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Introduction to Radiological Performance Assessment

National Low-Level Waste Management Program

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Introduction to Radiological Performance Assessment

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ABSTRACT

A radiological performance assessment is conducted to provide reasonable assurance that performance objectives for low-level radioactive waste (LLW) disposal will be met. Beginning in the early stages of development, a radiological performance assessment continues through the operational phase, and is instrumental in the postclosure of the facility. Fundamental differences exist in the regulation of commercial and defense LLW, but the radiological performance assessment process is essentially the same for both. The purpose of this document is to describe that process in a concise and straightforward manner. This document focuses on radiological performance assessment as it pertains to commercial LLW disposal, but is applicable to U.S. Department of Energy sites as well. Included are discussions on performance objectives, site characterization, and how a performance assessment is conducted. A case study is used to illustrate how the process works as a whole. A bibliography is provided to assist in locating additional information.

CONTENTS

FIGURES

ACRONYMS

ALARA	as low as reasonably achievable
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
LLRWPA	Low-Level Radioactive Waste Policy Act of 1980
LLRWPAA	Low-Level Radioactive Waste Policy Amendments Act of 1985
LLW	low-level radioactive waste
NRC	U.S. Nuclear Regulatory Commission

Introduction to Radiological Performance Assessment

INTRODUCTION

The purpose of this document is to explain the general radiological performance assessment process in a format that is easy to understand. The radiological performance assessment process is divided into steps and described, and a short case study is included to illustrate the process. Background information is provided on Federal regulations, site selection, and performance objectives.

Low-level radioactive wastes (LLW) are defined as radioactive wastes not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11(e)2 of the Atomic Energy Act, as amended. LLW is regulated by source as well as by content, and is separated into two main waste types: commercial and defense. Commercial LLW disposal is regulated by the U.S. Nuclear Regulatory Commission (NRC) under Title 10 Code of Federal Regulations Part 61 (10 CFR 61) or by agreement States under equivalent State regulations. Disposal of defense LLW is regulated by the U.S. Department of Energy (DOE) under DOE Order 5820.2A. Although the two waste types are subject to different regulations, the performance objectives are similar. This document is intended for commercial LLW siting efforts in the various host States and compact regions, but also will be a useful reference for other sites.

BACKGROUND

Low-Level Radioactive Waste Policy Act

The Low-Level Radioactive Waste Policy Act (LLRWPA) of 1980 made each State responsible for the disposal of all commercial LLW generated within its borders. States were encouraged to form compacts to facilitate disposal on a regional basis by a provision in the LLRWPA, allowing compact regions to exclude wastes from outside their borders after January 1, 1986. Many States are now affiliated with compact regions.

By the end of 1983, it was apparent that most States could not provide for their own LLW disposal capacity by the January 1, 1986, deadline, prompting Congress to pass the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) in 1985. The Amendments Act kept the three existing commercial disposal sites at Richland, Washington; Beatty, Nevada; and Barnwell, South Carolina, open through the end of 1992, while placing volume limitations on waste generators and setting several milestones for the development of new sites.

Purpose and Definition of Performance Assessment

A major milestone set forth in the LLRWPAA was for complete license applications to be filed by January 1, 1992. The potential licensee conducts a radiological performance assessment in support of a license application for a commercial LLW disposal site to provide a reasonable assurance of compliance with the specifications set forth in 10 CFR 61 or equivalent agreement State regulations.

A radiological performance assessment is a systematic analysis of a proposed LLW disposal facility and its immediate surroundings that estimates radiation dose to humans for comparison of the estimates with a set of performance criteria. The purpose of the performance assessment is to provide reasonable assurances that the LLW disposal facility will meet the performance objectives of 10 CFR 61. This analysis evaluates both the short and long-term impacts of the facility and compares those results with established performance criteria. A radiological performance assessment continues to be carried out during operational and postclosure periods to evaluate regulatory compliance (Case and Otis 1988).

Considerable uncertainty exists in these assessments and resulting estimates are not seen as accurate predictions of future facility performance. Rather, the performance assessment results indicate a possible range of values for radionuclide release, transport, and exposure intended to provide reasonable assurance of compliance with performance objectives. The performance assessment supplies general indications of performance and is part of the process for assessing the overall safety of the disposal facility.

THE PERFORMANCE ASSESSMENT PROCESS

The basic concept of a performance assessment is to develop a simplified representation of the physical world using research data, assumptions, documented information, and modeling techniques in an attempt to understand contaminant transport within the waste disposal system and along potential pathways of human exposure. Each radiological performance assessment begins with site-specific physical data that are used to formulate a conceptual model. The specific processes in the conceptual model are then described mathematically. Finally, the system is modeled with mathematical representations and computer programs, called computer codes, to obtain a range of results. The results of the performance assessment are compared with the performance objectives to determine if reasonable assurance is provided that the potential dose will be below the regulatory standard. The intent is not to predict the actual dose. This must be understood before starting a performance assessment as it will guide the data and models needed from using the best available to using those that are adequate for the purpose (see Figure 1) (Seitz 1992).

A model is a simplified representation of a real-world system. Models should represent the important components and interactions of the particular system being modeled, and should be selected based on the ability to represent site-specific phenomena. For a radiological performance assessment, the modeling process does not produce an absolute answer, but rather a conservative bounding approximation. This approximation is dependent on the accuracy of the input data, the conceptual and mathematical models, and the computer code(s).

Methodology

Several methodologies have been proposed for conducting a radiological performance assessment. For example, Case and Otis (1988) proposed a nine-step process, and the NRC has proposed a five-step process. The various methodologies differ mainly in the level of detail. The methodology detailed below outlines the main steps of each method. Figure 1 is a simplified representation of the performance assessment process and illustrates the iterative nature of that process. Performance objectives drive the process and are used as a measure of success. Each step is explained in greater detail in the following sections.

STEP 1: The first step in conducting a radiological performance assessment is to identify all applicable requirements and performance objectives. Those are contained in NRC regulations governing radioactive waste disposal and are listed in the next section, "Performance Objectives for LLW Disposal Sites." The objectives provide a basis to begin identifying pathways and scenarios considered in formulating the conceptual model.

STEP 2: The second step is to collect physical data, including site characterization, waste characterization, and facility design. Monitoring and data collection are used to understand the LLW disposal system and to formulate the conceptual model. Field and laboratory investigations are performed to gain an understanding of the site characteristics important to isolation of the LLW and long-term success of the disposal site.

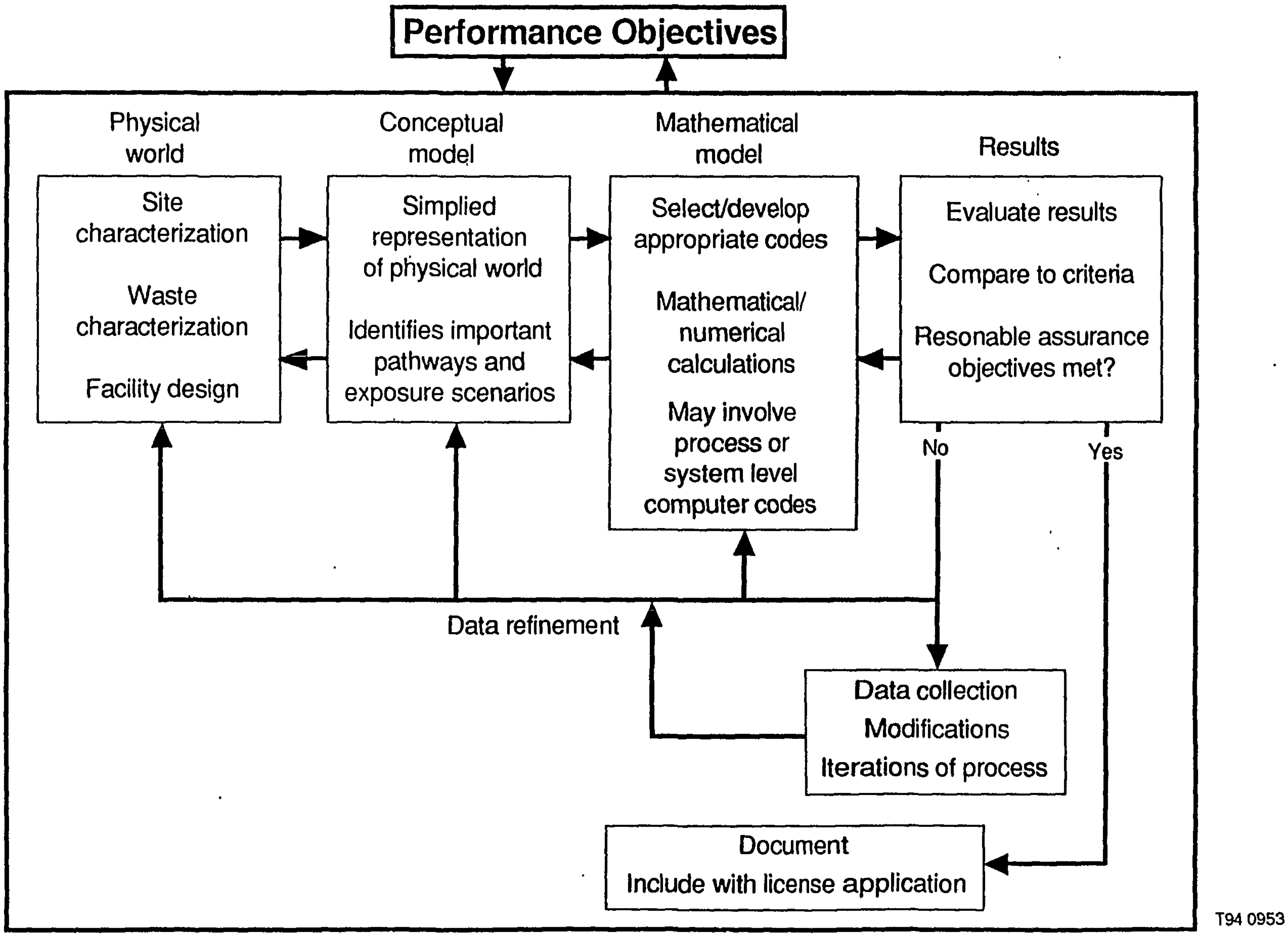

Figure 1. Radiological performance assessment process.

STEP 3: The third step is to develop a conceptual model for possible routes of human exposure. Exposure scenarios are developed using the information obtained in the first two steps. Important processes and pathways identified in those scenarios are represented in the conceptual model. Conceptual models should be simple and should be consistent with the available data, mathematical models, and computer codes.

STEP 4: The fourth step is to mathematically describe the process and pathways identified in the conceptual model. Screening calculations are first used to narrow the focus. Screening calculations, conducted with highly conservative models, can eliminate many of the radionuclides in the waste inventory from future consideration. Performance assessment efforts can then be focused initially on the limited number of radionuclides that contribute to potential dose.

Carefully selected computer codes and modeling approaches are then used to perform calculations on those radionuclides that were not "screened out" (Seitz 1992). Performance assessment calculations should not be considered absolute predictions of system performance due to the uncertainty associated with predicting future events and the assumptions made when conducting a performance assessment.

STEP 5: The fifth step involves evaluating the calculated results to identify where additional data may be required, and comparing the results to the performance objectives. Calculations should be evaluated using sensitivity analysis, uncertainty analysis, and validation with measured environmental variables.

PERFORMANCE OBJECTIVES FOR LLW DISPOSAL SITES

The purpose of a radiological performance assessment is to provide reasonable assurance that disposal objectives will be met for the time periods of concern as determined from 10 CFR 61, "Licensing Requirements For Land Disposal of Radioactive Waste." As developed by the NRC, there are four performance objectives contained in 10 CFR 61.41-44. Those objectives are listed below, and are applicable to commercial LLW:

1. Protection of the general population from releases of radioactive material (25 mrem/yr whole body, 75 mrem/yr thyroid, 25 mrem/yr any other organ)

2. Protection of individuals from inadvertent intrusion

3. Protection of individuals during operations (in accordance with 10 CFR 20)

4. Stability of the disposal site after closure.

Specific guidelines for technical analyses are established in 10 CFR 61.13. Those guidelines specify the analyses required to provide reasonable assurance that the performance objectives listed above will be achieved. The NRC will issue a license for commercial LLW disposal upon finding that all of the requirements of 10 CFR 61.23, "Standards for Issuance of a License," are met.

Special Considerations

Some details related to the performance objectives require special consideration and are examined in greater detail below. Those details include the inadvertent intruder scenario and the appropriate time periods and locations to be used in evaluating performance. Applicable time periods of concern are determined by waste class (A, B, or C). Exact locations of concern and inadvertent intruder scenarios will be determined from site-specific information.

Time Periods of Concern

Although each radiological performance assessment will be site-specific, there are three common time periods of concern. Those include the operational, institutional control, and postinstitutional control periods. The operational time period begins when waste is disposed at the facility. The institutional control period of postclosure maintenance and monitoring lasts about 100 years. The postinstitutional control period is the bounding timeframe for measuring disposal site performance. It is characterized by no active monitoring or maintenance and typically lasts 500 years or more. The postinstitutional control period represents the greatest potential risk of exposure to an inadvertent intruder because access to the site is assumed to be uncontrolled (Case and Otis 1988).

Locations of Concern

There are also three general areas of concern: the immediate area occupied by the disposal facility, the site boundary, and the area within a 10-km radius. Those are areas of active monitoring and data collection for the purpose of estimating exposure to workers and the public. Potential doses are calculated at or near each location and compared with performance objectives to assess regulatory compliance and disposal site performance. Site-specific requirements may exist.

Inadvertent Intruder Scenario

One of the performance objectives listed in 10 CFR 61 specifically provides for the protection of inadvertent intruders during postinstitutional control. A performance assessment will include scenarios in which an inadvertent intruder receives both an acute dose and a chronic dose. An acute dose refers to a high level of exposure for a short duration, whereas a chronic dose refers to a continued or periodic exposure for a long duration. Specific analyses regarding inadvertent intrusion are set forth in 10 CFR 61.13(b) for commercial disposal sites. Those analyses must provide reasonable assurance that waste classification and segregation requirements will be met and that adequate barriers will be provided.

Some examples of inadvertent intruder scenarios developed by the NRC include intruder-drilling, intruder-construction, and intruder-agriculture. The intruder-drilling scenario assumes that the waste is contacted through some type of exploratory drilling, whereby the waste is penetrated. The intruder-construction scenario assumes the waste is contacted while the intruder is excavating the basement of a home, and the intruder-agriculture scenario assumes that the intruder lives over the disposal facility where food is grown and consumed. The agriculture scenario is assumed to be chronic, whereas the others are assumed to be acute exposure events. Site-specific scenarios must be developed for each disposal facility (Kennedy and Peloquin 1988).

PHYSICAL DATA

Site Characterization

Site characterization is the first step in new site development and generally involves monitoring and data collection. The NRC defines this process as "the program of investigations and tests, both in the field and laboratory, undertaken to define the site characteristics affecting the isolation of the LLW, the long-term suitability of the disposal site, and the interactions between the disposal site and its surroundings" (Seifken et al. 1982, NUREG-0902).

The purpose of site characterization is to investigate the characteristics of the proposed disposal site to support a license application and environmental report, and to permit an independent evaluation of the proposed disposal facility. This characterization of the physical world may then be described in a simplified conceptual model. Specific objectives of site characterization are to develop the technical information needed for the following:

- Reasonable assurance that the performance objectives and the minimum technical requirements on site suitability will be met
- Evaluation of the ability of the site characteristics to contribute to isolation of LLW
- Design of the disposal facility
- Identification of interactions between the site characteristics and the LLW and waste containers
- Establishment of data collection points and a baseline of data for some portions of the site monitoring program
- Identification of potential environmental impacts resulting from construction, operation, and closure of the disposal facility.

There are several requirements listed by the NRC in 10 CFR Part 61.50 regarding natural site characteristics necessary to license a LLW disposal site. Specific technical information may be found in 10 CFR 61.12. At the present time, regulations have only been developed for near-surface disposal. Guidance is still being developed for other disposal technologies. The following are general categories that should be addressed in support of a site characterization, as identified in NRC guidance (Seifken et al. 1982, NUREG-0902; NRC 1988a, NUREG-1200; NRC 1988b, NUREG-1199; Shum et al. 1989, NUREG-1388; Pangburn et al. 1987, NUREG-1300).

NRC Site Characterization Data Categories:

- Geology
- Groundwater hydrology

- Surface water hydrology
- Geochemistry/hydrochemistry
- Water resources
- Geologic/timber/agricultural resources
- Geotechnical investigation
- Geography
- Demography
- Land use
- Meteorology
- Air quality
- Radiological assessment
- Ecology
- Socioeconomics
- Cultural resources
- Transportation
- Aesthetics.

Each of these categories has specific requirements for data collection and information gathering. The specific parameters required under each of these are beyond the scope of this document, but may be found in the NUREG documents listed in the Bibliography section and in the *Site Characterization Handbook for Low-Level Radioactive Waste Disposal Facilities* (National Low-Level Waste Management Program 1992).

Site characterization begins with premonitoring surveys, research, and planning. The actual data collection takes place in subsequent field surveys, which consist mainly of geologic sampling and measuring procedures. Following the surveys, data are analyzed and samples are tested in the laboratory. The results are used for several purposes, including site modeling, site characterization reports, license applications, environmental and safety analysis reports, and performance assessments.

Waste Characterization

Waste characterization is important for three reasons: 1) ensuring compliance with the licensing requirements of 10 CFR 61, 2) allowing classification of the waste for planning and designing the facility disposal units, and 3) using data in a radiological performance assessment to perform calculations and estimate the waste inventory/source term.

A waste inventory describes the physical and chemical characteristics of the waste. Important data for a waste inventory include physical form and volume, radionuclide content and concentration, activity, location, classification, type of radiation emitted, and specific chemical and physical data. This information is important for determining operating costs and capacity of the disposal facility, for calculating disposal surcharges, for assessing accidents, and as input data for performance assessments.

Classification of commercial LLW is based on radionuclide concentrations listed in 10 CFR 61. Class A LLW has low concentrations of the radionuclides listed in Tables 1 and 2 of 10 CFR 61.55. It is generally segregated from Class B and C waste unless the Class A waste form meets the stability requirements in 10 CFR 61.56(b). Class B LLW has intermediate radionuclide concentrations and must meet stability requirements. Class C LLW has the highest radionuclide concentrations (for which States are responsible under the LLRWPAA) and must meet stability requirements as well as additional protective measures against inadvertent intruders.

Institutional control for 100 years following site closure is sufficient to permit disposal of class A and B LLW without additional precautions for inadvertent intruders. However, Class C LLW must be disposed of at least 5 meters below the surface or with engineered barriers designed to protect against the inadvertent intruder for at least 500 years.

Facility Design

Isolation of LLW from the public and the environment is the primary goal of waste disposal. Groundwater is presumed to be the primary exposure pathway, and preventing release to nearby aquifers is a major concern in LLW disposal. Depth and type of cover material, depth to groundwater, and proximity to aquifers are important parameters in regard to possible release and transport, and are given special consideration in selecting a disposal technology. Technologies such as shallow-land disposal, modular concrete canister disposal, and earthen-covered abovegrade vault are now being considered by several States.

A design of a typical LLW disposal site includes several distinct areas. The waste is placed into disposal units in a restricted area. These units are defined by confines that may include walls, floors, trench sides, and earthen covers. Disposal units may be a concrete vault, pad, or trench. Unlike a vault, trenches and pads are not fully enclosed and extra stabilization measures are necessary. Soil, sand, or gravel may be used as grout to fill in between individual waste containers for added structural stability. These materials have the added benefit (as opposed to concrete) of allowing rapid movement of water through the units, minimizing contact with the waste containers.

Particular design features are dependent upon the disposal concept selected. Retention ponds are located in the restricted area and collect the runoff water from precipitation. A buffer zone is the area between the restricted zone and the site boundaries and is usually controlled by some security arrangements. Each design incorporates support facilities for the disposal operation and includes areas such as waste inspection stations, maintenance buildings, warehouses, receiving, and decontamination areas.

The site is generally designed to accept waste for 20–50 years and to isolate waste from the environment for hundreds of years. Depending on the disposal concept selected and anticipated volume, the size of the site may vary from 25 to 300 acres.

The features of the land disposal facility and disposal units are designed to minimize the infiltration of water into the disposal units. Principal design features should consider water infiltration, cover integrity, structural stability, contact with standing water, site drainage, and monitoring of the disposal site.

A design feature that provides a protective measure against water infiltration is a disposal unit cap that is a combination of layers of soil, clay, concrete, and synthetic liners. Caps are constructed in a manner designed to prevent water from reaching the waste containers and to divert runoff away from the disposal unit.

Should infiltration occur, the disposal facility monitoring system is designed to detect and measure any radionuclide release from the disposal site. Active monitoring must take place through the 100 year institutional control period and consists of periodic sampling and testing of air, water, vegetation, and wildlife in the facility, at the site boundary, and within a 10 km radius. Several monitoring wells must be drilled onsite and offsite for measuring radionuclide content in groundwater.

Other features should be designed to facilitate site closure and stability, avoid the need for long-term maintenance after site closure, provide barriers against inadvertent intrusion, reduce occupational exposure, and provide an adequate buffer zone.

Design criteria should reasonably ensure that the facility can adequately protect public health and safety under normal conditions, abnormal conditions, and relative to accident scenarios in accordance with 10 CFR 61 performance objectives (NRC 1988a, NUREG-1200).

CONCEPTUAL MODEL

A conceptual model is a simplified, yet technically credible description of the physical properties of a waste disposal system of interest (Case and Otis 1988). It illustrates contaminant sources and sinks, transport processes and pathways, transport media, and potential receptors. Exposure pathways are identified from performance objectives and are used along with site characterization data to formulate the initial model. System behavior is diagrammed as it is understood, and the model may be modified as more is learned. Potential exposure scenarios are analyzed in a pathway analysis, with separate components modeled independently using submodels.

Pathway Analysis

A pathway analysis examines how radionuclides may be transported through the environment and potential routes of human exposure. It is important to understand that contaminants do not move through the environment by themselves. Rather, they are transported by air or water through advective or diffusive processes. The principal means of exposure to humans is by direct radiation exposure, inhalation of gases or particulates, and ingestion of contaminated food or water. The pathways that lead to these types of exposures are analyzed using four different types of submodels (Figure 2).

Submodels

The four types of submodels include facility, transport, exposure, and demographic models. The facility model uses site-specific information and simulates potential radionuclide release and migration pathways within the facility boundaries. Results from these calculations become inputs for transport models. Transport models calculate the movement of radionuclides after release from the waste disposal system. Demographic models are used to analyze and estimate population distribution as well as agricultural and other land use patterns. The transport and demographic models will result in ranges of values for various parameters of interest. These results, or ranges of values, can be used as inputs to exposure models.

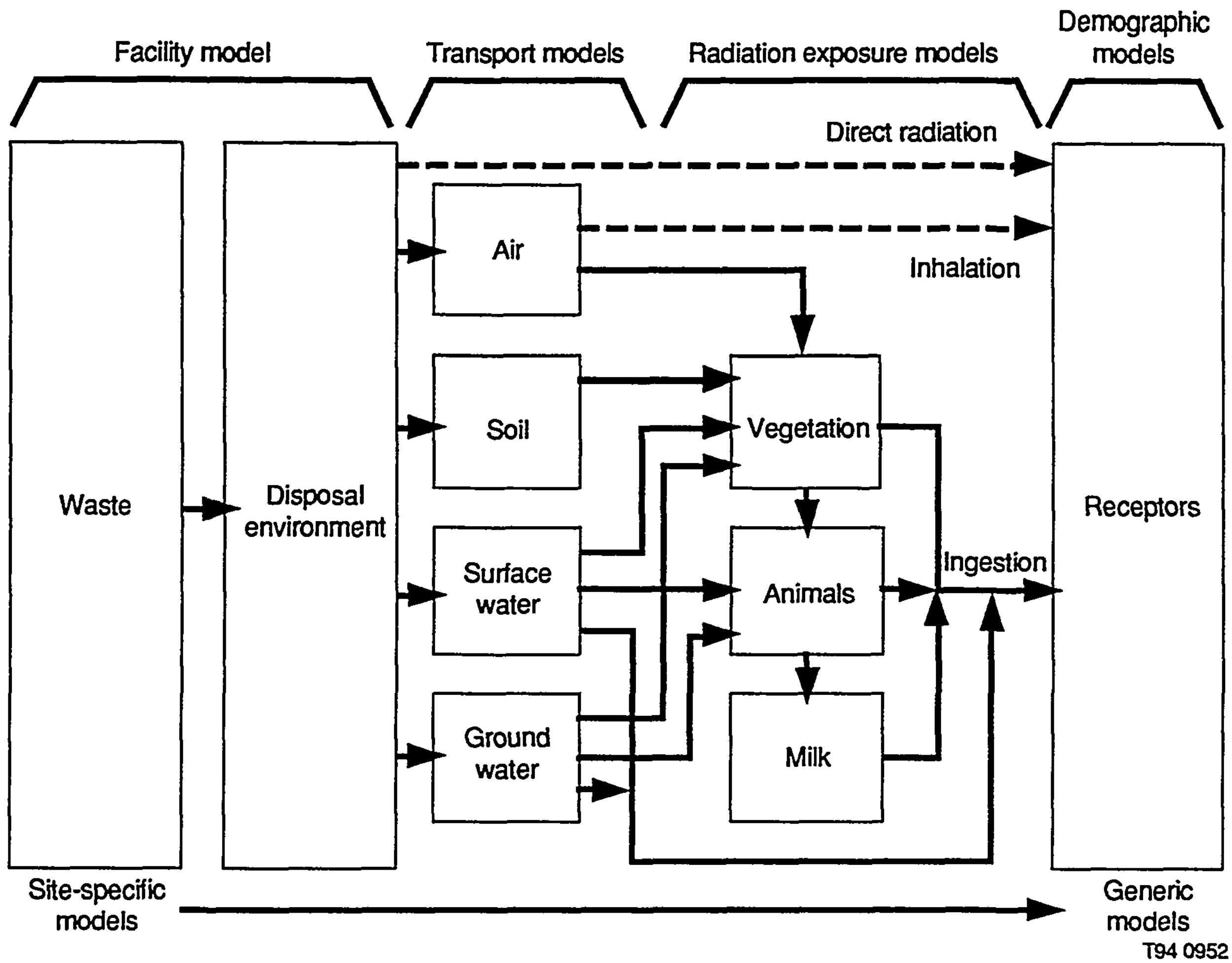

Figure 2. Major model components include information regarding the waste and the disposal environment, transport pathways and modes of exposure, and the potential receptors. Individual components may be analyzed in more detail using the four submodels (Case and Otis 1988).

MATHEMATICAL MODEL

The object of mathematical modeling is to quantify the processes and pathways identified in the conceptual model. A measure of how the waste might behave in the disposal environment is called a source term, and is usually expressed as a radioactive material release per unit time. Development of the source term begins with the conceptual model before being quantified with mathematical models. The value will be dependent on time as well as physical parameters relating to waste characterization and disposal technology. Mathematical models provide a quantitative estimation that may be compared with performance objectives as a measure of the disposal site's potential performance.

There are three types of mathematical models, including analytical, semianalytical, and discrete numerical. Analytical models may be solved by hand calculations or with a calculator. Semianalytical models are similar, but are extremely difficult to solve without additional aid, such as a special handbook of mathematical functions. Discrete numerical models are solved with the aid of a computer and are used to model more complex processes. A radiological performance assessment may involve one or all of these types of mathematical models.

Computer codes are often used to perform complicated calculations in the mathematical modeling phase. They are commonly classified as either process or system level codes, according to the level of analysis (Starmer et al. 1988). Process level codes are more specific and typically model a single process or pathway, whereas system level codes integrate several processes and/or pathways in a more general analysis. Various site-specific processes may be modeled with process level codes. These results may then become input for a system level code.

The capabilities and accuracy of each code used should be verified by running the code and reproducing the input and output data of a standard test case. The NRC suggests establishing and maintaining a quality assurance program throughout the performance assessment process. This program would provide guidance for collecting, managing, and analyzing data, as well as for documenting procedures and analyses (NRC 1988b, NUREG-1199).

RESULTS

The end result of a performance assessment will be site-specific projections of potential doses to be compared with deterministic NRC performance objectives. Generally, the results should include a range of values used to provide an envelope around the expected system behavior. Due to the uncertainties involved, subjective judgment will likely be a necessary part of the demonstration of compliance with the performance objectives.

Some inherent biases will be introduced into the analysis through model and parameter selection. Thus, it is important to involve a variety of technical disciplines in the reviews to try to minimize the impact of the biases that may be introduced. Sensitivity and uncertainty analysis should be used to identify the parameters with the greatest impact on the final results. These parameters can then be reviewed in more detail. Also, such analyses can provide guidance in identifying future data needs and areas where additional effort would provide no additional benefit. The results of these sensitivity and uncertainty analyses are a critical element in demonstrating an adequate understanding of system behavior to serve as justification for the conclusions of the analysis.

Further refinement of a model may be necessary or desirable. This may be accomplished by reducing parameter variability, identifying areas that require additional study or more detailed modeling, or using results to improve the monitoring program. Overall confidence in model projections may be increased by more thorough model validation (Case and Otis 1988). Validation involves comparison of model projections with actual measurements made in the disposal system and is very useful for evaluating accuracy. Correlation with those measured environmental variables will assist in reducing parameter variability.

A thorough and complete performance assessment will serve as a useful tool for the license application process and for assessing site performance over time. The process is dependent on a continuous monitoring program and the accuracy of data and models. A successfully designed disposal site will isolate the waste and protect human health and the environment in accordance with NRC performance objectives.

CASE STUDY

The following case study is provided to demonstrate a simplistic overview of the process of conducting a radiological performance assessment. This illustration will represent a commercial LLW disposal site; therefore, NRC regulations will apply.

STEP 1: Applicable regulations and objectives may be found in NUREG documents and in 10 CFR 61, "Licensing Requirements For Land Disposal of Radioactive Waste." Performance objectives provide a basis to begin identifying transport pathways and exposure scenarios.

STEP 2: When a potentially suitable site is located, monitoring activities are initiated to collect data for a site characterization. Data are collected relating to geology, hydrology, ecology, and other categories identified in NRC guidance. Additionally, information is collected on the disposal technology and waste characterization. The data are used to construct a representation of the physical world at the proposed disposal site (Figure 3). The representation reflects surface and subsurface features, as well as locations of the disposal unit, waste containers, and components of the monitoring system.

This disposal site is located within and over six distinct geological layers. The clay and shale layers are relatively impermeable and significantly slow the downward movement of contaminants. A confined aquifer is located below these layers at a depth of approximately 600 ft. The waste is contained in high-integrity drums and a layered cap covers the disposal unit. A well is located downgradient. For the purpose of this example, the well will serve both as a monitoring point and as a source of drinking water for the hypothetical receptor.

STEP 3: After the site characterization data have been collected, the physical world may be represented in a simplified manner by a conceptual model (Figure 4). In this case, the actual subsurface geology is shown as two distinct regions separated by a straight line boundary. Physical detail is surrendered in favor of a simple description of the system components. Attention is shifted to the important processes and pathways relating to the hydrological cycle and contaminant transport in the LLW disposal system. They are represented by arrows that point in the direction of movement. The arrows are straight, as transport is assumed to follow a straight path.

The exposure scenario identified for this case involves ingestion of contaminated groundwater. A pathway analysis is used to evaluate this potential exposure pathway. Some time after disposal, the waste containers are assumed to fail and allow release of radionuclides. Released contaminants are transported by precipitation that has infiltrated the unsaturated zone. The hypothetical receptor is exposed by drinking water from a well that taps the contaminated aquifer.

STEP 4: After development of the conceptual model, the processes and pathways identified by arrows are modeled mathematically by assigning values to some of the critical parameters of the conceptual model (Figure 5). Screening calculations are used to eliminate unimportant radionuclides and focus modeling efforts on those that may contribute to possible future exposure. Assuming that simpler models would be inadequate, computer codes are used. Each process or pathway is first evaluated with a process level code. The results from those analyses are used as input for a system level code that produces an estimated potential dose of 2 mrem/yr through ingestion of drinking water.

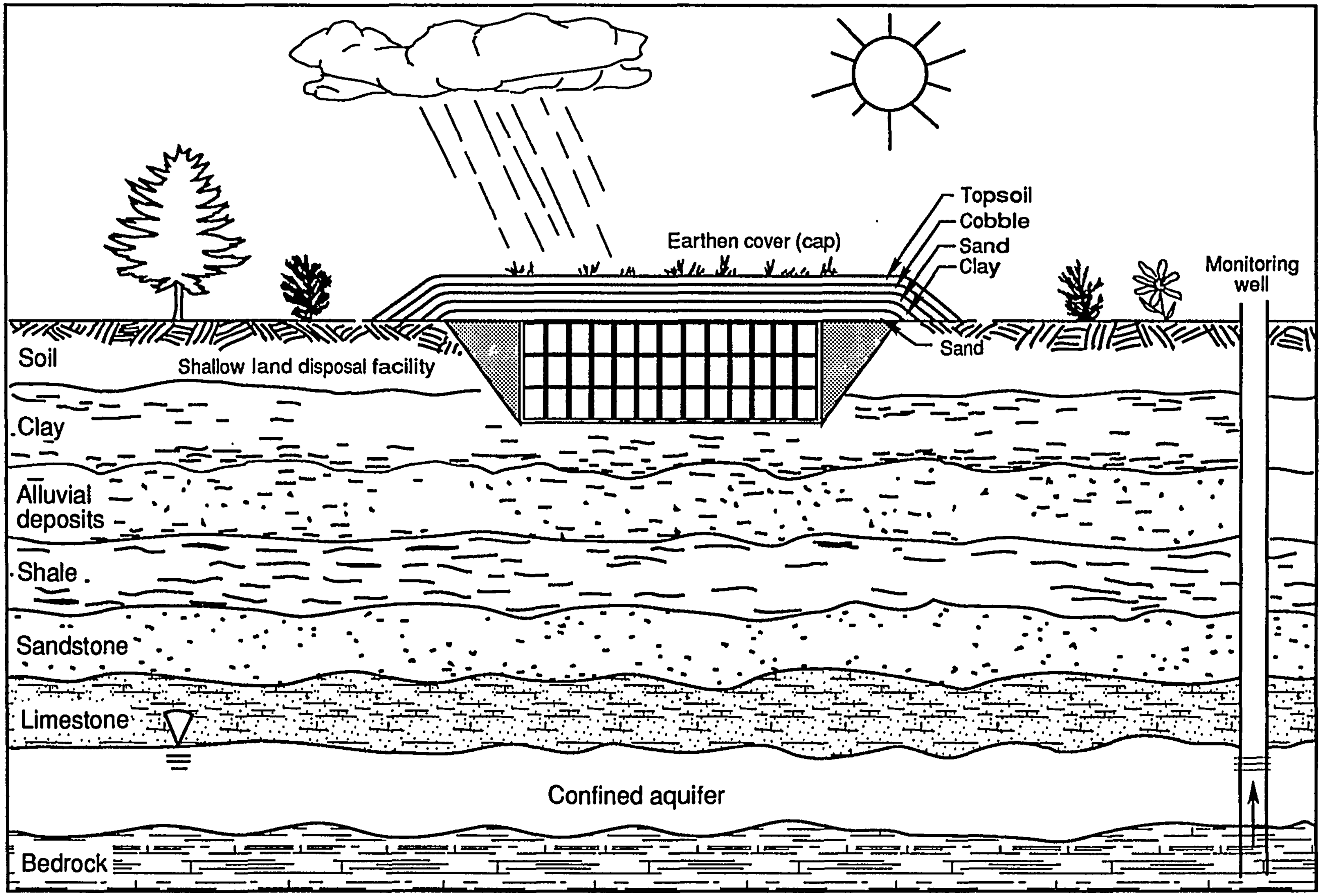

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Figure 3. Detailed representation of the physical makeup of the disposal site, as understood from site characterization, waste characterization, and facility design data.

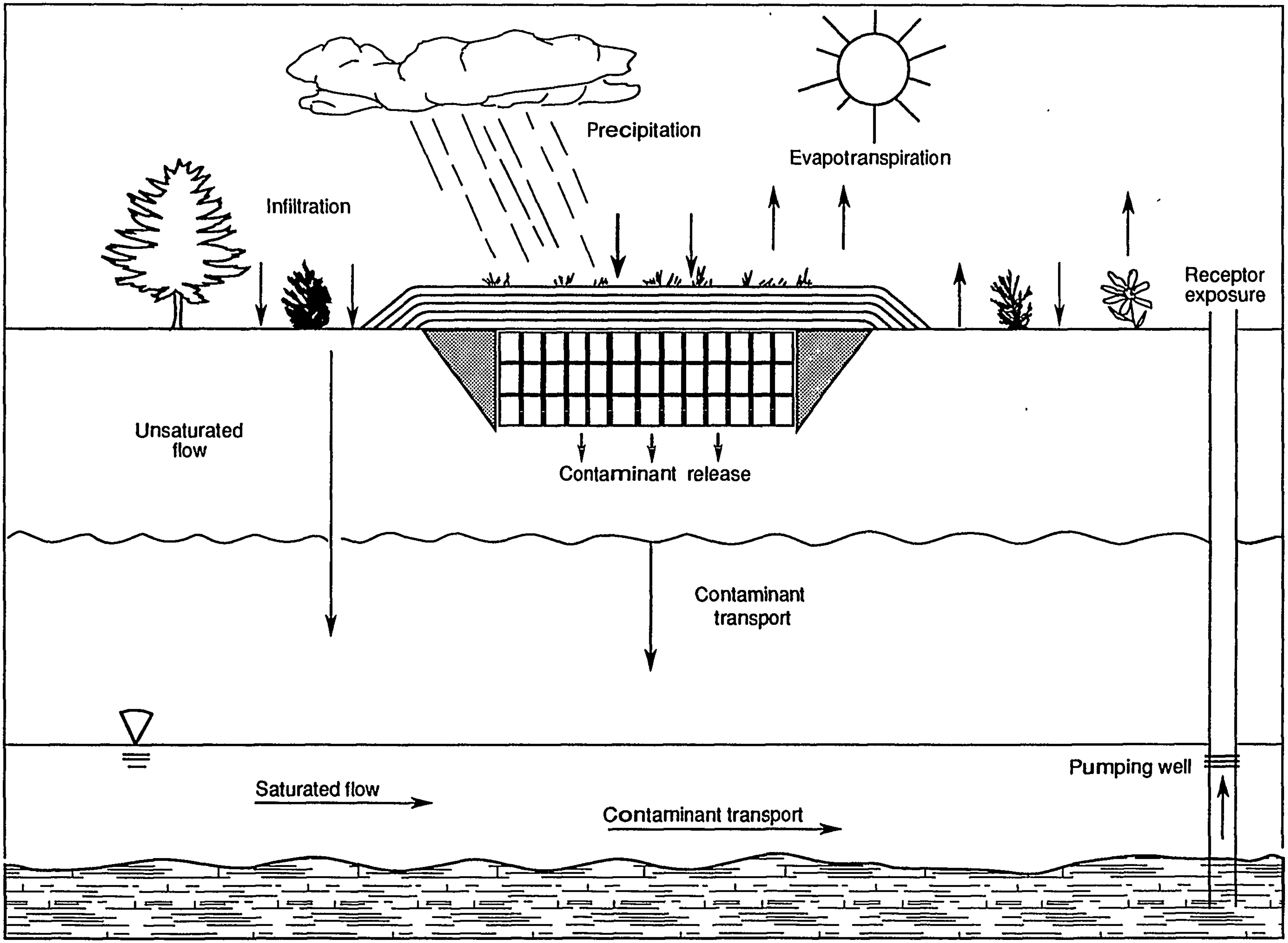

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Figure 4. Conceptualization of important processes and transport pathways within the disposal system as understood from the physical world data collection.

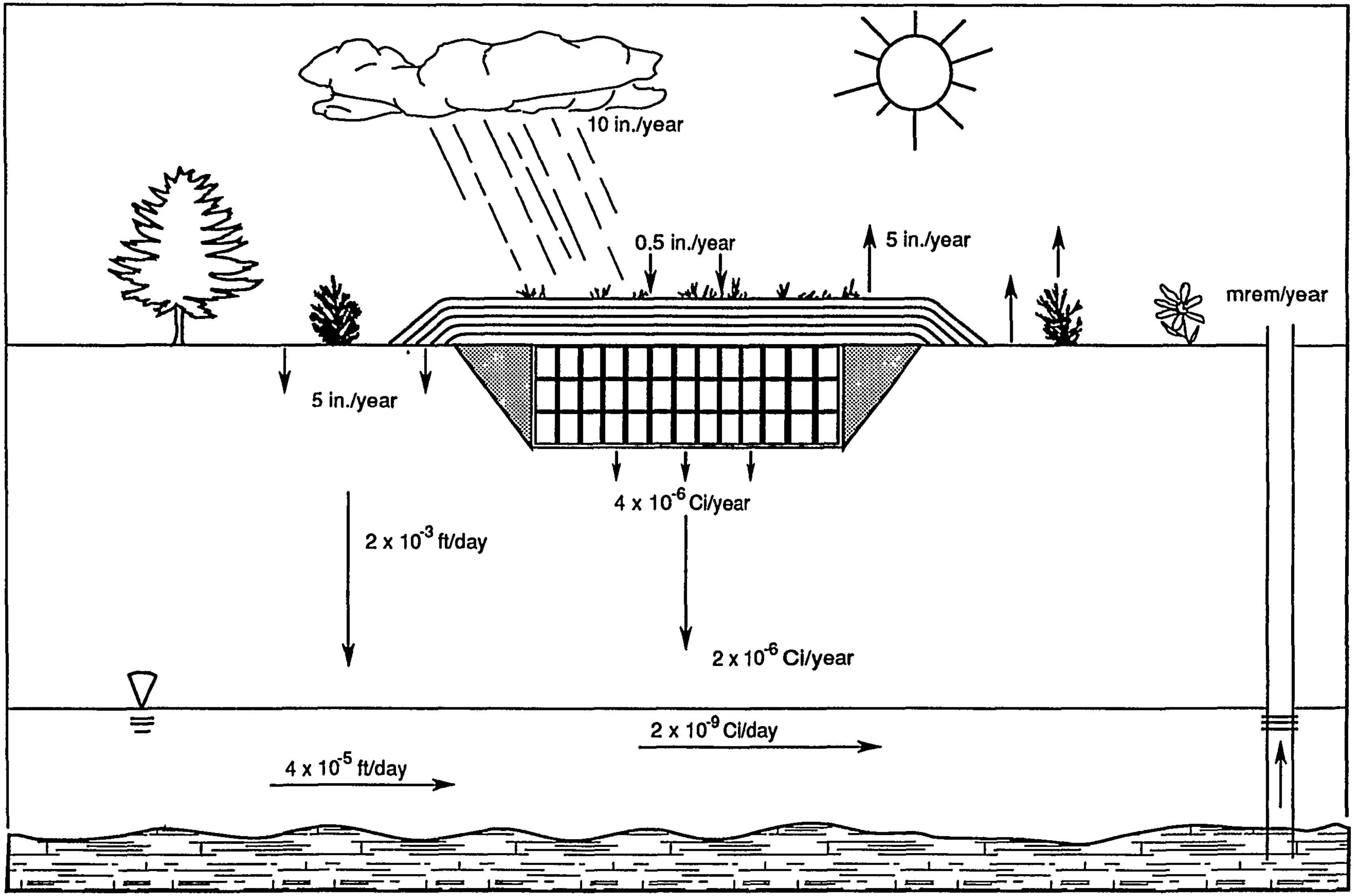

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Figure 5. Mathematical description of processes and pathways contained in the conceptual model.

STEP 5: Following contaminant release and transport, the model results may be analyzed through a post-audit by comparison with measurements taken from the well. However, those measurements will not be available in the license application phase. For the purpose of a license application, confidence will be demonstrated through model verification, and sensitivity and uncertainty analyses. Assuming the methods were correct and that the data were sound, the result may then be compared to dose limits established in the performance objectives. In this case, the estimated potential dose provides reasonable assurance that the performance objectives will be met.

This example provides a general, though somewhat simplified illustration of the process and the steps involved in conducting a radiological performance assessment. While this example only examined one exposure pathway, the same concept applies to others. If it can be reasonably ensured through modeling that performance objectives will be met and that exposure will be below regulatory limits, the site will be considered to perform acceptably. In reality, the radiological performance assessment effort is much more complex than the preceding example suggests and involves many more factors, disciplines, and trials.

REFERENCES

Case, M. J. and M. D. Otis, 1988, *Guidelines for Radiological Performance Assessment of DOE Low-Level Radioactive Waste Disposal Sites*, DOE/LLW-62T, July.

DOE, 1993, "Concepts for the Disposal of Low-Level Radioactive Waste," BP696-0893-3Mr-T, August.

Kennedy, W. E. Jr., and R. A. Peloquin, 1988, *Intruder Scenarios for Site-Specific Low-Level Radioactive Waste Classification*, DOE/LLW-71T, September.

National Low-Level Waste Management Program, 1992, *Site Characterization Handbook For Low-Level Radioactive Waste Disposal Facilities*, DOE/LLW-67T, Revision 1, January.

Nuclear Regulatory Commission, 1988a, *Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility*, NUREG-1200, Rev. 3, September.

Nuclear Regulatory Commission, 1988b, *Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility*, NUREG-1199, Rev. 2, January.

Pangburn, G. C., et al., 1987, *Environmental Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility*, NUREG-1300, April.

Seitz, R. R. et al., 1992, *Performance Assessment Handbook for Low-Level Radioactive Waste Disposal Facilities*, DOE/LLW-135, February.

Shum, E. Y., R. J. Starmer, M. H. Young, 1989, *Environmental Monitoring of Low-Level Radioactive Waste Disposal Facilities — Branch Technical Position*, NUREG-1388, December.

Siefken, D., G. Pangburn, R. Pennifill, R. J. Starner, 1982, *Site Suitability, Selection and Characterization Branch Technical Position —Low-Level Waste Licensing Branch*, NUREG-0902, April.

Starmer, R. J., 1988, "Overview of Performance Assessment for Low-Level Waste Disposal Sites," *Technical Coordinating Committee Performance Assessment Workshop, El Paso, Texas*, November 29-30.

Starmer, R. J., L. G. Deering, M. F. Weber, 1988, *Performance Assessment Strategy for Low-Level Waste Disposal Sites, Tenth Annual DOE Low-Level Waste Management Conference*, August 30-September 1, 1988, Denver, Colorado.

BIBLIOGRAPHY

Brown, H., 1986, *The Low-Level Waste Handbook: A User's Guide to the Low-Level Radioactive Waste Policy Amendments Act of 1985*, National Governor's Association Center for Policy Research.

Case, M. J. et al., 1989, *A Review and Selection of Computer Codes for Establishment of the Performance Assessment Center*, DOE/LLW-83, July.

Case, M. J. et al., 1989, *Recommended Format and Content for DOE Low-Level Waste Disposal Facility Radiological Performance Assessment Reports*, DOE/LLW-81, April.

Dodge, R. L. et al., 1991, *Performance Assessment Review Guide For DOE Low-Level Radioactive Waste Disposal Facilities*, DOE/LLW-93, October.

EG&G Idaho, 1989, *Guidance for Conduct of Waste Management Systems Performance Assessment*, DOE/LLW-63T, National Low-Level Waste Program, EG&G Idaho, Inc., February.

Golchert, N. W., J. Sedlet, and V. R. Veluri, 1985, *Long Term Monitoring for Closed Low-Level Radioactive Waste Management Program.*

Kozak, M. W., M. S. Y. Chu, C. P. Harlan, P. A. Mattingly, 1989, *Background Information for the Development of a Low-Level Waste Performance Assessment Methodology, Identification and Recommendation of Computer Codes*, NUREG/CR-5453, Vol. 4, December.

Kozak, M. W., M. S. Y. Chu, P. A. Mattingly, 1990, *A Performance Assessment Methodology for Low-Level Waste Facilities*, NUREG/CR-5532, July.

Maheras, S. J. and M. R. Kotecki, 1990, *Guidelines for Sensitivity and Uncertainty Analyses of Low-Level Radioactive Waste Performance Assessment Computer Codes*, DOE/LLW-100, September.

Miller, C. W. (ed.), 1984, *Models and Parameters for Environmental Radiological Assessments*, DOE/TIC-11468.

National Council on Radiation Protection and Measurements, 1986, *Screening Techniques for Determining Compliance with Environmental Standards*, NCRP Commentary No. 3, March 31.

National Low-Level Waste Management Program, 1990, Low-Level Waste Management Handbook Series, *Environmental Monitoring for Low-Level Waste Disposal Sites*, DOE/LLW-13Tg, Rev. 2, February.

Seitz, R. R. et al., 1992, *Input Data Required For Specific Performance Assessment Codes*, DOE/LLW-137, February.

Seitz, R. R., et al., 1991, *Sample Application of Sensitivity/Uncertainty Analysis Techniques to a Groundwater Transport Problem*, DOE/LLW-108, June.

Seitz, R. R., S. D. Matthews, K. M. Kostelnik, 1990, *Guidelines for Acquisition, Installation, and Testing of Performance Assessment Software*, DOE/LLW-102, September.

Shuman, R. D., 1985, *Low-Level Waste Disposal Performance Assessment Model Review*, July.

State of California, 1991, *State of California Indemnity Selection and Low-Level Radioactive Waste Facility—Final Environmental Impact Report/Statement*, Prepared by Dames and Moore, Santa Anna, California, April.

Van Der Heijde, P. K. M., 1987, *Quality Assurance in Computer Simulations of Ground Water Contamination*, EPA/600/J-87/084.

GLOSSARY

Active maintenance: Any significant activity needed at a disposal site to maintain a reasonable assurance that the performance objectives will be met.

Advection: The process by which dissolved solids are transported by the motion of flowing groundwater.

Aquifer: A saturated, permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

Aquifer, confined: An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer.

As low as reasonably achievable: With regard to low-level radioactive waste disposal, a licensing performance objective requires that a reasonable effort should be made to maintain releases of radioactivity to the general environment as low as is reasonably achievable (ALARA). ALARA is a basic concept of radiation protection that also requires that the state of the technology, the economics of improvement in relation to the benefits of public health and safety, and other socioeconomic considerations to be taken into account.

Class A waste: Commercial LLW that has low concentrations of long- and/or short-lived radionuclides. Class A waste must be disposed of separately from Class B and C waste unless it meets rigorous waste form requirements to ensure stability. Institutional control of disposal facilities for 100 years will permit disposal of Class A waste without special provisions for inadvertent intruder protection.

Class B waste: Commercial LLW that has intermediate concentrations of long- and/or short-lived radionuclides. Class B wastes must meet more rigorous waste form requirements to ensure stability. Institutional control of disposal facilities for 100 years and recognizable waste forms for 300 years will permit disposal of Class B waste without special provisions for inadvertent intruder protection.

Class C waste: Commercial LLW for which States are responsible that has the highest concentrations of long- and/or short-lived radionuclides. Class C wastes must meet more rigorous waste form requirements to ensure stability and must be disposed of at a depth of at least 5 meters below the surface or must be disposed of with intruder barriers designed to protect against inadvertent intruders for at least 500 years.

Closure: The end of waste acceptance and the decommissioning of a LLW disposal facility. Closure requires amendment of the facility operating license and is followed by a period of postclosure observation and maintenance before the license is finally transferred to the disposal site owner (usually either the Federal or State government).

Commercial Low-Level Radioactive Waste: LLW generated by commercial power plants, manufacturing industries, hospitals, universities, and research institutions. It does not include defense industry LLW.

Compact: With regard to LLW disposal, a formal agreement entered into by two or more States, pursuant to the LLRWPAA of 1985, for the purpose of establishing and operating regional disposal facilities. Compacts are ratified by the party State legislatures and the Congress. Compacts are authorized to restrict the use of their disposal facilities to wastes generated within the compact region.

Compaction: A mechanical or hydraulic process used to reduce the volume of dry solid waste. Compaction will not reduce the radionuclide content of the waste.

Curie: A common unit of measure of radioactivity that indicates the rate of radioactive decay. It is equal to the radiation from 1 gram of radium for one second, or about 37 billion disintegrations per second. The international measure is the becquerel, equal to one disintegration per second.

Defense Low-Level Radioactive Waste: LLWs generated in certain government-owned facilities, including weapons production plants, defense research laboratories, and naval ships.

Diffusion: The process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration.

Disposal: Isolation of waste from people and the environment with no expectation of retrieval.

Disposal facility: The engineered structures and appurtenances at a disposal site. The disposal facility includes such features as the disposal units prepared to accept the waste, construction equipment, security systems, administrative offices, and laboratories.

Disposal site: The physical location where a disposal facility is developed and operated. Characteristic features include its geology, hydrology, meteorology, soil properties, and adjacent land use patterns.

Disposal unit: A discrete portion of the disposal facility into which waste is placed for disposal. A disposal unit is delimited by physical boundaries that also define the extent of the radioactive waste. Such boundaries may include the floor, walls, and roof.

Dose: A quantity, total or accumulated, of ionizing radiation received.

Drums: LLW packages, usually steel, of 55-gal capacity, having either sealed or removable lids.

Evapotranspiration: The sum of evaporation plus transpiration.

Exposure: A term used to express the incidence of radiation on living or non-living material. Acute exposure generally refers to a high-level of exposure for a short duration; chronic exposure generally refers to continued or periodic exposure for a long duration. Exposure is commonly expressed in units of roentgens or sieverts.

Exposure pathways: The potential routes of exposure to radionuclides or radiation. For example, ingestion and inhalation.

Groundwater: All water found beneath the ground surface.

High integrity containers: Containers that are intended to provide structural stability of Class B and C LLW for a long period of time (at least 300 years), based on the design and the physical and chemical properties of the material from which they are fabricated.

Hydrogeology: The study of the interrelationships of geologic materials and processes with water, especially groundwater.

Hydrology: The study of the occurrence, distribution, and cycling of all waters of the earth.

Inadvertent intruder: A person who, after site closure, and at the end of the institutional control period of 100 years may engage in normal activities and be unknowingly exposed to radiation from the waste.

Infiltration: The flow of water downward from the land surface into and through the upper soil layers.

Ingestion: A radiation exposure pathway in which radioactive particles are brought into the body's digestive system by eating or drinking contaminated items.

Inhalation: A radiation exposure pathway in which radioactive gas or contaminated particles are brought into the body by breathing contaminated air.

Institutional control: The physical control of access to and planned maintenance of a LLW disposal facility. Following closure and transfer of control from the site operator to the site owner or custodial agency, an institutional control program will provide for environmental monitoring, periodic surveillance, custodial care, and the administration of funds for these purposes. The period of institutional control may vary, but cannot be relied upon for more than 100 years following the transfer of control.

Intruder barrier: A sufficient depth of cover over disposed LLW, or engineered structures that provide equivalent protection to the inadvertent intruder by preventing contact with or exposure to the waste.

Leachate: Liquid that has percolated through waste or other media and has extracted chemical or radioactive constituents.

Leaching: With regard to LLW disposal, the process of removal or separation of soluble components of the waste by contact with water or other liquids.

License: A license for building and operating a LLW disposal facility, obtained from the Nuclear Regulatory Commission or, if located in an Agreement State with authority to license a facility, from the appropriate State agency.

Licensee: The holder of a license to operate a LLW disposal facility.

Low-level radioactive waste: Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11e.(2) of the Atomic Energy Act.

Low-Level Radioactive Waste Policy Act: Legislation passed by Congress in 1980 that delegated disposal responsibility for certain LLW to the States and authorized the establishment of compact regions to provide for management and disposal of these wastes on a regional basis. The Act specified January 1, 1986, as the date that compact regions could restrict the use of regional disposal facilities for only those wastes generated within the compact region.

Low-Level Radioactive Waste Policy Amendments Act: Legislation passed by Congress in 1985 that amended the 1980 legislation. The Amendments Act established new procedures and deadlines for the development of new disposal facilities, surcharges to help finance those facilities, and allocations for utility disposal of waste at existing sites. The Act also granted Congressional consent to certain compacts.

Migration: Movement of radionuclides from the place where disposed waste was initially emplaced, generally by groundwater transport.

Millirem: One thousandth of a rem (0.001 rem).

Model: A conceptual description or mathematical representation of a system, component, or condition. A model can be used to predict change from a baseline state as a function of time or space, or a response to internal or external stimuli.

Monitoring: Continuous or periodic measuring of the level and quality of factors affecting the environment and human health in order to regulate and control potential impacts.

Near-surface disposal facility: A disposal facility in which waste is placed within the upper 30 meters of the earth's surface.

Performance assessment: A radiological performance assessment is a systematic analysis of a proposed LLW disposal facility and its immediate surroundings that estimates facility impact on human health and the environment. The purpose of the performance assessment is to provide reasonable assurances that the facility will meet the licensing requirements found in 10 CFR 61.

Performance objectives: Licensing requirements regarding the performance of a LLW disposal facility. In order to be licensed, a facility's performance assessment must describe how the system components will work together to ensure that radiation exposures are within the limits set in the performance objectives.

Quality assurance program: A program documenting that the design, construction, operation, and closure of the facility complies with applicable rules and regulations.

Radioactive waste: Unwanted radioactive materials resulting from the processing or handling of radioactive materials.

Radioactivity: The spontaneous emission of radiation, generally alpha or beta particles, or gamma rays, from the nucleus of an unstable radionuclide.

Radionuclide: Any species of atom that emits radiation.

Rem: A unit used in radiation protection to measure the amount of damage to human tissue from a dose of ionizing radiation.

Saturated zone: The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

Sensitivity analysis: An analysis that quantifies the change in a selected output measure produced by a change in a specific input parameter or set of parameters. The analysis indicates the dependence of output measures on specific input parameters.

Site characterization: The program of investigations and tests, both in the field and laboratory, undertaken to assess the site characteristics affecting the isolation of the LLW, the long-term suitability of the disposal site, and the interactions between the disposal site and its surroundings.

Source term: The amount, type, and method of release of radioactive material out of the disposal unit and into the surrounding soil matrix.

Trench cap: A layer or layers of compacted soil, clay, or artificial materials placed over a filled trench (also known as the "cover").

Uncertainty analysis: An analysis that quantifies the uncertainty in a selected output measure induced by the uncertain input parameters. This analysis uses the results of a sensitivity analysis together with parameter uncertainty.

Unsaturated zone: The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater, may exist in the unsaturated zone. Also called zone of aeration and vadose zone.

Validation: Model documentation process that compares model outputs with actual field measurements to determine accuracy and confidence in the model's abilities.

Verification: The process by which a computer code is checked to see that the correct formulas and algorithms were used to represent the conceptual model and that the results of computer calculations match hard calculations.

Water table: The upper boundary of an unconfined aquifer, below which lies the saturated zone.