PATHWAYS ANALYSIS MODEL TO EVALUATE DOE MIXED LOW-LEVEL WASTE DISPOSAL FACILITIES

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ABSTRACT

A Systems Analysis Methodology is being developed as part of the U.S. Department of Energy (DOE) Headquarters Mixed Low-Level Waste (MLLW) Management Program. The Methodology will be used to evaluate various options for "cradle-to-grave" management of MLLW generated and stored at DOE facilities and also MLLW that is projected to be routinely generated for the next 20 years. As part of the Methodology, a Pathways Analysis Model has been developed to evaluate the effectiveness of waste forms and disposal facility technologies with respect to compliance with the performance objectives of DOE Order 5820.2A and other applicable orders and regulations.

Codes to perform generic analyses as well as detailed site-specific analyses are included in the Model. The Model is based on a performance assessment methodology developed for use by the U.S. Nuclear Regulatory Commission (NRC) in evaluating license applications for low-level waste (LLW) disposal facilities. The codes are coupled through pre/post-processors to simulate possible migration of contaminants from the disposal facility and potential human exposure pathways.

Numerous physical and chemical property values that encompass waste form, disposal facility, site, and environmental properties have been compiled as input to the Model. Sensitivity analyses continue to be performed to identify those input parameters that have a significant influence on the predicted Model results. The sensitivity analyses consist of varying a parameter over its range of values while maintaining all other parameters at their most probable or reference values.

The model is being applied to evaluate the performance of a number of final waste forms and disposal concepts. The "Reference Case" is based on an aboveground vault for humid climates and a below-ground vault for arid climates. Once the Reference Case is evaluated, the Model will then be applied to evaluate the effectiveness of three alternative disposal concepts: a Resource Conservation and Recovery Act (RCRA) permitted landfill, a non-RCRA LLW disposal facility, and intermediate depth to deep geologic disposal. Uncertainties in the values of the input parameters are propagated to the Model output using Monte Carlo analysis with Latin Hypercube Sampling.

The results of the modeling will be integrated with the other components of the Systems Analysis Methodology (system life-cycle costs, implementation schedules, regulatory impacts, and risk assessment) using a multi-criteria decision technique to arrive at a quantitative comparison and ranking of the various MLLW management options.

INTRODUCTION

The Mixed Low-Level Waste (MLLW) Management Program is a U.S. Department of Energy Headquarters (DOE-HQ) initiative designed to develop a system wide integrated strategy for managing DOE's mixed low-level wastes. As part of the MLLW Management Program, a Systems Analysis Methodology is being developed to evaluate various options for "cradle-to-grave" management of MLLW generated and stored at DOE facilities. A typical option is defined as any combination of methods used during each stage of MLLW management from waste generation through disposal, including transportation, storage, and treatment. This paper provides an overview of the Pathways Analysis Model (referred to as the "Model") to evaluate the effectiveness of waste forms and disposal facility technologies with respect to compliance with the performance objectives of DOE Order 5820.2A (1) and other applicable orders and regulations.

The Model, as currently applied, provides a simplified approach to evaluating the effectiveness of various waste forms and disposal facility technologies located in representative or generic humid and arid locations. Results from the Model will be combined with other components of the Systems Analysis Methodology (system life-cycle costs, implementation schedules, regulatory impacts, and risk assessment) to provide a comprehensive tool for comparison of MLLW management options.

THE PATHWAYS ANALYSIS MODEL

Codes to perform simple (generic) analyses as well as detailed (site-specific) analyses are included in the Model. The Model is based on a performance assessment methodology (2) developed for use by the U.S. Nuclear Regulatory Commission (NRC) in evaluating license applications for low-level waste (LLW) disposal facilities. The Model is modular in structure to provide flexibility in replacing individual modules with improved or more site applicable codes as required. The simple or generic analyses provide a first-order approximation of performance since the spatial variability in site hydrologic properties is evaluated in a probabilistic manner over a range of expected values. The detailed codes or modules of the Model may be applied in the future to evaluate site-specific waste forms and disposal facility designs.

In evaluating the performance objectives of DOE Orders and other applicable regulations, the Model simulates migration and exposure pathways. Migration pathways are routes that transport contaminants to selected locations in media (e.g., groundwater, surface water, soil, and air). Exposure pathways are routes through which contaminants are transported from these selected locations to humans. Exposure pathways include external exposure to contaminated air, water and soil; inhalation of airborne contaminants; and ingestion of contaminated drinking water, crops, animal products, and aquatic foods. The important pathways for an undisturbed disposal facility and for disruptive scenarios involving human intrusion into the disposal facility are summarized in Fig. 1.

The processes simulated by the Model to evaluate the performance of waste forms and the disposal facility are shown in Fig. 2 and include the following:

- Infiltration of water through the soil cover of the disposal facility
- Flow of water through the disposal facility
- Release of contaminants from the waste forms and transport to the disposal facility boundary
- Transport of contaminants through the unsaturated or vadose zone
- Transport of contaminants through the saturated zone
- Transport of contaminants through surface water
- Transport of contaminants through air
- Exposure pathways and dosimetry assessment
- Human intrusion scenarios into the disposal facility.

Codes included in the Model to perform both simple (generic) analyses and detailed (site-specific) analyses by simulating the above processes are summarized in Table I. These major processes are initially included in the Model. If it is determined that the assumptions and processes do not adequately describe the system, then additional processes will be included, as required.

In the Model, two intruder scenarios are analyzed that represent combinations of previously developed scenarios (2). The first is the "intruder-construction" scenario, where it is assumed that an inadvertent intruder occupies the disposal site at the end of active institutional controls and excavates into the disposal structure. The intruder is also assumed to drill a well through the waste for use as a potential water supply source. Human exposure during this time period may include direct external exposure to the contaminated surface soil, external exposure to contaminated air, and inhalation of contaminated soil suspended in air. This scenario is used to evaluate compliance with the 500 mrem limit for a short-term, single, acute exposure as mandated by DOE Order 5820.2A (1).

The second scenario is called the "intruder-agricultural" scenario, where it is assumed that a farmer moves onto the waste disposal site and lives in the building constructed in the intruder-construction scenario (2). The farmer then commences agricultural activities using well water from a well constructed at the facility during the intruder-construction scenario. In addition to the doses due to ingestion of contaminated foods, the intruder may receive doses by direct exposure to contaminated soil and by consumption of contaminated well water. This second scenario is used to evaluate compliance with 100 mrem/yr limit for continuous exposure (1). The intruder-agricultural scenario is assumed to occur after the containers have failed and the contaminants have migrated through the vadose zone to the groundwater table.

The Model has been developed for use on DOS-based desktop computers with an installed math co-processor. As part of the development of the Model, pre- and post-processors (i.e., programs written in FORTRAN to manipulate the input and output files) have been developed to couple the individual modules for simple analyses into the Model. The modules and processors are called sequentially by a master driver program that is written in the format of a DOS batch file.

A master input data file is created for each run of the Model, which is then read by the various processors. This master input data file contains the values of the physical and chemical properties that are required by each module. The master input data file also specifies control parameters (e.g., number of time steps, number of cells, and convergence criteria) that are required by the various modules. The processors extract the relevant data from the master input data file, as well as data from the output file created by the previous module in the sequence of execution to create the input data file required for the next module in the sequence.

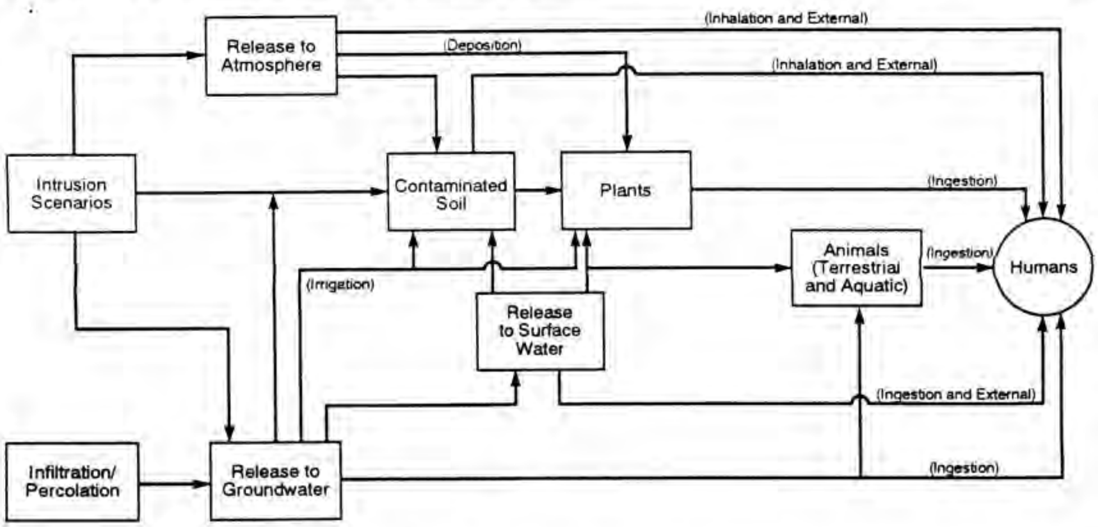

Fig. 1. Exposure pathways to humans.

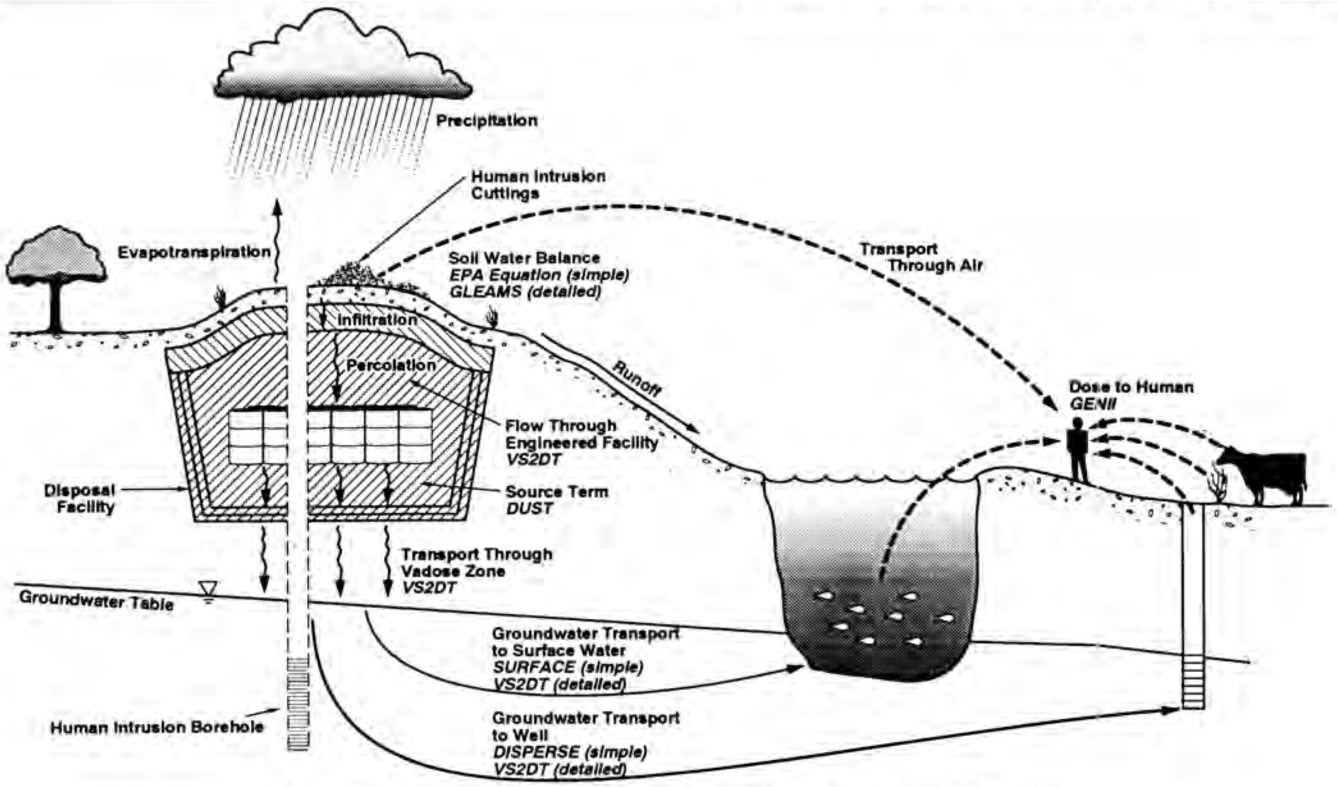

Fig. 2. Simulated processes and modules of the pathways analysis model.

MODEL INPUT PARAMETERS

The Model requires numerous physical and chemical property values that encompass waste form, disposal facility, site and environmental properties. The property values for use in the first round of evaluations employing the Model have been derived through calculations using data from existing waste characterization information, questionnaires and discussions with site personnel, modeling, and expert judgment.

Waste form properties include waste form density, contaminant concentrations, waste form leach rates, and contaminant solubility limits. Examples of required disposal facility properties are the times to container and to concrete failure, dimensions of the facility, and hydrologic properties of the materials comprising the facility such as relative permeability curves and porosities. Required site properties include the infiltration rate, distance to receptor wells and surface water bodies and other hydrologic properties of the unsaturated and saturated zones such as permeabilities, porosities, hydraulic gradients, dispersivities and retardation coefficients. The environmental properties include consumption rates of drinking water and various foods, lengths of the growing seasons of various foods and corresponding irrigation rates using potentially contaminated irrigation water.

Potential DOE disposal sites have been classified as either arid or humid according to their climatic conditions. Data from these disposal sites was used to establish a range (uncertainty) and a representative (mean) value for each parameter for the generic arid and humid sites.

SENSITIVITY ANALYSES

Sensitivity analyses are being performed to identify those input (key) parameters that individually have a significant influence on the predicted Model results. The sensitivity analyses consist of varying a parameter over its range of values while maintaining all other parameters at their most probable or reference values. The sensitivity analyses also serve as a screening methodology by identifying the significant radionuclides with respect to potential doses to humans. The parameters evaluated as part of the sensitivity analyses include:

- Infiltration rates
- Waste form leach rates
- Vadose zone travel times
- Concrete time-to-failure
- Container time-to-failure
- Actinide solubility limits
- Retardation coefficients of the radionuclides in different media
- Aquifer properties (thickness, groundwater velocity, longitudinal and transverse dispersivities)
- Surface water flow rates

UNCERTAINTY ANALYSES

Uncertainty analyses provide information on the uncertainty in model output as a function of the simultaneous uncertainty in the values of the input variables. Uncertainty analyses are commonly performed using the Monte Carlo technique with Latin Hypercube Sampling (LHS) (3). The Monte Carlo analysis coupled with LHS has been recommended as a method for addressing uncertainty in LLW performance assessment (4). This method is used with the Model to address the concurrent uncertainty associated with the key parameters identified during the sensitivity analyses.

APPLICATIONS OF THE MODEL

Current applications of the Model are not intended to replace site-specific models for detailed performance

TABLE I
Modules Selected for Simulating Processes in the Pathways Analysis Model

Process Simulated	Codes for Simple (Generic) Analyses	Codes for Detailed (Site-Specific) Analyses
Infiltration of Water Through Soil Cover	EPA Soil Water Balance Equation or Measured Rates	GLEAMS or Measured Rates
Flow of Water Through Disposal Facility	VS2DT	VS2DT
Release and Transport of Contaminants to Disposal Unit Boundary	DUST (Multi-Cell Mixing Cascade model)	DUST (Finite-Difference model)
Transport of Contaminants Through Unsaturated Zone	VS2DT for Flow Delay Time for Transport	VS2Dt
Transport of Contaminants Through Saturated Zone	DISPERSE/SURFACE	VS2DT
Transport of Contaminants Through Surface Water	GENII	GENII
Transport of Contaminants Through Air	Not required	GENII
Exposure Pathways and Dosimetry Assessment	DITTY Code of the GENII Package	GENII
Human Intrusion Scenarios	GENII and Groundwater Concentrations	GENII and Groundwater Concentrations

assessments. Instead, the Model is used as a screening tool to evaluate the effectiveness of various waste form and disposal facility options. The effectiveness of an option refers to the comparison of model results (annual effective dose equivalent, dose from drinking water, and human intruder doses) to the performance objectives in the applicable DOE orders and other regulations.

The Model is being applied initially to evaluate the effectiveness of different disposal options located in both a humid and an arid site. The disposal concept for the Reference Case is based on an aboveground vault for humid climates and a below-ground vault for arid climates. The two disposal facilities are comprised of identical components including:

- Robust waste forms (vitrified and/or cemented) where organics have been removed during thermal treatment
- High-integrity containers designed to resist corrosion by the waste, disposal facility materials, and crushing from static loads and also designed to maintain gross physical properties and identity for over 300 years, as provided by guidance in 10 CFR Part 61 (5)
- Fluid concrete-grout backfill to fill voids between containers
- An engineered multi-layer cap designed to minimize infiltration
- A steel-reinforced concrete vault comprised of one or more disposal cells that are separated by a reinforced concrete wall
- A Resource Conservation and Recovery Act (RCRA) liner system
- A leachate collection, detection, and removal system as required by RCRA.

After completion of the sensitivity analyses, the Model will be applied to evaluate the effectiveness of the Reference Case disposal concept. Uncertainties in parameter values will be evaluated using Monte Carlo analysis with LHS.

The Model will then be applied to evaluate the effectiveness of three alternative disposal concepts that have been defined to date. The first is a RCRA permitted landfill, the second is a non-RCRA LLW disposal facility (requires delisting of treated MLLW), and the third is intermediate depth to deep geologic disposal. As with the Reference Case, Monte Carlo analysis with LHS will be applied to evaluate uncertainties in input parameter values.

The applications of the Model are expected to be iterative, i.e., the Model will be run periodically using the best available information, with sensitivity and uncertainty analyses used to identify critical additional data needs. As new and improved data identified by these iterative analyses become available, the Model may be rerun to evaluate the effectiveness of the waste forms and disposal facility designs. Additional uncertainty analyses can then be performed, if needed, to establish whether the remaining uncertainties in performance are acceptable for a final decision on technology selection and system configuration.

Finally, the results of the modeling will be integrated with the other components of the methodology (costs, schedules, regulatory impacts and risk assessment) using a multi-criteria decision technique with uncertainty analysis to arrive at a quantitative comparison and ranking of the various TSD options. Details of the modeling of alternative disposal concepts and the Systems Analysis Methodology will be documented in a report scheduled for publication by the DOE in early calendar year 1994.

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