OVERVIEW OF A PERFORMANCE ASSESSMENT METHODOLOGY FOR LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES*

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ABSTRACT

A performance assessment methodology has been developed for use by the U.S. Nuclear Regulatory Commission in evaluating license applications for low-level waste disposal facilities. This paper provides a summary and an overview of the modeling approaches selected for the methodology. The overview includes discussions of the philosophy and structure of the methodology. This performance assessment methodology is designed to provide the NRC with a tool for performing confirmatory analyses in support of license reviews related to postclosure performance. The methodology allows analyses of dose to individuals from off-site releases under normal conditions as well as on-site doses to inadvertent intruders.

INTRODUCTION

Under the Low-Level Radioactive Waste Policy Act of 1980, and the Low-Level Radioactive Waste Policy Amendments Act of 1985, the NRC and Agreement States have the responsibility to license land disposal of low-level radioactive wastes using the requirements of 10 CFR Part 61 or comparable state requirements. Compliance with the performance objectives in 10 CFR Part 61.41 must be demonstrated by the licensee using quantitative analyses of the potential dose to the maximally exposed off-site person. This performance assessment methodology is designed to provide the NRC with a tool for performing confirmatory analyses for use in license reviews related to postclosure performance. The methodology allows analyses of dose to individuals from off-site releases under normal conditions as well as on-site doses to inadvertent intruders.

Performance assessment cannot be used to demonstrate unequivocally that a site will be safe; rather, it is a technique for examining factors that may affect site safety and providing a basis to assess whether reasonable assurance exists that a site will meet performance objectives (1). Estimated doses are calculated for comparison to performance objectives and are considered to be indicators of safety, rather than absolute predictions of doses that may be received by members of the general public (1). In this way, there can be confidence that a site meets regulatory performance objectives even though there is uncertainty in the estimated doses (2).

The performance assessment methodology has been developed at Sandia National Laboratories in a five-step program over a period of two years. Results from each step in the program were documented in a five-volume series of reports (3,4,5,6,7). The first two steps in the methodology development were identification of pathways of potential exposure in a low-level waste performance assessment (3), and screening of those pathways to identify which are of primary importance (4). The list of important pathways was developed for a generic site, and is based on a qualitative ranking of both the likelihood of migration occurring along the pathway, and the expected consequence of the pathway.

The third step in developing the methodology was to identify models that can be used to assess the pathways, and to demonstrate that those models can be integrated into a complete performance assessment methodology (5). This third volume of the series of reports contains discussions of the appropriateness of models for source-term release, ground-water flow and transport, air transport, surface-water transport, food chain, and dosimetry.

The fourth step in the development of the methodology was to select computer codes that implement the methodology (6). In this fourth volume in the series both simple and detailed analyses for all parts of the methodology were recommended, since for an arbitrary site any of the components of the methodology may require detailed analysis. Computer codes or analytical methods were recommended in this fourth report for both approaches.

The fifth step in the project was to acquire, implement, and assess computer codes for the methodology (7). Several of the early recommendations of Kozak et al. (6) were modified at this stage, and specific analytical techniques were suggested for simple source-term and ground-water transport calculations. These source-term and ground-water transport analysis methods are implemented in a computer code named PAGAN (8); the theoretical basis for this code is given in detail in Kozak et al. (7).

The methodology has been designed to be modular in structure, which allows the NRC to confirm or verify parts of, or all of the assertions made by a licensee by examining intermediate output from the various models. The modular structure allows use of the simplest models possible but permits substitution of more complex models when needed (9, 10). The methodology is intended to be capable of

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analyzing several different types of disposal facilities in a potentially wide variety of geological and climatic settings (11). The methodology consists of a loosely grouped collection of computer codes for different parts of the analysis. The data interfaces between the codes must be provided by the user, which makes the methodology less user friendly. In addition, the modular structure of the methodology permits updating of selected models as better models are developed. This prevents the methodology from becoming obsolete with passing time.

The primary modules considered in the methodology are ground-water flow, source term, ground-water transport, air transport, surface-water transport, food chain, and dosimetry. Other effects, such as biointrusion, can be analyzed using the methodology, but are not considered to be of primary importance. For each of the modules in the methodology, either a simple analysis or a more complicated analysis can be chosen. For example, in the ground-water flow and transport modules, the analyst can use either simple one-dimensional steady-state semi-analytical solutions for homogeneous media, or a more elaborate numerical analysis that can account for transient phenomena in a variety of heterogeneous media with various boundary conditions. The exceptions to this structure are the food chain and dosimetry modules. The models for these phenomena are fairly standardized, as embodied in NRC Regulatory Guide 1.109 (15) and ICRP Publication 26 (16). As a result, there is only one method for food chain and dosimetry analyses in the methodology.

PROCESSES CONSIDERED IN THE METHODOLOGY

Radionuclides released following closure of a low-level waste facility are most likely to reach the accessible environment by two principal pathways, which are (a) source to ground water, with subsequent human exposure to well water, and (b) source to ground water to surface water, with humans and food products coming in contact with the contaminated surface water (4). Other pathways such as releases directly to surface water or to the air may be of importance at particular sites, and for particular disposal options, and the critical pathways must be identified for each site. Consequently, while the methodology has the capability to analyze a variety of pathways, emphasis has been placed on these two ground-water pathways.

To assess the effect of releases through the two principal ground-water pathways, the methodology must account for a number of physical and chemical processes that are expected to occur in and near the facility. Releases to the ground-water pathway begin with percolation of water through the vadose zone (recharge). The amount of percolation at a site is dictated in a complicated way by the incident rainfall, evapotranspiration, and surface runoff. The water that passes through the engineered cover into the disposal units induces failure of concrete and steel barriers in and around the disposal units. As waste becomes accessible to the water, it can dissolve by leaching processes, and can be transported to the boundary of the disposal units (near-field transport). The overall set of processes (container breach, leaching, and near-field transport) leading to release of radionuclides from the boundaries of the disposal units is called the source term in this discussion. Radionuclides exiting the disposal units are convected and dispersed by water flowing in the vadose and saturated zones. Once the radionuclides enter the saturated zone, the potential exists for contamination of a water well. If the aquifer is in hydraulic connection with surface waters, the potential exists for the surface waters to become contaminated.

Once either ground water or surface water becomes contaminated, the potential exists for humans to contact the contaminants in a number of ways. A person may drink contaminated water, or the water can contaminate the food chain. This contamination may occur naturally (contamination of fish in the surface water or root uptake of ground water) or through man-made intervention (consumption of well water or irrigation of crops). Consumption of contaminated water and food leads to an internally received dose. Similarly, use of contaminated surface water for recreation can lead to an externally received dose that must be accounted for in the methodology. The sum of the doses from all radionuclides transported along all these pathways is the total dose to the receiving person.

It may often be unnecessary for a license applicant to perform intruder analyses in conducting a site-specific performance assessment. A demonstration of intruder protection may consist of a demonstration that the waste classification and segregation requirements of 10 CFR Part 61 have been met, and that adequate barriers to inadvertent intrusion have been provided for (11). However, dose analyses may be required in special cases when an applicant requests an exemption from the 10 CFR Part 61 waste classification scheme (2). Consequently, the methodology has the capability to perform analyses of processes in intruder analyses, but intruder analyses are of lesser regulatory importance compared to analyses of doses to off-site persons. Intruder analyses will not be discussed further here.

MODELS IN THE METHODOLOGY

In this section, a brief summary of the models and computer codes selected for the performance assessment methodology is given.

Ground-Water Flow

The processes that dictate the amount of percolation that will exist at a given site are extremely difficulty to characterize, and there is no universally applicable method for determining the percolation at any site (14,15). Consequently, there is no provision in the methodology at this time for estimating percolation. Instead, the percolation rate is assumed to have been estimated prior to the use of the methodology by some combination of experimental data and modeling, and the percolation rate enters the ground-water flow analysis as a boundary condition.

The flow analysis must account for flow in both the saturated and unsaturated (vadose) zones. A moisture-barrier cover is usually included as part of the design of a low-level waste facility, which complicates the vadose-zone flow analysis. Designs for cover systems typically include several soil layers that provide low permeability coupled with high capillarity (16). Flow through such barriers is intrinsically multidimensional, since the purpose of the engineered cover is to laterally divert a vertical flow rate. Consequently, it is usually necessary to use multidimensional analysis to determine the optimum performance of the cover. If one-dimensional analyses are used in the performance assessment, it is necessary to compare these with a multidimensional model of the cover to demonstrate that the one-dimensional model provides a satisfactory representation of the cover behavior. VAM2D (17) has been recommended for the flow analysis in this methodology. This code has considerable flexibility in the types of boundary conditions that can be specified, and has been found to contain robust numerical methods (7).

Source Term

Source-term analyses must contain components that analyze the failure of structures and containers, the leach rates of radionuclides, and the transport of those contaminants to the boundary of the disposal unit.

Failure of concrete structures is modeled in this methodology as a delay time to the onset of releases. There is no adequate existing model to analyze the details of failure of concrete structures to estimate the failure time or the mode by which they fail (18). Instead, currently available models are only adequate to make qualitative comparisons between types of concrete (19).

One of two methods can be used to analyze the breach rate of waste containers in the methodology. A simple approach can be used, in which the failure of containers is modeled as a delay time to the onset of releases. Alternatively, the method of Sullivan et al. (20) can be used to analyze the breach of carbon-steel containers. This method uses a semi-empirical model for pitting and general corrosion rates, with empirical parameters determined from generic subsurface corrosion data. The advantages and drawbacks of this approach have been discussed in detail by Sullivan et al. (20) and by Kozak et al. (5). This method for determining container corrosion is incorporated into the BLT (Breach, Leach, and Transport) computer code (21).

There will often be large uncertainty in modeling the leach rates in the disposal unit. This uncertainty arises from the large number and variety of waste types and forms in low-level waste, and from the complex chemistry of interaction between waste constituents and their surroundings. As a consequence of this uncertainty, an approach should generally be used that provides confidence in the conservatism of the source term analysis. One approach that can usually be considered conservative is to use a surface-wash leaching model. In this model it is assumed that the waste resides at the waste form surface, and is immediately available to be washed off by passing water. The idea behind the model is that mass-transfer limitations are neglected, which leads to rapid predicted releases. This modeling approach is particularly appropriate for use in modeling releases from unstabilized waste, since unstabilized waste is particularly uncertain in chemical form and physical structure. For stabilized waste forms, the analyst must determine if the releases are affected by convection through the waste form. If convection is unimportant, a diffusion-limited leach rate may be appropriate (22), and such a model has been incorporated into the methodology. If a demonstration cannot be made that convection is unimportant, a surface-wash leach model should be used.

A simple analytical source-term model has been developed for use in the methodology. This model is based on a mixing-cell model, but incorporates dispersion in the disposal unit in a simplified manner (7). Either surface-wash or diffusion-limited leaching releases can be modeled. This simple source-term model provides analytical estimates of releases from the disposal unit, and retains much of the flexibility of more complicated analyses. However, more detailed source-term models have been retained in the methodology in the form of BLT (21).

Ground-Water Transport

Both simple and more complicated codes are included in the methodology for analyzing ground-water flow and transport. A Green's function solution is used for simple analyses of ground-water transport. The solution method is strictly valid for constant one-dimensional aquifer flow in an isotropic aquifer of constant or infinite thickness. When these criteria are not strictly fulfilled, the method can often be used to approximate ground-water concentrations by using conservative estimates of parameters in the model. Similar solutions have recently been recommended for use in low-level waste performance assessment applications (22, 23). The Green's function solutions and the simple source-term model have been combined in a program called PAGAN (Performance Assessment Ground-water Analysis of low-level Nuclear waste), which provides a simple menu-driven input and output structure for the analysis (8). More complicated ground-water transport analyses can be performed in the methodology using BLT (21) or VAM2D (17). Complications in the analysis may include transient and multidimensional flow fields, and complicated boundary conditions.

Surface-Water Transport, Air Transport, Food Chain, and Dosimetry

The results from the source-term and ground-water transport codes can be used as input to analyses of surface-water transport, air transport, and food-chain and dosimetry. The computer code GENII (24) has been recommended for use in the methodology for these pathways. GENII contains both simple and more complicated modeling approaches for both surface-water transport and air-transport analyses, which is in keeping with the philosophy of maintaining the flexibility to perform analyses in more than one way.

The result of the performance assessment analysis is a series of dose histories for each radionuclide of importance. The contribution of each radionuclide to the dose must then be added together to produce the total predicted dose. This dose estimate is intended to be compared with the regulatory performance objectives in 10 CFR Part 61.41. Estimated doses are not intended to reflect actual doses that may be received by members of the general public.

A summary of the recommended analytical methods and computer codes for the modules in the methodology are shown in Table I. It should be emphasized that the computer codes selected for this methodology were judged to be the best available for NRC's use. These are not considered to be the only suitable set of computer codes for use in low-level waste performance assessment.

SUMMARY

A performance assessment methodology has been developed for use by the NRC in conducting license reviews for low-level radioactive waste facilities. This paper provides an overview of the processes and models included in the methodology, along with discussions of the philosophy and structure of the methodology.

The methodology contains models and computer codes for source-term release, ground-water flow and transport, air transport, surface-water transport, food chain, and dosimetry. The methodology is put together in a modular structure, in which the codes are loosely grouped. This structure greatly increases the flexibility of the methodology to handle a wide variety of disposal options and environmental conditions, but at the cost of increased user interaction to provide coupling between the codes. The purpose of the methodology is to provide the NRC with a tool for performing analyses for comparison with the regulatory performance objectives in 10 CFR Part 61.41. The results generated by the methodology should not be construed as indicative of actual doses that may be received by members of the general public.

TABLE I

Codes in the Methodology

Vadose-Zone Flow	VAM2D
Source-Term Analysis	PAGAN BLT VAM2D
Vadose-Zone Transport	PAGAN (Delay Time) VAM2D BLT
Saturated-Zone Flow	Darcy Model VAM2D
Saturated-Zone Transport	PAGAN VAM2D BLT
Surface-Water Transport	PAGAN (Dilution Factor) GENII
Air Transport	GENII AIRDOS-PC (Not Implemented)
Food Chain and Dosimetry	GENII

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