DOE'S PERFORMANCE EVALUATION PROJECT FOR MIXED LOW-LEVEL WASTE DISPOSAL*

Robert D. Waters, Sandia National Laboratories; Marilyn M. Gruebel, Tech Reps, Inc.; Margaret S.Y. Chu, Sandia National Laboratories; Donald W. Lee, Oak Ridge National Laboratory

ABSTRACT

A performance evaluation (PE) is an analysis that estimates radionuclide concentration limits for 16 potential Department of Energy (DOE) mixed low-level waste (MLLW) disposal sites based on the analysis of two environmental exposure pathways (air and water) to an off-site individual and an inadvertent-intruder exposure pathway. Sites are analyzed for their ability to attenuate concentrations of specific radionuclides that could be released from wastes in a hypothetical MLLW disposal facility. Site-specific data and knowledge are used within a generic framework that is consistent across all sites being evaluated. After estimates of waste concentrations for the three pathways are calculated, the minimum of the waste concentration values is selected as the permissible waste concentration for each radionuclide. The PE results will be used as input to the process for DOE's MLLW disposal configuration.

Preliminary comparisons of results from the PE and site-specific performance assessments indicate that the simple PE results generally agree with results of the performance assessments, even when site conditions are complex. This agreement with performance-assessment results increases confidence that similar results can be obtained at other sites that have good characterization data. In addition, the simple analyses contained in the PE illustrate a potential method to satisfy the needs of many regulators and the general public for a simple, conservative, defensible, and easily understandable analysis that provides results similar to those of more complex analyses.

INTRODUCTION

The Federal Facility Compliance Act (FFCAct) of 1992 (1) requires DOE to work with its regulators and with members of the public to establish plans for the treatment of DOE's mixed wastes. Although the FFCAct does not specifically address disposal of treated MLLW, both DOE and the States recognize that disposal issues are an integral part of treatment discussions. The DOE established its MLLW Disposal Workgroup in June 1993 to work with the States to define and develop an evaluation process for disposal options. This joint DOE-State process has narrowed the sites for further evaluation from 49 to 16.

A PE has been developed to quantify and compare the limitations of 16 DOE sites for the disposal of MLLW. The principal goal in developing the PE is to estimate, for residues resulting from the treatment of MLLW, permissible concentrations of radionuclides that could be disposed at each site. The PE consists of simple analyses consistent with the approach used in many low-level waste (LLW) performance assessments. The objective is to use a set of modeling assumptions of sufficient detail to capture major site-specific characteristics and yet be general enough for consistent application at all sites. Additionally, the analyses must ensure that no systematic biases are introduced, the sites are analyzed consistently, and all major assumptions are clearly stated.

Although the approach is simple, every effort is made to ensure that the PE is technically adequate for the intended purpose and that the PE results reflect the strengths and weaknesses of each of the 16 sites for the disposal of

* This work was performed at Sandia National Laboratories and Oak Ridge National Laboratory, which are operated for the U.S. Department of Energy under Contract Nos. DE-AC04-94AL85000 and DE-AC05-84OR21400, respectively, and funded by the Department of Energy's Office of Environmental Restoration and Waste Management.

DISCLAIMER

MLLW. To ensure technical adequacy, the following strategy was adopted:

- Use the existing knowledge, analyses, and data at each site to the extent practical;
- Use well-established policies and recommendations on disposal-related issues; and
- Use extensive and continuous reviews from both internal and external experts.

The PE analysts rely extensively on interactions with site personnel to utilize important research, site characterization, modeling, and other analyses that have been performed. These interactions include visits by the PE analysts to each of the sites. Based on discussions with personnel who have spent years studying their sites, the PE analyses incorporate the best documented understanding of the sites into the PE framework.

FRAMEWORK OF THE PERFORMANCE EVALUATION

The PE is solely a radiological assessment even though the waste is mixed with hazardous components that are subject to Resource Conservation and Recovery Act (RCRA) requirements (2). This approach is taken by assuming that the hazardous component of the waste is treated and the disposal facility designed per RCRA specifications. Further analysis of the performance of hazardous components currently is not required by the Environmental Protection Agency (EPA) or any state with RCRA primacy.

The PE estimates permissible concentrations of radionuclides in disposed waste using the performance objectives specified in DOE Order 5820.2A (3) as "performance measures" for the radiological assessment. Performance measures are used in the PE to relate radionuclide concentrations in disposed waste to permissible doses to individuals for three exposure pathways: ingestion of drinking water and all-pathways exposure to atmospheric releases to an individual at the performance boundary (i.e., point of compliance), and all-pathways exposure to an inadvertent intruder. All of the performance objectives in DOE Order 5820.2A could be used as performance measures in the PE. However, experience with performance assessments (4, 5) has shown that some of the performance objectives are generally more restrictive than others. Thus, the performance measures used in the PE are

- 4 mrem (0.04 mSv) per year from the drinking-water pathway for releases to water;
- 10 mrem (0.1 mSv) per year from all pathways for atmospheric releases; and
- 100 mrem (1 mSv) per year from all exposure pathways for chronic exposure of inadvertent intruders.

Based on guidance for conducting performance assessments (6), calculations for the PE use a performance boundary that is located 100 m from the edge of the disposal facility, and the period for consideration is 10,000 years from the time the disposal facility is closed.

Two generic disposal facilities are considered in the PE: a RCRA-compliant, below-ground trench and a RCRA-compliant, above-ground tumulus. The size and shape of each generic facility is assumed to be the same for all sites. The generic disposal facilities were selected to provide consistency in evaluation of the 16 sites.

The same list of radionuclides is used in the PE to enable comparisons of the 16 sites. Because the actual radionuclide inventory that might be disposed in a facility is unknown, the duration of contaminant release is also unknown. Therefore, a continuous release of radionuclides from the disposal facility is assumed. Assuming a continuous source is considered to be reasonable and conservative.

The waste form in the PE is assumed to be grouted treatment residuals. Grout, which consists primarily of hydrated Portland cement and fly ash, is often used to stabilize both wastes containing hazardous metals and residues resulting from thermal treatment. Grout is the primary waste form considered in three LLW performance assessments: Oak Ridge Solid Waste Storage Area 6 (4); Savannah River Z-Area (5); and Hanford grout (7).

For the water and atmospheric pathways, the sequential attenuation of contaminants that occurs between the waste in the disposal facility and the performance boundary is represented by "concentration reduction factors" (CRFs). The CRF approach is used so that intermediate results can be displayed to allow for comparisons of effects of the disposal facility and site on overall performance. For the water pathway, the CRFs represent concentration attenuation related to the contaminant release rate from the facility and dilution of leachate with uncontaminated groundwater. For the atmospheric pathway, the CRF represents the reduction in contaminant concentration provided by diffusion through the overlying soil and by atmospheric dispersion to the performance boundary.

METHODOLOGY

Three sets of calculations—for the drinking-water, atmospheric, and inadvertent-intruder pathways—form the foundation of the PE. In general, for each pathway the maximum permissible contaminant concentration at the performance boundary is determined for each radionuclide by using the performance measures and the appropriate pathway or scenario dose conversion factors (annual effective dose equivalent per unit concentration) based on EPA dose conversion factors (8). Conceptual models for environmental flow and transport are developed based on interactions with site personnel. For the water and atmospheric pathways, the concentration reduction provided by the environment is estimated using results of site analyses and data evaluation. For the intruder analyses, concentration reduction is estimated for appropriate exposure pathways for several intrusion scenarios; interactions with site personnel focus on selecting appropriate "credible" intrusion scenarios based on site-specific conditions. Once estimates of waste concentrations are calculated for the three pathways, the minimum of these values is selected as the permissible waste concentration for each radionuclide.

Water Pathway

Different hydrogeologic environments cause the water flow to vary considerably from one site to another; therefore, an acceptable conceptual model and its associated assumptions must be supported by site-specific knowledge and data. Depending on site-specific conditions, pathways to be considered may be surface water, the vadose zone, and groundwater. Once the water-flow paths are established, similar radionuclide-transport assumptions are imposed on each site to provide consistency in the PE analyses. A generic conceptual model incorporates site-specific geometry and water-flow pathways into a simple transport analysis (Fig. 1). Results are compared with available site-specific analyses to identify areas where differences exist.

PLACE FIG. 1 HERE

Site-specific data required to perform the water-pathway analysis come from site personnel either as data from site characterizations and reports or from site-selected literature. The minimum data that are required are natural infiltration rates, distance between the disposal facility and groundwater, Darcy flow rates, porosity, ambient moisture content, mixing depth in the aquifer, dry bulk density of the porous media, and solid/liquid partition coefficients of the porous media.

Two CRFs are calculated for the drinking-water pathway: one for the concentration attenuation between the disposed waste and leachate exiting the bottom of the disposal facility, source CRF; and one for the concentration attenuation between the leachate exiting the disposal facility and the water at the performance boundary, the environmental transport CRF for drinking water. The source CRF is defined as the dimensionless ratio of the waste concentration to the resulting leachate concentration. Desorption with advecting flow is the mechanism used to describe the leaching of radionuclides from the grout, consistent with analyses in LLW performance assessments that have evaluated grouted waste forms (4, 5, 7). Because the desorption model is based on a grouted waste form, the radionuclide-specific values for the source CRF for each type of generic facility are the same for all 16 sites.

The environmental transport CRF for drinking water is defined as the ratio of the concentration of the leachate exiting the disposal facility to the resulting concentration in water at the performance boundary. The concentration attenuation represented by the transport CRF for drinking water consists of dilution due to mixing with uncontaminated groundwater and/or surface water. Effects of radioactive decay and decay product ingrowth are also included in the analysis.

Atmospheric Pathway

The conceptual model for evaluating the atmospheric pathway is derived from performance assessments for LLW disposal facilities (5, 7, 9, 10). The model is generalized for the PE and uses site-specific data for many of the parameters. Only the volatile radionuclides ^{3}H and ^{14}C are considered in the PE for atmospheric transport. In the model, radionuclides are transported from the disposal facility to the soil surface by vapor diffusion. When the radionuclides reach the soil surface, they are entrained in the air and are transported to an assumed receptor located at the performance boundary. Atmospheric dispersion also causes minor attenuation.

Site-specific data required to perform the atmospheric pathway analysis come from site personnel either as data from site characterizations and reports or from site-selected literature. The site-specific data required for the soil diffusion calculation are the same as those required for the water pathway. Atmospheric dispersion data include probabilities of wind speed and direction and stability class.

Three CRFs are used to account for the attenuation encompassing diffusion to the ground surface, mixing in air, and dispersion in the atmosphere to the performance boundary. The CRF for diffusion in soil is conservatively modeled (i.e., large diffusion constants) in an attempt to bound releases from alternative transport mechanisms (e.g., desiccation cracks, burrowing animals, and root uptake). The CRF for diffusion in soil is defined as the ratio of the radionuclide concentration in the waste to its resulting concentration in the upper one centimeter of soil. The CRF for mixing with air is defined as the ratio of the radionuclide concentration in the upper one centimeter of soil to its resulting concentration in air at the facility boundary. The CRF for atmospheric dispersion is defined as the ratio of the concentration at the facility boundary to its resulting concentration at the performance boundary 100 m from the edge of the disposal facility. Gaussian dispersion is the concentration-attenuating mechanism used in the dispersion CRF. The effect of radioactive decay is included in the analysis.

Inadvertent Human Exposure

Standard scenarios that were developed for performance assessments of LLW disposal facilities (4, 11) are used in the PE to analyze inadvertent intrusion. These scenarios were selected based on experience indicating that the chronic agriculture (homesteader) and post-drilling scenarios are generally the most restrictive scenarios for most sites and facility designs. In some cases, however, these scenarios are tailored for site-specific conditions. The agriculture scenario includes establishment by an intruder of a permanent homestead directly above a disposal facility with the foundation of the home extending into the waste; some of the waste exhumed from the disposal facility is mixed with native soil in the intruder's vegetable garden. The post-drilling scenario considers the construction of a well for a domestic water supply by an intruder who resides permanently nearby a disposal facility; the well is drilled through the disposal facility.

Total intruder doses consist of doses from several exposure pathways (e.g., external exposure to the waste, ingestion of food or soil, and inhalation of suspended soils). Factors that are used to calculate the doses and, therefore, scenario dose conversion factors include, for example, correction factors for the amount of natural soil mixed with exhumed waste, plant to soil concentration ratios, shielding factors, and fraction of time exposed through a certain exposure pathway. Some of the factors used to calculate the scenario dose conversion factors are constant, while others may vary depending on such factors as exposure pathway and disposal technology. The effect of radioactive decay prior to intrusion is included in the analysis.

DISCUSSION

The PE project provides estimates of the maximum permissible concentrations that can be disposed of at 16 DOE sites for 58 radionuclides based on the most constraining of three performance measures: 4 mrem (0.04 mSv) per year dose from drinking water, 10 mrem (0.1 mSv) per year dose for all pathways from atmospheric releases, and 100 mrem (1 mSv) per year dose for all pathways from inadvertent intrusion. These estimates of concentrations are based on a relatively simple analysis considering existing generic and site-specific knowledge and data.

The primary use of the PE results will be to compare the estimates of permissible concentration limits for disposal with concentration estimates for stabilized MLLW residues resulting from treatment processes. The comparison will provide indicators both of the amounts and types of waste that are acceptable for disposal at each site and of the wastes that are not acceptable for disposal at each site.

Comparison of results from the 16 sites requires that the general analysis framework be as consistent as possible, while site-specific input is required to ensure that the analyses are representative of site conditions. A simple flow and transport analysis that allows incorporation of site-specific flow conditions meets both these objectives. The project framework and results are reviewed by internal and external panels to ensure consistency of application among sites and to ensure that results and conclusions are supported by the data and analyses. Interactions with site personnel familiar with site-wide characterization efforts, environmental restoration efforts, and performance-assessment and modeling efforts ensure that the best understanding of site characteristics and data relevant to waste disposal are incorporated into the analyses.

The PE is a deterministic analysis, and a quantitative uncertainty analysis is not performed. The degree of uncertainty associated with site-specific data and conceptual models varies from site to site, depending on the current level of understanding of radionuclide transport and availability of data to support the conceptual model. Less uncertainty may exist at sites where extensive site characterization work has been done. Uncertainty is addressed qualitatively in the PE by discussing confidence in data and results based on the quality of the data source (e.g., well-documented site-specific data, site-supported literature data, or unsupported assumed data) and level of understanding of flow and transport at the site.

Care has been taken in executing the PE to avoid bias in analyses that draw comparisons between sites with vastly differing attributes (e.g., small versus large sites, western versus eastern sites, or arid versus humid sites), and efforts have been made to ensure that the results of the PE do not indicate unwarranted advantages or disadvantages for any disposal site. Sensitivity analyses are used to identify the magnitude of change in parameter values required to change the controlling pathway or scenario. For example, one sensitivity analysis will determine the increase in infiltration rate required to change the controlling pathway for a permissible radionuclide concentration from the intrusion pathway to the drinking-water pathway. Analysis results indicating that a large change in infiltration rate would be required indicates the robustness of results to the assumed value of infiltration. Similar analyses will be performed for other input values and modeling assumptions.

Preliminary comparisons of PE with performance-assessment results have shown that the results of the simple PE model generally agree with results of the performance assessments, even when site conditions are complex. No direct comparisons can be made at sites with no existing performance analyses, but, based on the comparisons with performance-assessment results, the PE results are expected to provide a reasonable representation of site conditions when good characterization data are available. Sites with little characterization data will have the greatest uncertainty in results.

CONCLUSION

While the PE cannot be used as a substitute for performance assessments, it illustrates a potential method to satisfy the desires of regulatory agencies and the general public for a simple, conservative, defensible, and easily understandable analysis that provides results similar to those of more complex analyses. Simple representations of complex phenomena may be the only way to gain public acceptance of MLLW disposal facilities that evoke deep concerns in a cautious, non-technical public.

REFERENCES

1. Federal Facility Compliance Act of 1992, P.L. 102-386 (October 1992).
2. Resource Conservation and Recovery Act of 1976, P.L. 94-580, Stat. 2795 (1976).
3. DOE, "Low-Level Waste," Radioactive Waste Management, Chapter III, Order 5820.2A (1988).
4. ORNL, "Performance Assessment for Continuing and Future Operations at Solid Waste Storage Area 6," ORNL-6783, Oak Ridge National Laboratory (1994).
5. MARTIN MARIETTA ENERGY SYSTEMS, INC., EG&G IDAHO, INC., WESTINGHOUSE HANFORD COMPANY, AND WESTINGHOUSE SAVANNAH RIVER COMPANY, "Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility (U)," WSRC-RP-92-1360, Rev. 0, Westinghouse Savannah River Company (1992).
6. D. E. WOOD, R. U. CURL, D. R. ARMSTRONG, J. R. COOK, M. R. DOLENC, D. C. KOCHER, K. W. OWENS, E. P. REGNIER, G. W. ROLES, R. R. SEITZ, AND M. I. WOOD, "Performance Assessment Task Team Progress Report," DOE/LLW-157, Rev. 1, Idaho National Engineering Laboratory (1994).
7. C. T. KINCAID, J. W. SHADE, G. A. WHYATT, M. G. PIEPHO, K. RHOADS, J. A. VOOGD, J. H. WESTSIK, JR., M. D. FRESHLEY, K. A. BLANCHARD, AND B. G. LAUZON, eds., "Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford," WHC-SD-WM-EE-004, Rev. 0, Pacific Northwest Laboratory and Westinghouse Hanford Company (1993).
8. EPA, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," Federal Guidance Report No. 11, EPA 520/1-88-020, Environmental Protection Agency (1988).
9. STEVEN J. MAHERAS, ARTHUR S. ROOD, SWEN O. MAGNUSON, MARY E. SUSSMAN, AND RAJIV N. BHATT, "Radioactive Waste Management Complex Low-Level Waste Radiological Performance Assessment," EGG-WM-8773, DOE Idaho Operations Office (1994).
10. MAGNUSON, SWEN O., STEVEN J. MAHERAS, HOA D. NGUYEN, ARTHUR S. ROOD, JANICE L. SIPOS, MARILYN J. CASE, MICHAEL A. MCKENZIE-CARTER, AND MARY E. DONAHUE, "Radiological Performance Assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site," 11-1-2, Rev. 1, DOE Idaho Operations Office (1992).
11. WSRC, "Radiological Performance Assessment for the E-Area Vaults Disposal Facility (U)," WSRC-RP-94-218, Rev. 0, EG&G Idaho, Inc., and Westinghouse Savannah River Company (1994).

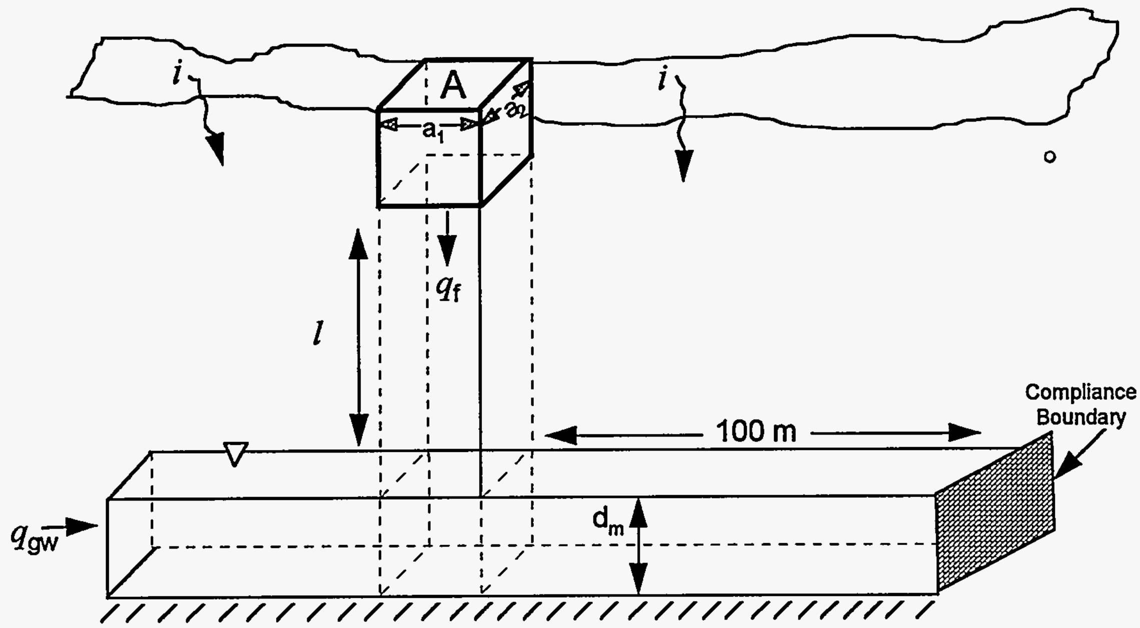

Fig. 1. Generic conceptual model that is modified for each site.