific pathways and components. Using multiple codes and coupling various models together provides a more comprehensive evaluation of the complex processes associated with LLW disposal facilities. The final calculations and supporting site-specific data used in support of a license application must be defensible and understandable. Furthermore, the quality and quantity of site-specific data should be consistent with the level of model used for the analysis since it will be used in future performance assessments.

Institutional Control Period

The facility closure period can be divided into two phases: the active phase (final site closure and stabilization), when design features and stabilization techniques are completed; and the observation phase (post-closure observation and maintenance), when surveillance is conducted to assure that the facility is stable and ready for institutional control.

The active closure phase consists of two activities including evaluating performance and environmental monitoring data to assure that the current and projected performance of the site will facilitate closure, and inspecting closed disposal units to assess whether any remedial action is required.

The passive phase of disposal facility closure involves monitoring to assure that the facility is stable and ready for institutional control. If the performance assessment performed at this phase indicates that the facility is performing properly and will continue to meet the performance objectives, the licensee applies for a license amendment to transfer custody of the facility to the disposal site owner, who must be a state or federal entity. Approval of this amendment by the licensing authority signifies completion of the active and observation phases of facility closure.

During the active institutional control period, the responsible entity must execute a monitoring program to assure continued site performance, conduct physical surveillance to restrict access to the site, and perform minor custodial activities. After determining that these requirements have been met, the license is terminated. Thereafter, during the passive control period, the disposal site must continue to meet the regulatory performance objectives relying only on passive intruder controls such as land markers and signs as well as documented land records.

Performance and environmental monitoring data should be evaluated to ensure that the site continues to meet the closure objectives. The type of monitoring to be employed during the institutional control phase should be selected based on the site's characteristics, facility design features, and specific functions of the monitoring processes.

Duration (active and passive)

Active

Closure activities for LLW disposal facilities must comply with NRC's or agreement state's closure and post-closure requirements. Before beginning closure operations and 30 days prior to expiration of the operating license, the owner or operator must apply for an amendment to the license. The application must include a final revision of the site closure plan. The period when final site closure and stabilization activities are implemented is the site closure, or active, phase (10 CFR 61.29). A time limitation on this period is not specified in 10 CFR 61.

Passive

The passive phase immediately follows the disposal site closure phase. For a period of 5 years, the licensee must remain at the disposal site for a period of post-closure observation and maintenance to assure that the disposal site is stable and ready for institutional control. The regulatory agency may approve shorter or require longer periods of maintenance if conditions warrant. At the end of that period, the licensee applies for a license transfer to the disposal site owner. Following completion of closure authorized in 10CFR61.28, the licensee shall observe, monitor, and carry out necessary maintenance and repairs at the disposal site until the license is transferred by the regulatory agency in accordance with 10CFR61.30.

The regulatory agency determines the period of institutional controls, but institutional controls may not be relied upon for more than 100 years following transfer of control of the disposal site to the owner. After determining that the site has been closed satisfactorily, the agency transfers the license to the state or federal landowner, who must have a program to restrict access to the site throughout the 100-year institutional control period.

Basis of Determination

Transfer

The license is transferred when the regulatory agency finds that the closure of the disposal site has been made in conformance with the licensee's disposal site closure plan, as amended and approved as part of the license. Reasonable assurance, including performance assessments, must also be provided by the licensee that the performance objectives of Subpart C of 10CFR61 are met. The disposal site owner must have received from the licensee any funds and necessary records for care. The licensee must also provide proof that the post-closure monitoring program is operational for implementation by the disposal site owner. The federal or state government agency that will assume responsibility for institutional control of the disposal site must be prepared to assume responsibility and ensure that the institutional requirement's found necessary under will be met.

Termination

A license is terminated only when the regulatory agency finds that the institutional control requirements under 10CFR61.23 (g) have been met and that any additional requirements resulting from new information developed during the institutional control period have also been met. The agency will also assure that permanent markers or monuments warning against intrusion have been installed.

Zoning Plan of Disposal Site During Operation and Post-Closure

Copies of records of the location and quantity or radioactive wastes contained in the disposal site must be transferred upon license termination to several separate executive offices in the vicinity of the facility. The chief executives of the nearest municipality and the county in which the facility is located must receive copies of the records. Additionally, the county zoning board or land development and planning agency, the state governor and other state, local, and federal governmental agencies as designated by the regulatory agency at the time of license termination will also be designated recipients of the these records.

Licensing Issues

The NRC requires that disposal sites be sited so as to achieve the performance objectives set forth in Subpart C of 10 CFR 61. To implement this, the NRC has promulgated extensive siting criteria focusing on geologic, geotechnical, hydrologic, meteorologic, climatologic, and biologic features of the area.

License applications are required to provide a reasonable assessment of potential radioactive releases via the most significant transport mechanisms for each institutional phase of the facility (US NRC, 1988a). This regulation emphasizes the need to maintain releases of radioactivity as low as reasonably achievable (ALARA). The NRC or the appropriate Agreement State agency reviews performance assessments to determine the adequacy of regulatory compliance for the proposed facility. The NRC provides guidance on their PA review process in *Standard Review Plan for Review of a License Application for a Low-Level Radioactive Waste Disposal Facility*, NUREG-1200, Rev. 1. Section 6 of NUREG-1200 outlines the review criteria for the different elements of a Safety Assessment. Examples of topics addressed in the review process include validity of assumptions; adequacy of conceptual models for representation of site-specific processes; justification, documentation, verification, and calibration of numerical models; and appropriateness of balance between conservatism and realism in the assessment calculations with respect to the performance objectives.

Although performance assessment is one of the more problematic aspects of licensing a disposal facility there are some other factors affecting the United States LLW commercial disposal system. Three of the most discussed include revisions to regulations for licensing LLW disposal facilities, disposal of mixed waste, and the requests by many for on-site, long-term storage.

The ability to license a LLW disposal facility depends on three principal factors. First, regulations must be sound and established using public input. Second, applicants must demonstrate that the proposed facility meets all safety and environmental regulations. Third, regulator decisions to license must ensure protection of the public safety, health, and environment and the ability to withstand legal challenges. Some regulators believe that revisions to 10CFR61 that would require more specific technical requirements for licensing alternative disposal technologies, would allow states to apply more active disposal concepts than the passive concepts in part 61. Active disposal concepts reflect many of the attributes inherent in storage such as retrievability, active maintenance, and longer institutional care and monitoring. Regulators suggest that these revisions would allow states to gain greater public acceptance for LLW disposal concepts.

Mixed waste, LLW that contains both a hazardous and radioactive constituent, has presented some regulatory and disposal problems in the United States. Currently, only limited disposal capacity exists for some mixed waste and only limited treatment capability exists. Mixed waste disposal plans in the states are on hold pending decisions between the states and the federal government.

Storage of LLW is authorized and licensed, on a case-by-case basis under 10CFR Parts 30, 40, 50, and 70. A preference for storage of LLW has been expressed by some waste generators, agencies of state and local governments, and opponents of disposal facilities as an alternative to disposal. Some opponents do not believe that a clear case has been made that near-surface disposal adequately protects public health and safety. Others suggest that on-site storage eliminates potential transportation accidents and the need for committing the use of clean land. The NRC staff considers disposal to be designed as permanent with no plans for retrieval. The siting, design, construction, operation, and safety analysis are conducted to ensure waste is permanently isolated and the facility meets the performance objectives and technical requirements of Part 61. The NRC defines storage as a facility designed for a definite design life and as such is not required to meet the requirements for permanent isolation in Part 61. However, some generators believe that acceptance by the NRC of long term storage will represent lower costs and avoid potential Superfund liability for reported contamination of a disposal site in the future.

Related Research and Development Activities

The science of performance assessment is constantly being advanced with the improvements in computational capability and sensor technology. However, the basic approach for conducting performance assessments has not changed. Research and development in this area is primarily funded and performed by U.S. Government agencies and private industry involved in the management of radioactive waste materials.

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