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Fact Sheet: Environmental Pathway Models—Ground-Water Modeling in Support of Remedial Decision Making at Sites Contaminated with Radioactive Material

Quick Reference Fact Sheet

BACKGROUND

Mathematical models that characterize the source, transport, fate, and effects of hazardous and radioactive materials are used to help determine cleanup priorities and select remedial options at sites contaminated with radioactive materials.

A joint Interagency Environmental Pathway Modeling Working Group has been established by the EPA Offices of Radiation and Indoor Air (ORIA) and Solid Waste and Emergency Response (OSWER), the DOE Office of Environmental Restoration and Waste Management (EM), and the Nuclear Regulatory Commission (NRC) Office of Nuclear Material Safety and Safeguards (NMSS). The purpose of the Working Group is to promote the more appropriate and consistent use of mathematical environmental models in the remediation and restoration of sites contaminated by radioactive substances.

The Working Group has published reports intended to be used by technical staff responsible for identifying and implementing flow and transport models to support cleanup decisions at hazardous and radioactive waste sites. This fact sheet is one of a series of fact sheets that summarize the Working Group's reports.

REPORT

Purpose

This report identifies the role of, and need for, modeling in support of remedial decision making at sites contaminated with radioactive materials. It addresses all exposure pathways, but emphasizes ground-water modeling at EPA National Priority List (NPL) and NRC Site Decommissioning Management Program (SDMP) sites.

The primary objective of the report is to describe when modeling is needed and the various processes that need to be modeled. In addition, the report describes when simple versus more complex models may be needed to support remedial decision making.

Contents of Report

Following the introductory section, Section 2 presents a generic discussion of the role and purpose of modeling in support of remedial decision making. Section 3 describes the various ground-water flow and transport processes that may need to be modeled. A matrix is provided that describes ground-water modeling needs as a function of site characteristics and phase in the remedial process.

The report also includes two appendices. Appendix A addresses the role of modeling within the context of specific EPA, DOE, and NRC programs pertaining to the remediation of sites contaminated with radioactive material. Appendix B summarizes the characteristics of NPL and SDMP sites contaminated with radioactive material and defines the range of site conditions where modeling may be used to support remedial decision making.

Role of Modeling

Modeling often is required to make informed decisions about remedial actions at a site and to demonstrate compliance with remedial criteria. In combination with field measurements, fate and effects models are used to screen sites that may need remedial action, support the design of environmental measurement/sampling programs, help understand the processes that affect radionuclide behavior at a site, and predict the effectiveness of alternative strategies for mitigating impacts.

Models are not substitutes for data acquisition and expert judgement. Models should not be used until the specific objectives of the modeling exercise are defined and the limitations of the models are fully appreciated.

Why Modeling is Needed

The table below presents a list of the reasons for modeling and the phases in the remedial process when modeling likely will be needed. Many of the reasons for modeling will affect the processes that require modeling and the complexity of the models.

What To Model

The table below presents an overview of the range of site conditions, transport processes, doses, and risks from all exposure scenarios and pathways that may need to be modeled during the various phases of the remedial process. These conditions and processes also represent attributes of fate and effects models.

Opportunities for Modeling

	Scoping	Characterization	Remediation
1. It is not feasible to perform field measurements due to limited access, budget, or time.	●	○	○
2. There is concern that downgradient locations may become contaminated in the future.	●	●	●
3. Field data alone are not sufficient to fully characterize the nature and extent of contamination.	●	●	●
4. There is concern that conditions at a site may change, affecting the fate and transport of contaminants.	○	●	●
5. There is concern that institutional control at the site may be lost in the future.	○	●	●
6. Remedial actions are planned and there is a need to predict the effectiveness of alternative remedies.	○	○	●
7. There is a need to predict when the concentration of contaminants at a location will decline to acceptable levels.	○	●	●
8. There is concern that individuals have been exposed to contamination and it is desirable to reconstruct the doses.	○	●	○
9. There is concern that contaminants may be present but below the lower limits of detection.	○	●	○
10. Field measurements reveal the presence of contaminants and it is desirable to determine if and when other contaminants associated with the source may arrive and at what levels.	○	●	○
11. Field measurements reveal the presence of contaminants and it is desirable to identify their source.	●	●	○
12. There is a need to determine future environmental and health impacts if the remedy is delayed.	○	○	●
13. There is a need to determine remedial action priorities.	○	○	●
14. Demonstrating compliance with regulatory requirements.	●	●	●
15. Estimating the benefit in a cost-benefit analysis of alternative remedies.	○	○	●
16. Performing a quantitative dose or risk assessment.	○	●	●
17. There is uncertainty regarding the proper placement of monitoring wells.	●	○	●
18. Developing a site conceptual model.	●	○	○
19. Developing a site characterization plan and determining data needs.	●	○	○
20. There is a need to anticipate the potential doses to remediation workers.	●	○	●

Processes that Can Be Modeled

Source Term

Routine Emissions
- Waste form/waste container performance
- Natural barrier performance
- Engineered barrier performance

Transient or Accidental Emissions
- Natural (flood, high winds, tornado, earthquake)
- Anthorpogenic (construction, agriculture, drilling)

Environmental Transport

Air Transport Processes
- Suspension
- Evaporation
- Volatilization
- Dispersion
- Deposition
- Radioactive decay and buildup

Ground-Water Transport—Unsaturated Zone
- Miscible
- Immiscible
- Vapor transport
- Mass transport (advection, diffusion, dispersion)
- Physical/chemical processes (decay, sorption, dissolution/precipitation, acid/base reactions, complexation, hydrolysis/substitution, redox reactions, density dependent flow)
- Biologically mediated transport

Ground-Water Transport—Saturated Zone
- Miscible (mass transport, advection, diffusion, dispersion)
- Immiscible
- Physical/chemical processes (decay, sorption, dissolution/precipitation, acid/base reactions, complexation, hydrolysis/substitution, redox reactions, density dependent flow)
- Biologically mediated transport

Ground-Water Transport—Fractured Zone
- Nonpercolating
- Percolating
- Matrix diffusion effects

Surface Water Transport
- Dispersion
- Deposition
- Sediment transport
- Radioactive decay and buildup

Exposure Scenarios

- Postulated scenarios causing radiation exposure via various pathways
- The no action alternative
- Alternative remedies
- Trespassers
- Inadvertent intruder (construction, agriculture)
- Routine and transient emissions
- Accidents

Exposure Pathways

- Pathway or medium to which individuals and populations are exposed
- External exposure to deposited radionuclides
- External exposure to airborne, suspended, and resuspended radionuclides
- Inhalation exposure to airborne, suspended, and resuspended radionuclides
- Ingestion of radionuclides in food and drinking water
- Ingestion of contaminated soil and sediment
- External exposure from immersion in contaminated water

Doses

- mrem/yr EDE to individuals
- Person rem/yr EDE to population

Public Health Impacts

- Individual risk (acute, carcinogenic, mutagenic, teratogenic risk per year and per lifetime)
- Population impacts (acute, carcinogenic, mutagenic, teratogenic effects per year)

The products of the modeling process typically are one or more of the following results for a broad range of exposure scenarios:
- Time-varying and time-averaged radionuclide concentrations;
- Radiation field in the vicinity of the radioactive material;
- Radionuclide flux;
- Transit or arrival time of a radionuclide at a receptor;
- Volume of water contained within or moving through a hydrogeological setting;
- Radiation doses to individuals;
- Radiation risks to individuals;
- Cumulative radiation doses to the population in the vicinity of the site;
- Radiation doses and risks to remedial workers; and
- Uncertainties in the above impacts.

When Modeling May Not Be Needed

There are three general scenarios in which modeling may be of limited value:
- Presumptive remedies can be readily identified.
- Available data indicate no problem.
- The site is too complex to model realistically.

If a site is poorly characterized or poorly understood, any simulation of the transport and impacts of contaminants using mathematical models could be highly misleading. The use of models under such circumstances can help to support only limited types of decisions, such as planning and prioritizing activities. As a general rule of thumb, it is prudent to continually question the results of modeling and the potential consequences of site decisions based on misleading results, and consider what can be done to verify modeling results.

Factors Affecting Model Complexity

The purpose of referring to simple and complex sites and models is to alert the project manager to circumstances when relatively complex processes may need to be simulated so that the appropriate resources and expertise are included in the planning process. In general, analytical models are considered simple models and numerical models are considered complex, though there are gradations of complexity within each category. Analytical models are limited to simplified representations of physical situations and generally require only limited site-specific input data. They are useful for screening sites to determine data needs and the applicability of more detailed numerical models. Numerical models generally require a large quantity of data and an experienced modeler-hydrologist.

The required complexity of the model is determined by a combination of five factors, the first three of which generally have the greatest influence:
- Objectives of the modeling;
- Form, distribution, and composition of waste;
- Environmental characteristics of the site;
- Phase of the remedial process; and
- Site demography and land use.

Modeling Objectives

Modeling objectives are often determined based largely on existing regulatory requirements and potential exposure scenarios at the site. Exposure pathways that will need to be modeled initially are determined during the planning phase, based on judgement regarding the likelihood that a given pathway may be an important contributor to risk. For example, if available data indicate that the contamination is buried or covered with water, the suspension pathway need not be addressed unless it is postulated that the buried material will be removed or the water drains or evaporates.

Site Conditions

The environmental characteristics of remedial sites are highly diverse. The sites containing radioactive materials that are currently undergoing remediation include both humid and dry sites, sites with and without an extensive unsaturated zone, and sites with simple and complex hydrogeological characteristics. These different environmental settings determine the processes that need to be modeled and required complexity of modeling.

In general, the need for complex models increases with increasingly complex hydrogeology. However, if a conservative approach is taken at complex sites, where transport through the unsaturated zone is assumed to be instantaneous, then flow and transport through the unsaturated zone may not need to be modeled. Such an approach would be appropriate at sites that are relatively small and contamination is shallow and well defined. Under these conditions, the remedy is likely to be removal of the contaminated material, and use of conservative screening models may be sufficient to support remedial decision making.

At more complex sites, an understanding of the physical system may allow an early determination of the types of models appropriate for use at the site. In general, relatively complex models may be required for complex hydrogeological characteristics such as:

- Thick unsaturated zone;
- Layered, fractured, or heterogenous underlying rocks;
- Presence of surface water bodies on, or in the vicinity of, the site;
- Irregular land surface topography;
- Sub-regional recharge and discharge areas; and
- Processes or conditions that vary significantly over time.

Waste Characteristics

Radioactive contaminants are present in a wide variety of waste forms that may influence their mobility. In most cases, the radionuclides of concern are long-lived and the integrity of the waste form or container cannot be relied upon for long periods of time. Therefore, the source term often can be modeled as a uniform point or areal source and the waste form does not need to be accounted for, allowing the use of relatively simpler models.

More complex geochemical models may be needed to predict the performance of the waste container or transport in a complex geochemical environment. Such models would need to simulate the degradation rate of concrete, corrosion rate of steel, and leaching rate of radionuclides associated with various waste forms. To account for container and waste form degradation, the model would need to include a user-defined algorithm that estimates the delay in contaminant release.

Certain radionuclides have properties that are difficult to model and may not be adequately simulated with analytical models. For example, thorium and uranium decay into multiple daughters whose mobility may differ from their parents. Geochemical processes that affect radionuclide transport include: complexation of radionuclides with other constituents; phase transformations of the radionuclides; adsorption and desorption; and radionuclide solubilities at ambient geochemical conditions. To model these processes, complex geochemical models may be needed.

Phase of Remedial Process

The remedial process is divided into three phases: the scoping and planning phase; the site characterization phase; and the site remediation phase. In general, the complexity of modeling will increase as the remedial process proceeds.

During planning and scoping phase, only limited site-specific data generally are available. Therefore, modeling is limited to simple analytical models even if the characteristics of the waste and the site indicate that more complex models eventually may be needed. As a result, modeling during scoping generally consists of screening-level calculations to identify potentially significant radionuclides and pathways of exposure using simplified, conservative assumptions.

Site characterization is designed to determine the nature and extent of contamination and the potential risks posed by the site. In general, simple models may be adequate where: 1) the waste form or engineered barriers are not accounted for; 2) transport through the unsaturated zone is not accounted for; and 3) the saturated zone is treated as a homogeneous, isotropic medium. Any other assumptions regarding the behavior of the waste or site conditions will likely necessitate the use of more complex models.

A method of predicting peak concentrations of radionuclides emanating from a source and reaching the water table is to model the movement of ground water and radionuclides through the unsaturated zone. In some instances, the risk assessment may require that radionuclide concentrations be determined at a receptor located at some distance downgradient from the source. In this case a model that can simulate flow and transport in the saturated zone should be used.

During the site remediation phase, modeling primarily is used to support the selection and implementation of alternative remedies and determine the degree to which the remedy has achieved remedial goals. Remedial alternatives can be grouped into three categories: immobilization, containment, and removal/destruction. Treatability studies, prior experience, engineering judgement, and conservative design may be the only reliable methods for ensuring the performance of a containment or immobilization remedy.

The removal alternative is generally the most expensive remedy for long-lived radioactive contaminants. Though modeling is expensive and time consuming, it can be cost-effective if it convincingly demonstrates that remedies other than removal will protect human health and the environment. Physical and chemical processes that may need to be modeled to support removal remedies include: three dimensional flow and transport; matrix diffusion; resaturation of the nodes; heat energy transfer; sharp contrasts in hydraulic conductivity; multiple aquifers; and complex flow conditions.

Land Use

The land use and demographic patterns at a site, especially the location and extent of ground-water use, affects potential exposure pathways and modeling needs. At sites where the ground water currently is being used, or may be used in the future, complex ground-water models may be needed to gain insight into plume arrival times and geometries. At sites with multiple user locations, two- and three-dimensional models may be needed to realistically estimate the likelihood that the contaminated plume will be captured by wells located at different directions, distances, and depths relative to the sources of contamination.

Simple models typically are limited to estimating the radionuclide concentration in the plume centerline. If it is assumed that the receptors are located at the plume centerline, a simple model may be appropriate. Such an assumption often is made even if a receptor is not currently present at the centerline location because the results generally are conservative.

CONTACTS

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REPORTS

Computer Models Used to Support Cleanup Decision-Making at Hazardous and Radioactive Waste Sites, EPA 402-R-93-005, March 1993. Also available from the National Technical Information Center (NTIS), (703) 487-4650, PB93-183333/XAB.

Environmental Characteristics of EPA, NRC, and DOE Sites Contaminated with Radioactive Substances, EPA 402-R-93-011, March 1993. NTIS, PB93-185551/XAB.

Environmental Pathway Models — Ground-Water Modelling in Support of Remedial Decision-Making at Sites Contaminated with Radioactive Material, EPA 402-R-93-009, March 1993. NTIS, PB93-196657/XAB.

Technical Guide to Ground-Water Model Selection at Sites Contaminated with Radioactive Substances, EPA 402-R-94-012, September 1994. NTIS, PB94-205804/XAB.