Radionuclide Transport in the Environment

Research Program Plan, March 2002

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1. Introduction

A portion of the Office of Nuclear Regulatory Research's (RES's) overall research is devoted to radionuclide transport in the environment (RTE). The RTE research program addresses the effect on public health and safety and the environment from nuclear materials that enter the environment from NRC-licensed activities. The technical issues examined include:

- source-term characterization,
- the effectiveness of engineered and natural containment systems surrounding the radioactive material,
- multi-phase flow of water, including episodic infiltration, into and through contaminated systems
- the transport of radioactive material through the geosphere
- the transport of radioactive material through the biosphere, and
- exposures of members of the public to radiation from these materials.

The primary customer for RTE research is the NRC's Office of Nuclear Material Safety and Safeguards (NMSS). Potential customers include the Office of Nuclear Reactor Regulation, NRC Regional Offices, Agreement State Regulatory programs, licensees, and public interest groups. Results from the RTE research program are intended to be generically applicable to NRC licensing activities including the decommissioning of facilities, disposal of uranium mill tailings, low-level radioactive waste (LLW) disposal, and high-level radioactive waste disposal, as shown in **Figure 1**.

This plan establishes the basis for the RTE research program, describes the key elements of the program, describes how research priorities are set, and presents a plan for carrying out specifics of the research.

In 2001, this plan was issued as "Radionuclide Transport in the Environment: Draft for Comment." Comments were solicited from other NRC program offices, the Advisory Commitee on Nuclear Waste, the public (though an October 18, 2001, Federal Register Notice), and the Board on Earth Sciences and resources of the National Academy of Sciences. Modifications to the *Draft for Comment* are included in this revision of the plan.

1.1 Vision Statement

The NRC and RES Vision Statements are as follows:

NRC: *In implementation of its mission, NRC's actions enable the Nation to safely (sic) use nuclear materials. NRC's actions should be such that the public, those it regulates, and other stakeholders in the national and international nuclear community have the utmost respect for and confidence in the NRC.*

RES: *The Office of Nuclear Regulatory Research furthers the regulatory mission of the NRC by providing technical advice, technical tools and information for identifying and resolving safety issues, making regulatory decisions, and promulgating regulations and guidance. RES conducts independent experiments and analyses, develops technical bases for supporting realistic safety decisions by the agency, and prepares the agency for the future by evaluating safety issues involving current and new designs and technologies. RES develops its program with consideration of Commission direction and input from the program offices and other stakeholders.*

The RTE research program is structured to support the NRC and RES vision statements. The RTE research program's Vision Statement is:

RTE: The Radionuclide Transport in the Environment research program includes the conduct of independent confirmatory and anticipatory research and analyses to provide data and models and other technical information that will support credible, realistic, and defensible estimates of risk to the public from alternative courses of action at decommissioning and nuclear waste disposal facilities and will support agency decisions concerning decommissioning and waste disposal. This research will be planned and executed in response to Commission direction, input from the other NRC offices and other stakeholders, industry and other federal agency initiatives, and the best scientific information on uncertainties and risk.

The NRC makes decisions on a daily basis that deal with the decommissioning of licensed facilities and on a less frequent basis with disposal facilities. These decisions generally deal with very low levels of radioactivity. However, they are levels that are or will be found in the environment and the best information and scientific tools must be applied to these decisions in order to accomplish the agency's primary mission: "to protect public health and safety and the environment." The plan that is contained in the following sections provides the rationale for research to support these goals and identifies the areas in which research is needed. The last section provides details on current and proposed future program content.

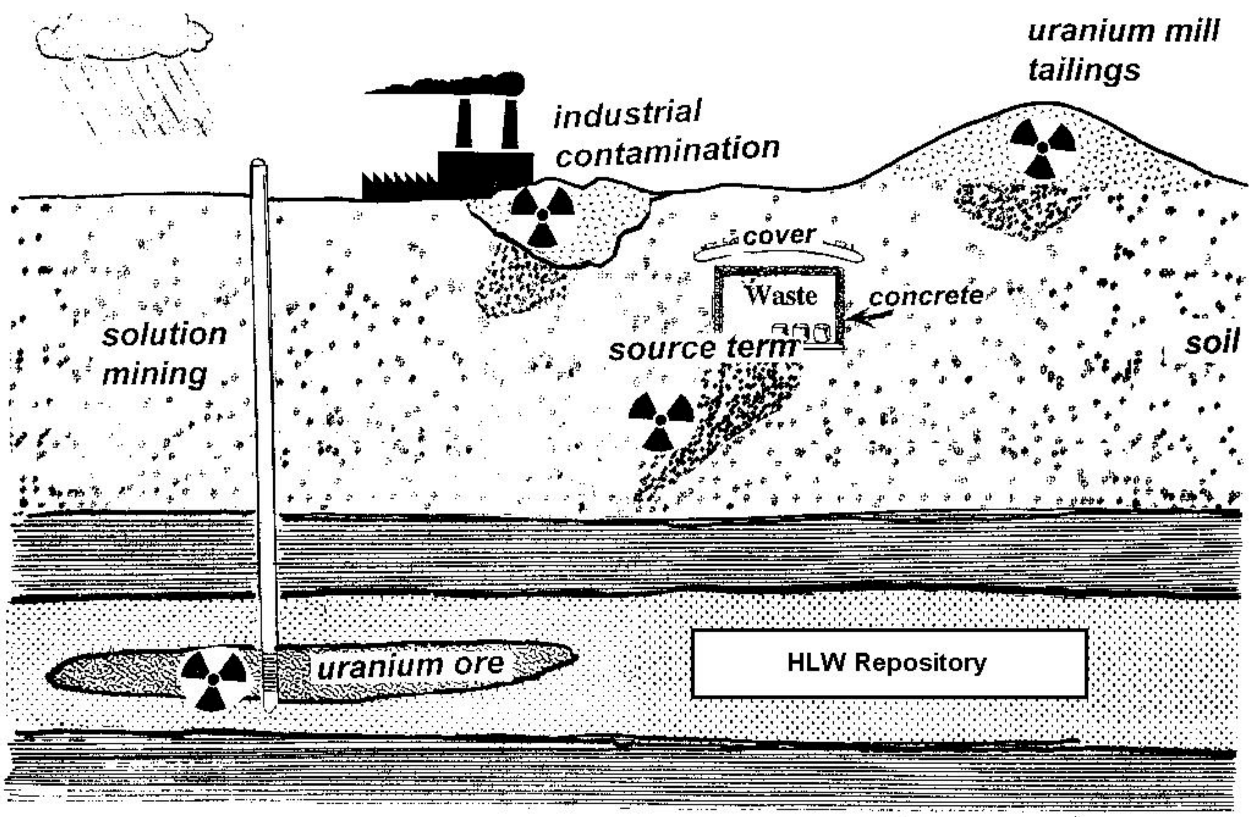

Figure 1: Areas of applicability of RTE research

2. Basis for Research

2.1 Conditions for Doing Research

In the Nuclear Waste Safety Strategic Arena, there is an interlocking set of performance goals, strategies, and measures, summarized in this plan's Appendix A, that define the decisions that must be made and the actions that must be taken to support these decisions. The RTE research program supports decisions relating to limits on long-term doses from releases of radioactive materials to the environment.

Given the NRC's strategic goals and the regulatory framework, there is a need for research to accomplish the Nuclear Waste Safety Strategic Arena's strategies where there are limitations in knowledge and uncertainties in data and models supporting regulatory decisions or the regulatory framework. Where models are known to be oversimplifications of complex systems, uncertainties are known to be large, or calculations are known to be inconsistent with data, dose calculations can significantly underestimate or overestimate individual exposures. Underestimations could support decisions that realistic estimates would show to be inconsistent with regulatory limits. In this case, opportunity and obligation exist to improve the NRC's assessment capabilities. Overestimates could cause unnecessary regulatory burden on stakeholders. In this case, opportunity and obligation exist to improve the efficiency, effectiveness, and realism of agency analyses.

2.2 Research Objective

The ultimate objective of research on radionuclide transport is more realistic and defensible estimates of exposure of the public to radiation from radionuclides released from contaminated sites or waste disposal facilities.

Bounding estimates of the consequences of radionuclide transport from radioactive waste to humans may be hard to defend. The fundamental issue for estimates of the consequences from radionuclide releases to the environment is credibility. Parameter and model uncertainty and unanticipated sensitivities to parameters or processes assumed to be unimportant can invalidate the results of overly simplified analyses. More confidence in safety evaluations is attainable if they are based on realistic estimates of radionuclide transport.

Current estimates of risk from releases of radioactive materials use computational tools that attempt to compensate for uncertainty and lack of knowledge with parameter and model selections intended to overestimate potential exposure. Such "conservative" estimates lead to decisions that may be more restrictive than necessary and may actually incorrectly predict the locations and arrival times of radionuclides, and underestimate the greatest magnitude of potential exposure. In each case where conservative assumptions are employed, great care must be taken to assure that those assumptions are justified and will have the intended result. When they are not justified or when the regulatory response associated with such an approach is extreme, more realistic tools are needed to support an appropriate regulatory position, i.e. one that is consistent with a realistic estimate of the risk from public and environmental exposures.

2.3 Applicability of the Research

The NRC makes use of data and models developed by RES to provide technical support to the development or modifications of regulations and guidance, and in reviews of licensing submittals and licensing actions. The review actions focus on issues being addressed by the RTE research program, namely those associated with the decommissioning of sites and facilities contaminated with residual radioactivity. However, because of the generic nature of the RTE research, it also is applicable to the disposal of uranium mill tailings, LLW, and high-level radioactive waste (HLW). The common technical needs of regulating these diverse activities must be a primary factor in identifying and prioritizing research. As part of the development of this plan and to assure the applicability of its results, user office review has been sought both to assess current and planned content of this program and to identify additional issues or questions to be addressed.

All projects developed under this plan will be coordinated with NMSS and other affected user offices.

2.4 Establishing the Content of the Research

While responses to user needs must form the core of this program, an important component will be research that addresses future needs anticipated by RES and NMSS. One function of research is to maintain awareness of the latest scientific or technological developments that may challenge accepted understanding or offer opportunities for more robust analyses that were precluded by older technology. In soliciting ideas from NRC staff and other peers we will develop a reservoir of topics to be addressed.

2.5 Anticipatory Research on High-Level Radioactive Waste Regulatory Issues

Prior to Fiscal Year 1996, RES conducted an HLW research program that was primarily confirmatory. Following budget cuts in Fiscal Year 1996, the confirmatory research was severely curtailed and its management was transferred to NMSS. In a recent letter to NRC Chairman Richard Meserve[1], the NRC's Advisory Committee on Nuclear Waste (ACNW) recommended that the NRC expand its HLW program "to have a modest, long-term 'anticipatory' research component." The NRC's Executive Director for Operations, William D. Travers, subsequently agreed with this recommendation[2].

Because the decision on anticipatory HLW research is so recent, there has been no coordination between RES and NMSS to establish the content of such a program and no resources have been identified to apply to such issues. Once the content and resources for anticipatory HLW research are established, this plan will be modified to include discussions on this topic.

3. Key Elements of the RTE Research Program

The RTE research program will contribute to improvements in the NRC's performance assessment capabilities. The program has four key elements that support performance assessment.

The NRC and its licensees often use performance assessment (PA) to estimate the hazard of radioactive materials that are available or may become available for transport to and through the biosphere and to humans. A typical PA uses data and mathematical models to estimate the inventory and possible means of transporting the radioactive material from its original location to the biosphere and to humans. The data and mathematical models used in a PA estimate the effects of any process considered significant for the specific situation and provide an estimate of doses to humans as a function of time and location. The steps taken in a typical PA, shown in **Figure 2**, consist of estimations of water infiltration at a decommissioned or disposal facility; the performance of any engineered barriers meant to confine radionuclides; the rates and amounts of release of radionuclides when the engineered barriers fail to confine them; the transport of radionuclides by ground water, surface water, air, and biota; and doses to humans. PA is generally an iterative process because uncertainty is inherent in all PA's. The uncertainties are attributable to conceptual errors or simplifications used to obtain PA's mathematical models and to a lack of precise values of parameters used in the mathematical models. The RTE research program focuses on the most important of these uncertainties. The key research elements are described in more detail in Chapter 5.

Table 1: Performance Assessment Components and Key RTE Research Elements

PA Component	Key Research Element
Infiltration	Transport (ground-water flow)
Engineered-barrier performance	Engineered barriers to radionuclide transport
Rates and amounts of release of radioactive materials	Release of radioactive materials
Transport by ground water	Transport
Transport by surface water	Transport
Transport by air	Transport
Transport by biota	Transport
Dose	Performance assessment

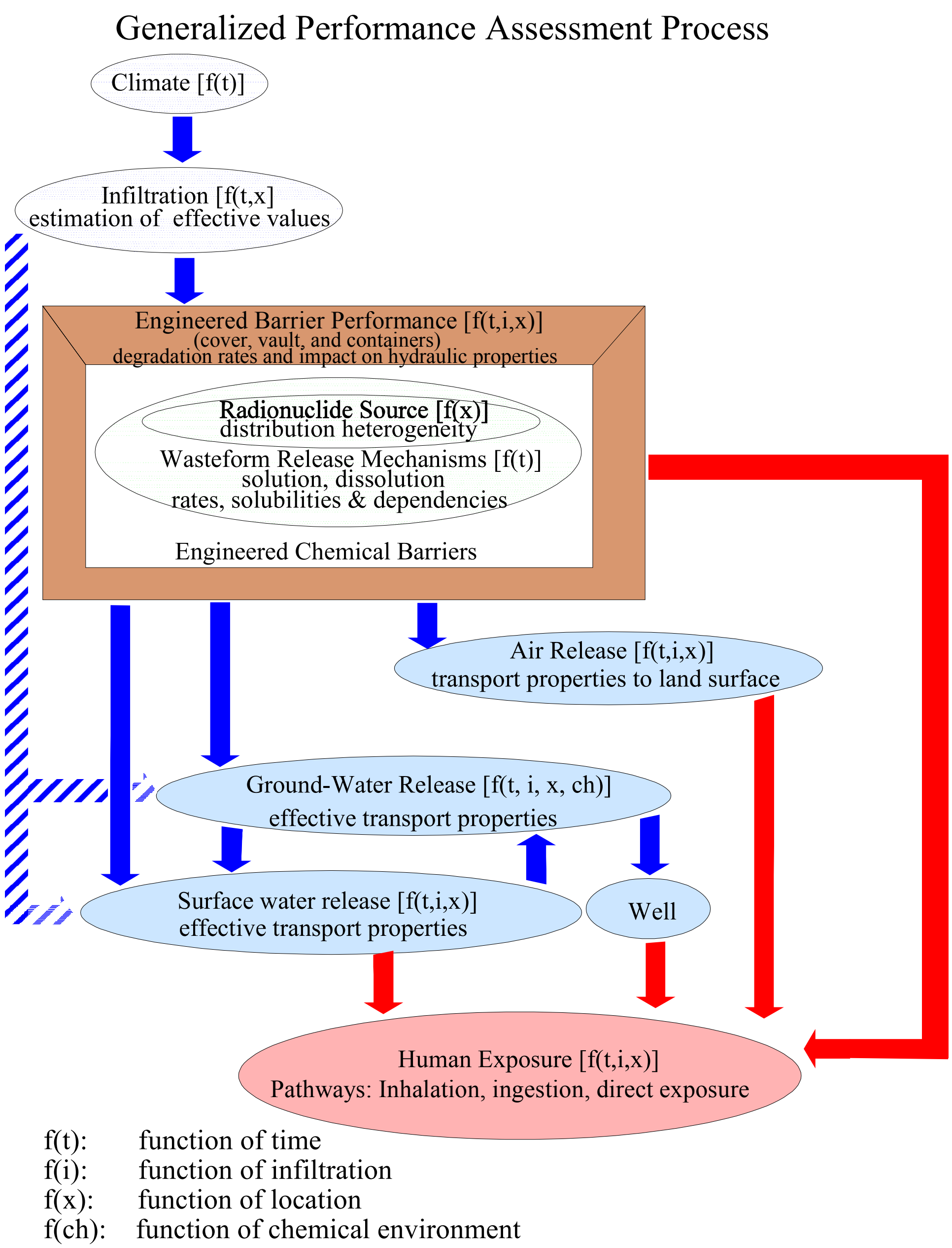

Figure 2: Generalized Performance Assessment Process

4. Setting Research Priorities

4.1 Introduction

Research priorities for RTE research program are set at the project level within the program itself and within the context of other RES activities. This chapter describes the criteria for setting priorities gives the results for the project-level prioritization. Appendix B lists the criteria used to prioritize all of RES's reactor and nuclear waste safety activities.

4.2 Program-Level Prioritization

Research priorities for projects within the RTE research program are set by considering five major attributes:

- Dose estimation impact
- Uncertainty reduction
- Burden reduction
- Cost effectiveness
- Issue support

All of the factors treated equally. For each factor, one has to decide for a particular project how strongly a project supports the factor, on an integer scale from 0 to 2, with 0 not supporting the factor at all and 2 supporting the factor very strongly.

4.2.1 Dose estimation impact

The dose-estimation-impact priority factor addresses the NRC Strategic Plan's Performance Goal of Maintaining Safety and Protecting the Environment for the Waste Arena. For this Strategic Arena long-term safety is evaluated by estimating the dose to members of the public from radioactive materials that are gradually released to the environment over long time periods. Research in this area is focused on data and models that will allow more realistic estimates of dose by replacing "conservative" or "bounding" assumptions with models and parameter values which attempt to more accurately simulate natural processes that effect the movement of radioactive materials through the environment.

Priority scores for dose estimation impact	
	Criterion
0	Project addresses an issue that has no effect on dose estimation.
1	Project addresses an issue that has a moderate effect on dose estimation.
2	Project addresses an issue that has a strong effect on dose estimation.

4.2.2 Uncertainty reduction

The uncertainty-reduction priority factor addresses the Performance Goal of making NRC activities and decisions more effective, efficient, and realistic.

Priority scores for uncertainty reduction	
	Criterion
0	Project's results are not expected to have any effect on uncertainty reduction.
1	Project addresses either modeling or experimental (field or laboratory) work that improves the understanding of uncertainties.
2	Project integrates experimental and modeling work that improves the understanding of uncertainties.

4.2.3 Burden reduction

The burden-reduction priority factor addresses the Performance Goal of reducing unnecessary regulatory burden (activities that increase costs with no significant reduction in risk or result in no significant improvement in the protection of the public health and safety) on stakeholders.

Priority scores for burden reduction	
	Criterion
0	Project's results, if adopted in the regulatory process, may increase regulatory burden.
1	Project's results, if adopted in the regulatory process, may cause little or no increase in regulatory burden.
2	Project's results, if adopted in the regulatory process, may decrease regulatory burden.

4.2.4 Cost effectiveness

Projects that are cost-effective, for example because of considerations of sunk cost or leverage, are often given high priority in RES decision making because they increase the effectiveness of limited resources.

Priority scores for cost effectiveness	
	Criterion
0	The project does not receive additional support from other sources, and does not harvest a useful product from previous investments (sunk costs).
1	The project is somewhat leveraged or has a moderate sunk cost.
2	The project is inexpensive, is highly leveraged or will harvest useful products from large sunk costs.

4.2.5 Issue support

This factor reflects the degree to which the issue addressed by a project has support within the NRC. The issue-support factor corresponds to RES's issue-credibility factor.

Priority scores for issue support	
	Criterion
0	There is no support for the issue at any agency management level or by any advisory committee.
1	The issue has support within RES.
2	A Staff Requirements Memorandum has directed RES to address the issue, the issue has a user need statement from another NRC office, or the issue is supported by an advisory committee or other recognized authority.

4.2.6 Computing the priority score for a project

One calculates the priority score for a project by summing all of the priority scores and dividing the result by the maximum possible score so that each project's priority score falls between 0 and 1. Table 2 shows the current priority scores for the projects proposed in this plan.

Projects in Table 2 that are scored 0.6 or greater have extended descriptions in Chapter 5. The page numbers for the descriptions are given in the right-most column of Table 2.

Table 2 **Prioritized RTE research projects**	Dose estimation impact	Uncertainty reduction	Burden reduction	Cost effectiveness	Issue support	Project Score	Technical Area	Described on page
Hydrologic conceptual, parameter and scenario uncertainty assessments	2	2	1	1	2	0.80	Trans	25
Assessment of parameters used in environmental pathways models	2	2	1	1	2	0.80	PA	32
Characterization and mechanisms of radionuclide sorption in soils: fundamental routes to predictive capabilities	2	2	1	1	1	0.70	Trans	26
Following EPA and DOE work on reactive permeable barriers and impermeable subsurface barriers	1	2	1	2	1	0.70	Eng	20
Evaluating the use of the FRAMES system	0	2	1	2	2	0.70	PA	33
Field studies to confirm uncertainty estimates of ground-water recharge	1	1	1	2	2	0.70	Trans	26
Development of Probabilistic RESRAD-OFFSITE Code	1	1	1	2	2	0.70	PA	32
Integrated Ground-Water Monitoring Strategy	1	2	1	1	2	0.70	Trans	25
Evaluation of entombed structures for decommissioning nuclear structures	2	2	0	1	1	0.60	Eng	21
Radionuclide colloid transport	1	2	1	1	1	0.60	Trans	29
Radionuclide Solubilities	2	1	1	1	1	0.60	ST	16
Radionuclide Source Terms: Waste Characterization and Leaching Studies	2	1	1	1	1	0.60	ST	15
Performance of non-concrete barriers	1	2	1	1	1	0.60	Eng	21
Retardation of Radionuclides in the Environment	1	2	1	1	1	0.60	Trans	28
Characterization of soil-particle coatings	1	2	1	1	1	0.60	Trans	28
Support for interagency cooperative research	0	1	1	2	2	0.60	PA	34
Assessment of new waste disposal and storage technologies e.g., assured isolation	2	1	1	1	0	0.50	ST	
Microorganism Effects on Radionuclide Release and Transport	1	1	1	1	1	0.50	ST	
Testing the validity of 14C transport models	0	1	1	1	2	0.50	Trans	
Soil Biotic Effects on Radionuclide Transport	1	1	1	1	1	0.50	Trans	
Addition of radionuclide transport and sorption to the 4SIGHT code	1	1	1	1	1	0.50	Eng	

Table 2 **Prioritized RTE research projects**	Dose estimation impact	Uncertainty reduction	Burden reduction	Cost effectiveness	Issue support	Project Score	Technical Area	Described on page
Investigation of the effects of various admixtures in concrete e.g., silica fume, fly ash, blast furnace slags, fiber reinforcement on the durability of concrete barriers	1	1	1	1	1	0.50	Eng	
Bioaccumulation of Radionuclides	1	1	1	1	1	0.50	Trans	
Performance Assessment for Sites Containing 232Th	0	0	2	1	1	0.40	ST	
Historical case analysis of plumes	0	1	1	1	1	0.40	Trans	
Determination of releases and assessment of transport of radionuclides in waste streams that are not listed in Part 61 and not considered in current PAs.	1	1	0	1	1	0.40	ST	
In-situ and real-time monitoring of radionuclides at waste disposal facilities over long times	1	1	0	1	1	0.40	ST	
Testing the validity of performance assessment computer codes	1	1	1	1	0	0.40	PA	

5. Proposed Research

This section divides the program into several components that include the processes considered in PA. Section 5.1 addresses research into issues involving the release of radioactive material to the biosphere, or source term characterization. Section 5.2 addresses research involving issues with engineered barrier systems. Section 5.3 addresses research on issues associated with the transport of contaminants through the geosphere. Section 5.4 addresses research on PA modeling tools. Section 5.5 addresses research involving cooperation with other organizations separately, because some of it crosses over different disciplines. Detailed write-ups are included for projects that scored above 0.5. Brief write-ups are included for those that scored 0.5 or below. As new information is obtained on these and other potential research needs, prioritizations will be re-calculated.

5.1 Release of Radioactive Material (Source Term)

5.1.1 Technical and Regulatory Background

Releases of radionuclides to the environment from waste disposal facilities and decommissioned sites must be understood to predict the transport of radionuclides in soil, rock fractures, ground water, surface water, and atmospheric systems to the public and to ensure compliance with NRC regulations.

Determining radionuclide releases from decommissioning and waste materials under varying chemical and physical conditions is one of the most difficult but important aspects in assessing the performance of decommissioning and radioactive waste facilities. Within the context of a risk informed and performance based assessment, this "source term" modeling uses input from the infiltration analysis (i.e., the calculated flux of water through engineered barriers into the disposal facility)and radionuclide leach rates to estimate radionuclide releases that are then used in environmental ground-water or atmospheric transport models. Additionally, one needs to consider various features of the decommissioning and waste disposal facilities that affect radionuclide releases when developing a source term model.

In order to estimate radionuclide releases, one needs to consider radionuclide inventories, radionuclide solubilities and release rates, waste behavior and dissolution, waste types and forms, waste containers and cladding, backfill, and chemical conditions impacting these materials.

Specific data and information on long-lived fission products, activated materials, and transuranic radionuclides are used as input to computer codes used to assess the performance of decommissioning and waste disposal facilities to meet applicable NRC design objectives and regulatory requirements, including dose commitments. Much of the radionuclide data and information needed for use in establishing inventories, determining source terms and understanding the chemical behavior of radionuclides in PA applications are not available, or if available, the data are generally of either poor quality or have been obtained under differing conditions from those that could be expected to be present in decommissioning and waste disposal facilities.

Further research is needed to support source-term models used in PAs by updating existing mathematical models where deficient, identifying analysis required for PAs, and validating models with experimental and field data derived from waste stream spills to the environment, and investigating spent fuel and waste stream leaching.

5.1.2 Technical and Regulatory Objectives

The primary objective of the release element of the RTE research program is to provide experimental data and information to be used to determine realistic radionuclide inventories and to calculate realistic radionuclide releases from radioactive waste disposal facilities and decommissioned sites using source term computer codes.

Both laboratory and field research studies of actual decommissioning and waste disposal materials are needed to provide an understanding of radionuclide release, to understand and quantify, where possible, conceptual, parameter, and data uncertainties associated with radionuclide source term models used in PA computer codes, and to test the validity of the source-term models.

5.1.3 Research to be Performed and Products

RES is currently conducting research on (1) SDMP slags and soils[3], (2) characterization and leaching of decontamination waste obtained from nuclear power stations[4], and (3) evaluating radionuclide-chelating complexes in soils and groundwaters from decontamination waste[5]. The research results are expected to be used to revise and update PA codes, provide data and information for decommissioning SDMP sites and to provide information for use in determining radiological criteria for license termination of NRC-licensed nuclear facilities.

Proposed new projects in this element of the RTE research program are listed below.

1.	*Radionuclide Source Terms: Waste Characterization and Leaching Studies.*			
Priority Score		JCN		Duration
0.6		TBD		4 years

Objectives

(1) Provide more realistic data and information to obtain defensible estimates of radionuclide source term releases from performance assessment computer code calculations.
(2) Obtain radionuclide inventories in radioactive waste forms.
(3) Determine radionuclide release rate data from radioactive waste forms and activated metals.
(4) Address chemical factors and uncertainties associated with determining radionuclide release rates.
(5) Provide data and information on source term release conceptual models, parameters, and data sources for calculating dose at waste disposal facilities.

Brief Scope of Work

1. Determine radionuclide concentrations and chemical forms of radionuclides in waste forms and activated metals.
2. Perform laboratory dissolution and leaching studies on decommissioning materials (concrete, activated metals and other radioactive waste), and determine waste form dissolution rates and radionuclide release rates.
3. Perform leaching studies under varying chemical (e.g., pH, Eh, alkalinity) conditions, physical environments (e.g., temperature) and radiation fields and determine radionuclide leach rates.
4. Assess capabilities of microorganisms in waste disposal environments to release radionuclides from radioactive waste forms.
5. Provide probabilistic distributions and associated statistical parameters for radionuclide release rates and other data.
6. Determine important radionuclide chemical species leached from radioactive waste forms and activated metals.
7. Determine chemical thermodynamic data to theoretical calculate radionuclide release rates and source terms under a variety of chemical, physical and radiation conditions.
8. Provide data and information on source term release conceptual models, parameters, and

data sources for calculating radionuclide releases and dose at waste disposal facilities.

2.	*Radionuclide Solubilities.*			
Priority Score		JCN		Duration
0.6		TBD		3 years

Objectives

(1) Determine solubilities of radionuclides in radioactive waste expected to be buried in waste disposal facilities.
(2) Investigate the chemical and physical factors affecting the solubility of radionuclides in waste disposal environments.
(3) Address uncertainties associated with determining radionuclide solubilities use in source term computer codes in performance assessment models.
(4) Assess solubility conceptual models, parameters, uncertainty analysis and data sources for performance assessment dose calculations.
(5) Apply radionuclide solubility data in a risk-informed and performance base regulatory environment to special situation test cases.

Brief Scope of Work

(1) Obtain waste form samples and determine radionuclide and chemical characteristics.
(2) Experimentally determine radionuclide solubilities for important radionuclides in waste forms.
(3) Determine solubilities under varying chemical (e.g., pH, Eh, alkalinity)) chemical conditions, physical environments (e.g., temperature) and radiation fields..
(4) Provide probabilistic distributions and associated statistical parameters of radionuclide solubilities for use in performance assessment models.
(5) Determine solubility limiting chemical compound and important chemical species involved in the solubility measurements.
(6) Determine chemical thermodynamic data to calculate radionuclide solubilities under a variety of chemical, and physical conditions.
(7) Provide analysis of solubility conceptual models, uncertainty analysis and data sources used in performance assessment models to calculated doses.
(8) Apply solubility data to test case situations.

3.	*Microorganism Effects on Radionuclide Release and Transport*	
Priority Score	0.5	

Microorganisms present in disposal facility environments could influence the release of radionuclides from waste disposal facilities. Microorganisms present in the subsurface environment could interact with fission products and transuranics to alter the behavior of radionuclides in groundwaters, soil and rock fractures and either retard or enhance their mobility in groundwater systems. Such behavior could either increase or decrease the estimated dose to people from exposure to radionuclides in PAs. The models in PAs that simulate radionuclide transport do not include effects due to microorganism interactions with radionuclides. These microorganisms exist in the soils at low-level waste disposal and decommissioning sites and in deep geologic waste repositories[6]. The wide diversity and widespread occurrence of microorganisms, particularly bacteria, suggest that these microorganisms may effect the long-term stability and mobility of radionuclides in waste disposal facilities and decommissioned sites. These microorganisms appear also to create chelates and other organic compounds in the environment that could react with radionuclides to increase their mobility in the transport process. Because the size of microorganisms falls within the colloidal size range of 1 nm to 1 μm, they may attach themselves to radionuclides in ground water and soils and be transported as biocolloids. Results from a recent NRC LLW research program on microbial organism effects on cement-solidified

LLW containing ion-exchange resins provided results which suggest that microbial organism could release radionuclides from the resins in leaching experiments[7]. More recent research has shown that: (1) the biosorption of uranium and plutonium occurs in microorganisms found in groundwaters at the WIPP site and the Grimsel Test Site in Switzerland [8]; (2) Plutonium and uranium can react with chelates and extracellular polymers produced by aerobic soil microorganisms[9]; (3) sorption and desorption of plutonium and uranium occur with soil bacteria and aerobic soil bacteria react with Pu(VI) to form Pu(VI) complexes, reduction of Pu(VI) to Pu(V) and the formation of Pu (IV)[10]; (4) sulfate reducing bacteria may reduce and precipitate Np(V) thereby reducing its solubility in aqueous solutions[11], and (5) actinides can interact with microbial cells and exopolymers[12].

Research is needed to determine the effects of microorganisms found in soils and groundwaters at waste disposal and decommissioning sites on the release and migration of radionuclides that contribute to the dose to people. The data and information will be used to modify existing PA models and computer codes to account for microorganism affects on the retardation of radionuclides, confirm research results on microbial interactions with radionuclides, and provide information to the NRC staff to review independently applicants' and licensees' data, information, analyses and computer codes.

4.	*Assessment of new waste disposal and storage technologies (e.g., assured isolation).*	
Priority Score	0.5	

New technologies are being proposed to store and dispose of radioactive waste in waste disposal facilities. Radioactive waste is planned to be incorporated in waste forms that have not been tested to ensure that they meet NRC's branch technical position on waste form criteria (e.g., leaching, compression). Independent research results using actual radioactive waste would provide a basis for evaluating whether the waste forms conform to the NRC's guidance.

New LLW waste form disposal technologies will be evaluated to determine if they meet the BTP's guidance. These new disposal technologies will include, but not be limited to assured isolation storage, waste compaction, incineration, glassification, and molten metal. Testing procedures will be developed where necessary to ensure the waste forms meet NRC requirements for disposal. The initial research effort is expected to focus on assessing the performance of a proposed polymer waste solidification method for use in assured waste storage. The waste will be characterized for radionuclide and chemical content and leaching experiments will be performed to determine radionuclide releases.

5.	*In-situ and real-time monitoring of radionuclides at waste disposal facilities over long times*	
Priority Score	0.5	

Disposal facilities are required to monitor water and soils for radionuclides to ensure compliance with NRC regulations. Many of these radionuclide measurements are difficult, costly, and require considerable time to compile and collect the data for interpretation and analysis. Recently advances in radiological and chemical instrumentation and in on-line radionuclide monitoring methods suggest the possibility that in-situ and real-time isotopic and chemical measurements can be made for radionuclides in soils and groundwater at waste disposal and decommissioned sites.

This work will assess the feasibility of determining radionuclides in soils and rocks (matrices and fractures) *in-situ* and in real time over long times using radionuclide/chemical measurements and fiber optics systems. The fiber optics and sensitive probes will be buried in soils and rock fractures below waste disposal facilities and along expected radionuclide transport plumes to measure actual concentrations of radionuclides released from the disposal facilities using chemical spectrophotometer or other chemical measuring systems outfitted with conventional and laser light sources. The system will also measure water using standard adsorption bands eliminating the need for monitoring wells. The data will be collected in computer systems, transported by satellite, and be available for review in real time by NRC staff.

6.	*Determination of releases and assessment of transport of radionuclides in waste streams that are not listed in Part 61 and not considered in current PAs.*	
Priority Score	0.4	

Recent research studies have shown that radioactive metals and other materials (e.g. concrete) from nuclear power plants that are disposed in waste disposal facilities contain long-lived neutron activation products. Data and information on material solubilities, release rates and sorption coefficients for these activation products are needed to estimate radionuclide releases and migration in soils.

The release and transport of long-lived radionuclides present in activated metals (e.g, ^{10}Be, ^{36}Cl, ^{93}Mo, ^{93m}Nb, ^{108m}Ag, ^{113m}Cd, and ^{121m}Sn) and concrete will be assessed. Radionuclide solubility and leaching studies on activated metals and concrete will be performed. Radionuclide release mechanisms will be proposed and PA computer codes will be modified to account for radionuclide release from activated materials and hardened concrete.

7.	*Performance Assessment for Sites Containing ^{232}Th*	
Priority Score	0.4	

Some sites contain ^{232}Th and its progeny at low activity levels. Research results indicate that Th in these soils and slags has extremely low solubility limits. Therefore, it may be possible for NRC to perform a generic PA in house for ^{232}Th in these soils and slags to show that the doses from the sites to people may be below NRC regulatory limits. Such a determination may be cost effective in determining that ^{232}Th is not a problem at these sites.

Doses at decommissioning sites containing ^{232}Th and daughter products as the major radionuclides will be assessed generically using the experimental thorium solubility data obtained in ongoing research. This approach may allow for a generic assessment to be made for all thorium related decommissioning sites and provide support for decisions regarding decommissioning of these sites thus reducing unnecessary burden.

5.2 Engineered Barriers to Radionuclide Transport

5.2.1 Technical and Regulatory Background

Engineered barrier systems may be used (1) to limit the contact of infiltrating surface and/or ground-water with the radioactive materials and/or (2) to mitigate the leaching and migration of radionuclides to the surrounding environment. Typical engineered barriers used to limit water infiltration are “caps” composed of soil materials, geomembranes, clay liners, etc., placed over waste deposits. Other barriers used to mitigate the release of radionuclides include reinforced and plain concrete structures and boxes, high integrity containers that isolate the radioactive materials, hot mix asphalt, and various backfills and infill materials that can mitigate radionuclide transport by sorption and retardation. Subsurface barriers to contaminant migration and transport include cement and bentonite slurry walls and grout curtains, geotextiles and sheet pile impermeable walls, and permeable reactive barriers designed to intercept contaminant plumes that transform contaminants into environmentally acceptable forms at the discharge end of the barrier. Another class of engineered barriers arises from stabilization approaches often used to immobilize radionuclides and hazardous chemicals and thereby preclude their leaching and migration. The material is either combined with chemical additives such as lime, Portland cement, etc., or transformed into solid or glass forms from which the radionuclides will not leach or migrate easily. In the case of hydraulic barriers, ground water collection and extraction with subsequent pump-and-treat methodologies may provide an effective but temporary barrier to transport.

The key technical issue that needs to be addressed for the use of engineered barriers for isolation of radioactive material is the effective performance lifetimes of these barriers, for both natural and synthetic materials, as a function of climate, hydrology, geology, and time. Convincing scientific and engineering evidence that barriers retain their effectiveness and isolation capabilities for periods of hundreds of years is needed. There is a critical need for examining the credit that can be taken for engineered barriers in the PAs of decommissioning and waste disposal facilities. Of concern to regulators is the lack of available supporting technical bases and scientific proof of isolation. For example, in the development of the NRC's PA methodology for LLW facilities[13], it became clear that only by assuming that the engineered barriers (cover soil and other materials in conjunction with the concrete vaults containing the wastes and/or separately) precluded contact with and leaching of the wastes for a period of 300 to 500 years, would it be possible to assure that no dose from the mobile short-term radionulides would be possible. Such assumptions have no basis in the scientific and technical literature and experience. Similar results have been evidenced from PA to ascertain releases from engineered barriers from HLW and degraded engineered soil "caps" placed over mill tailings and other radioactive wastes including some decommissioned sites. For instance, in the latter case, the results of dose assessments are predicated on the assignment of service life estimates on the performance of engineered caps placed over contaminated fills including slags.

Implicit in the assessment of the effective lifetimes of engineered barriers for radioactive materials is the realization that it is very difficult to predict long-term environmental events and the attendant physical, chemical and biological factors that can cause degradation of engineered barriers. Development and refinement of invasive and non-invasive techniques may be useful in ensuring that engineered barriers are functioning as designed as well as for detection of defects in the barriers. There is little understanding of the long-term performance of some engineered containment systems which may be used in the near future and there is an absence of effective methods to verify that such systems are properly installed or that they can provide effective long-term performance. The National Academy of Sciences (NAS) recommends that research will be needed in the development of methods for assessing the long term durability of containment barrier systems[14]. The NAS also has considered contamination isolation measures and stated that, due to the lack of experience with engineered barriers, there is a need to confirm and ensure the effectiveness of barrier structures and durability over time by the use of management measures such as sampling and/or monitoring to determine if the barriers are in fact functioning as designed[15].

5.2.2 Technical and Regulatory Objectives

It is imperative to have a technical basis for assessing the long-term performance of engineered barriers, particularly in critical areas of uncertainty such as the performance effectiveness of engineered barrier systems to prevent releases of radionuclides over long periods of time. As a result, research projects are needed to support the development of guidance on engineered barrier performance. Research needed includes the development of mathematical models of engineered barrier degradation behavior, testing of the mathematical models with data from the published literature and controlled laboratory and field testing, mathematical modeling to determine compliance with regulations, and the analysis of monitoring data for confirmation of the effectiveness of both successful and unsuccessful barrier installations.

The regulatory objectives outlined above cover a whole range of licensing areas such as: (1) entombment of nuclear reactor facilities, (2) rubblization of buildings and materials as applied to the decontamination and decommissioning of NRC licensed facilities, (3) LLW disposal facilities that include assured isolation facilities and earth mounded/above ground/below ground reinforced concrete facilities, (5) sites with engineered soil "caps' and other composite materials placed over waste materials and/or subsurface barriers to intercept contaminant plumes, and (6) engineered barriers for the containment of waste in the Independent Spent Fuel Storage Installations (ISFSI) and other Monitored Retrievable Storage (MRS) programs.

The NRC staff has developed a rulemaking plan and an Advance Notice of Proposed Rulemaking for Commission approval in anticipation of the development of a rule to allow entombment as a decommissioning option for nuclear power plants. As part of this development, the NRC staff has identified research needs for evaluating performance criteria for entombed structures. They include two topics pertaining to the effectiveness and performance of the entombment structure and the surveillance and monitoring of its performance over the period of entombment. They include evaluation strategies for the entombment structure to determine the physical condition of the structure, and obtain the necessary data for inputs to concrete performance codes in the PAs of these facilities and evaluating surveillance and monitoring strategies to obtain data to confirm the performance modeling of the entombed structures.

5.2.3 Research to be Performed and Products

Engineered barrier systems are widely used to isolate waste and mitigate leaching and migration of radionuclides. Key technical issues associated with their use that need to be addressed are the effectiveness of these systems and their ability to function for hundreds of years. RES has concluded research projects[16] to predict the durability and service life of reinforced concrete engineered barriers primarily for concrete structures for LLW, proposed assured-isolation-facilities, and entombment structures. The computer program 4SIGHT developed under the program can be used to evaluate the degradation and fluid transport properties of entombed waste structures, rubbilized concrete disposed in concrete structures, subsurface grout curtains and slurry walls that use cement materials. Major conclusions from the concrete engineered barriers research program was that although the modified 4SIGHT code developed under the program represents the-state-of-knowledge of sound scientific and engineering principles, the absence of data from the in-service performance of concrete makes it necessary to obtain and analyze surveillance and monitoring data from these barriers to confirm code predictions. A description of these projects follows.

1.	*Following EPA and DOE work on reactive permeable barriers and impermeable subsurface barriers.*

Priority Score		JCN		Duration
0.7		None		5 years

The RES staff will do this work.

The technology of reactive permeable barriers involves the passive removal of contaminants, e.g., uranium, technetium, chlorinated organic compounds etc., in ground-water, through redox driven precipitation and sorption to iron and other materials. Information on the monitoring and performance evaluation that is underway should be obtained to better understand these processes and develop predictive methods on the flow through iron filings or iron-rich rocks in concrete and other media, the potential for clogging, and the design and long-term effectiveness of the reactive permeable barriers and their ability to sequester various radionuclides.

Impermeable subsurface barriers include viscous-liquid barrier walls, *in-situ* vitrification, and cement-based grout curtains. Results from these programs are expected to improve prediction and understanding of these barriers' long-term behavior.

2.	*Evaluation of entombed structures for decommissioning nuclear structures.*			
Priority Score		JCN		Duration
0.6		Y633 1		4 years

Objectives

(1) Evaluate strategies and techniques (including non-destructive approaches for testing (NDT)) for assessing the condition of an entombed structure prior to entombment. The purpose of this activity is to focus on the evaluation of methodologies to assess and quantify the degradation of the structure's components and obtain the necessary inputs to concrete performance codes in the PA of the facility.

(2) Conduct research on promising non-destructive technologies identified under item 1) with focus on techniques that can characterize the orientation, extent, width and spacing of cracks and other imperfections in concrete that may provide rapid pathways for radionuclide transport.

(3) Assess strategies for surveillance and monitoring of entombed structures with focus on obtaining data to confirm the performance modeling of these structures.

Brief Scope of Work

(1) Obtain parameters necessary as inputs for PA of entombed structures, evaluate strategies to assess penetrations in the concrete structure and inaccessible areas of the structure, review existing American Concrete Institute documents and identify promising technologies for NDT evaluations.

(2) Conduct detailed evaluations of promising NDT methods identified above.

(3) Evaluate techniques and methodologies for conducting surveillance and monitoring of entombed facilities. The focus of this activity is to obtain data to confirm the performance modeling of the entombed structure.

3.	*Performance of non-concrete barriers.*			
Priority Score		JCN		Duration
0.6		Y646 3		3 years

Objectives

(1) Assess the performance of soil caps as a function of climatic, geologic and hydrological

conditions so that effective lifetimes of these barriers can be estimated.
(2) Develop and test models of the degradation of geomembranes that are being widely used as barriers in waste facilities.
(3) Develop strategies to test and verify the effectiveness of subsurface vertical barriers such as grout curtains, slurry walls, and permeable and impermeable vertical walls.

Brief Scope of Work

(1) Obtain and analyze data on the performance of both successful and unsuccessful soil caps in different climatic, geologic and hydrologic regions to obtain reliable estimates of effective lifetimes of these barriers.

(2) Conduct controlled accelerated tests e.g., centrifuge testing to test and verify mathematical models of cap performance.

(3) Develop and test mathematical models of the mechanisms that cause degradation of geomembranes, e.g., ultraviolet light, radioactivity, biological and chemical processes, thermal effects and oxidation.

(4) Obtain and analyze data on the performance of subsurface vertical walls.

4.	*Investigation of the effects of various admixtures in concrete e.g., silica fume, fly ash, blast furnace slags, fiber reinforcement on the durability of concrete barriers.*	
Priority Score	0.5	

LLW sites in France, England, Spain have used some of these admixtures in their constructed facilities. Experimental research results and monitoring data from these facilities would be obtained and considered for incorporation in the 4SIGHT code.

5.	*Addition of radionuclide transport and sorption to the 4SIGHT code.*	
Priority Score	0.5	

The code as presently available considers the transport of only non- radioactive ions such as H, Ca, Na, K, OH etc. This work will incorporate the radionuclides of prime importance to decommissioning and waste disposal. Results from this work will allow determination of the rate of radionuclide transport through concrete.

5.3 Transport

5.3.1 Ground-Water Flow and Transport

5.3.1.1 Technical and Regulatory Background

Ground water is the principal pathway for radionuclide migration through the subsurface environment. Ground-water conditions such as infiltration affect radionuclide leaching, mobilization, transport rates and concentrations. Many of the important exposure pathways involve ground-water sources for drinking and irrigation water. Information on location of ground-water wells, pumping and irrigation application rates, as well as water use, are needed to characterize scenarios and quantify potential doses to an individual.

Analyses of ground-water flow and radionuclide transport involve an evaluation of hydrogeologic features, events, and processes, and their attendant uncertainties. This realization of uncertainties in both the conceptual ground-water flow and transport models, and the parameter estimates, is based in part on research insights learned from real-site contaminant studies, and from NRC Staff participation in international cooperative ground-water studies (e.g., INTRACOIN, HYDROCOIN and INTRAVAL). Significant insights were derived from ground-water monitoring and modeling studies at DOE's uranium remediation sites, DOE's Nevada Test

Site and West Valley Site, DOE national laboratories (e.g., Hanford Reservation tank evaluations, Oak Ridge National Laboratory's White Oak watershed, and Savannah River wetland studies), and foreign nuclear facilities (e.g., Atomic Energy Canada, Ltd's Chalk River Facility, and Russia's Chernobyl and Mayak sites). These studies have greatly improved NRC staff understanding of ground-water features, processes, and events that influence radionuclide transport. In recent years the NRC has funded field studies (e.g., Las Cruces Trench, Apache Leap Research site, and the Maricopa Environmental Monitoring site) to develop further the technical bases for reviewing ground-water models and monitoring programs, and to collect detailed datasets for testing new ground-water flow and transport models (e.g., MIT stochastic model, PNNL water budget model).

Ground-water analyses have evolved to the point that analysts now recognize the need to examine realistic site features, events, and processes. Previously, ground-water analyses involved simplistic, "worst-case" scenario analyses based on the analysts' assumption of steady-state vertical migration through fully saturated homogeneous media. The ground-water portion of the RTE research program focuses on the technical and regulatory objectives which require more detailed and realistic analyses in order to assess uncertainties.

An additional long-standing area of concern in subsurface transport modeling is the representation of complex chemical sorption processes with computationally efficient distribution coefficients that compare, by laboratory experiment, the amount of radionuclide held by at least one of several mechanisms in the geologic media to that remaining in the liquid ground water. With increases in readily accessible high-speed computing capacity, practical alternatives to simple linear distribution-coefficient-based mathematical models of radionuclide retardation may be within reach. The NRC needs to assess these new models to determine if they should be incorporated into its PA methodologies.

Surface complexation models have been developed for use in the prediction of radionuclide transport in the environment. Much theoretical and laboratory work has been done to date. There has been some application of surface complexation modeling to the Alligator Rivers natural analog site in Australia. More recently, RES has been working cooperatively with the U.S. Geological Survey at the Naturita, Colorado, uranium waste site to assess the application of surface complexation modeling for prediction of uranium migration at an actual field site. Characterization of the soil particles indicates that there are particle coatings and the coatings may play an important role in the sorption and desorption of uranium. Unknown are the phases present in the coatings, their composition, and more importantly, the role played by the particle coating in sorption/desorption of uranium. The applicability of this uranium-specific work to other radionuclides needs to examined and exploited to the extent possible.

5.3.1.2 Technical and Regulatory Objectives:

The regulatory objective of groundwater flow and transport research is to develop technical bases in the form of ground-water information, databases, models, and monitoring strategies to support staff reviews of licensees' submittals. Although these regulatory objectives cover a wide range of licensing areas such as nuclear power plant siting and operations, LLW site characterization, modeling and monitoring, HLW site characterization and analyses, uranium mill tailings and *in-situ* leach uranium recovery monitoring, and decommissioning reviews, there are common technical objectives. The common technical objectives involve characterizing the hydrogeologic system and ground-water use scenarios in order to calculate potential exposures to an individual. The research objective is to develop tools and technical bases to support each licensing area by focusing on the appropriate hydrogeologic features, events, and processes associated with the applicable performance measure.

Early radionuclide analyses in PA were limited to conservative, bounding analyses. For simple hydrogeologic sites with a well-defined source term at or near the surface, these analyses are still used. NUREG-1549[17] addresses the needed complexity of generic screening and site-specific models. However, for more complex sites with either an established ground-water contaminant plume, or for evaluating the potential of long-term consequences of radionuclide releases, a realistic, risk-informed analysis that takes into account conceptual model and parameter uncertainty is being used in PA. Current outstanding issues in ground-water flow and transport focus on these conceptual model and parameter uncertainties as well as retardation mechanisms.

Conceptual model uncertainty arises from the fact that several alternative conceptual models of subsurface flow and transport can be derived from a single set of site characterization data which are often sparse. Since site characterization data generally cover only a few years or decades, regulatory authorities need to have confidence that alternative conceptual models of the systems characterized are consistent with all available data and that they will not diverge significantly over time with regard to estimates of system performance. The NRC needs to be able to evaluate the conceptual models used in licensee submittals to determine if a licensee's choice of one or more conceptual models is sufficient to support claims of regulatory compliance made in the submittal.

Among the unresolved questions in ground-water transport is the degree to which colloidal transport enhances the movement of radionuclides. There have been cases where ground water contains colloidal-sized material that incorporate radionuclide species. In fact, colloid-based transport has been proposed by numerous researchers to account for the unexpectedly rapid transport of some radionuclides (e.g. Pu and Cs). However, there is also a lingering question related to the influence of sampling methods, particularly that of ground water extraction in partially saturated media. In saturated media, pumping associated with ground-water sampling may disturb sediments and mobilize colloidal sized material that would otherwise be inert.

For site stewardship, protection of ground-water is a key technical issue and research needs to focus on monitoring and model confirmation. An important technical objective is the development and testing of integrated unsaturated-saturated zone monitoring strategies to understand the selection, placement and calibration of field instruments and methods.

5.3.1.3 Research to be Performed and Products

The current hydrologic research program involves studies on: (1) development of a methodology to assess hydrogeologic conceptual model uncertainty [18]; (2) a related effort to develop a methodology on hydrologic parameter uncertainty[19]; (3) field studies at the Beltsville Agricultural Research Center to confirm uncertainty estimates of ground-water recharge[20]; and (4) partial funding of a workshop on conceptual models of flow and transport in the fractured vadose zone[21].

Current RTE research also is addressing sorption, a major chemical effect on subsurface radionuclide transport, to determine a more realistic methodology for estimating radionuclide retardation in soil[22]. A complementary effort involves the NRC's participation, along with organizations from other OECD/NEA member countries, in an effort to test and compare various models of sorption[23].

Additional research and anticipated products to address questions that are common to many waste facilities and decommissioning sites are listed below:

1.	*Hydrologic Conceptual, Parameter and Scenario Uncertainty Assessments*			
Priority Score		JCN		Duration
0.8		Y656 5		3 years

Objectives

(1) Develop an integrated strategy for selecting methods and tools for assessing hydrologic conceptual model, parameter, and scenario uncertainties.
(2) Apply the comprehensive strategy to a series of "real" sites which encompass a range of hydrogeologic settings, conditions and complexities to test the strategy's robustness and completeness.
(3) Establish hydrological data base incorporating regional and national data. Link scenario uncertainty to the conceptual model and parameter uncertainty within the integrated strategy.

Brief Scope of Work

The investigators will: (1) couple the University of Arizona and Pacific Northwest National Laboratory (PNNL) strategies developed for conceptual model and parameter uncertainties, respectively; (2) incorporate scenario uncertainty assessment into the strategy to provide a unifying and integrating aspect to ground-water flow and transport conceptual model selection, use and evaluation; (3) test the strategy by application to specific "real" site datasets which represent hydrologic conditions and scenarios assumptions in licensing performance assessment models; (4) document the strategy and its applications; and (5) provide technology transfer of the research results including the tested strategy to the NRC staff and Federal cooperative partners thru documentation and a technology transfer seminar at NRC Headquarters.

2.	*Integrated Ground-Water Monitoring Strategy.*			
Priority Score		JCN		Duration
0.7		Y602 0		3 years

Objectives

The objective of this project is to develop a strategy that provides an integrated and systematic approach for monitoring ground-water flow and transport from the land surface through the unsaturated zone to the underlying water-table aquifer which will be useful in confirming nuclear waste and decommissioning site performance, and quantifying uncertainties. The research will develop a technical bases with citable references and identified guidance and analytical tools for assessing the completeness of an integrated unsaturated-saturated zones monitoring program. The strategy developed will focus on quantifying uncertainties of the hydrologic features, events and processes using the real-time, near-continuous monitoring data for confirmation of the performance assessment analysis. The strategy will link the ground-water monitoring program to the detection level required for early warning of releases.

Brief Scope of Work

The investigators will extend the methodology developed in NUREG/CR-5698 to the capillary fringe and shallow water-table aquifer. The investigators will develop an integrated monitoring strategy and test the methodology using field data. "Real-time" monitoring data will be collected to evaluate conventional ground-water flow and transport modeling assumptions for coupled unsaturated-saturated zone systems and their interaction with engineered containment systems. The project will document the integrated monitoring strategy and technical bases developed with emphasis on relevancy to decommissioning sites such as entombment facilities and remediated sites. The investigators will provide a "hands-on" technology transfer seminar to NRC staff, Agreement State regulators and contractors, and industry scientists; and a "lessons-learned" briefing at NRC headquarters to decommissioning stakeholders.

3.	*Field studies to confirm uncertainty estimates of ground-water recharge.*	
Priority Score	JCN	Duration
0.7	Y636 3	2 years

Objectives

The objective of this project is to confirm "real-time" monitoring data needs, field instrumentation and analytical methods (e.g., PNNL Water Budget Model) used to estimate uncertainties associated with infiltration and ground-water recharge calculations using field monitoring data from both small (e.g., lysimeter) to large (e.g., watershed) scales representative of datasets relevant to decommissioning and waste disposal facilities.

Brief Scope of Work

ARS researchers, working cooperatively with RES staff under an Interagency Agreement, will (1) calculate ground-water recharge estimates using "real-time" piezometer and multi-sensor capacitance probe data; (2) confirm temporal and spatial data needs and methods for estimating ground-water recharge; (3) calculate infiltration and ground-water recharge estimates using watershed-scale data; (4) document uncertainty estimation procedures and results; and (5) provide technology transfer to the NRC staff at NRC Headquarters and stakeholders at NRC-convened seminars and at professional society meetings.

4.	*Characterization and mechanisms of radionuclide sorption in soils: fundamental routes to predictive capabilities.*	
Priority Score	JCN	Duration
0.7	Y646 4	4 years

Objectives

This project's regulatory objective is to provide data and geochemical models that can be used in a multi-media environmental transport model associated with a flexible computational platform such as FRAMES.

Brief Scope of Work

The project will use focused laboratory measurements and theoretical calculations to characterize the processes controlling radionuclide sorption on soil. Simulations at an atomistic scale of both anionic (e.g. ^{129}I as I^- and ^{99}Tc as TcO_4^-) and metallic cationic (e.g. ^{137}Cs as Cs^+ and ^{90}Sr as $Sr2^+$) species will provide insights into the processes involved. Results of the characterization and simulation research will be combined into a probabilistic analysis of sorption and hydrologic flow which is to be applied to prediction of performance at one or more actual field sites. The research will be done as three distinct but related tasks:

(1) Identification and characterization of soil particle coatings. The success of sorption models in the performance assessment of radionuclide transport is often limited by lack of information on the soil components that control sorption and retardation of radionuclides in soil.

Sorption and retardation are controlled typically by particle coatings such as ferrihydrite, goethite, and clay minerals. Bulk chemical analyses of soil commonly overlook the small volumes represented by the phases that comprise the surface coatings of soil particles. Traditional analytical methods (e.g. x-ray diffraction, electron microprobe etc.) have had limited success in identifying and characterizing soil particle coatings because of nano-size, amorphous structure, heterogeneity, extensive site disorder, and multicomponent behavior. Specialized spectroscopies and analytical methods (e.g., synchrotron-based analytical methods and micro-tomographic methods) have now been developed and matured to provide the necessary details needed to identify and characterize soil particle coatings. The identification and characterization of soil particle coatings will be applied to one or more field sites to identify the soil components controlling retardation. The information on the components controlling sorption and retardation will then be used to improve prediction of radionuclide sorption and retardation in soils.

(2) Application of molecular modeling to Identification of mechanisms controlling sorption. Computational chemistry and molecular modeling methods have progressed to the extent where theoretical approaches can elucidate the mechanisms of radionuclide sorption, and even be used to predict the distribution of metal cations onto various mineral surfaces. These computer "experiments" provide a level of control of the mineral-solution interface that cannot be obtained by field or experimental observations. Computer-based models of mineral substrates and idealized aqueous solutions can be used to derive idealized and limiting distributions for the sorbing species. Molecular dynamics methods, in particular, present a computational approach where the sorption of a representative radionuclide can be monitored and then used to derive bulk K_d values. This is useful in the evaluation of sorption parameters used in performance assessment models where often non-unique and uncertain experimental and field K_d values are incorporated into hydrologic transport codes. The distribution of widely ranging K_d values can be narrowed by recognizing the limits indicated by the molecular dynamics methods and recognizing meaningful K_d values for the specific mineral substrate. This task will (1) extend previous work on the sorption of Cs^+ and Sr^{2+} on kaolinite and montmorillonite clays to perform molecular dynamics simulations of the sorption of uranyl ion onto the basal surfaces of various clay phases (kaolinite, montmorillonite, and illite); (2) identify radionuclide-substrate geometries; and (3) derive relative binding energies. Anionic species are to be addressed too and the research will examine the relative behavior of anionic radionuclides (I^- and TcO_4^-) onto the basal surfaces of kaolinite and montmorillonite clay minerals.

(3) Probabilistic analysis of sorption parameters and hydrologic flow. The mechanistic-based modeling of sorption processes provides a link between the macroscopic observations (bulk retardation and K_D values) and the atomistic behavior of the chemical species at the mineral-solution interface. Although rigorous in providing a thermodynamic description of sorption, surface complexation models are often limited due to the inherent uncertainties associated with the thermodynamic sorption parameters. Beyond being fundamentally difficult experiments, any evaluation of sorption parameters is further complicated by applying the limited amount of sorption data to environmental conditions beyond those of the experiment. A helpful approach to evaluate the acceptable uncertainties for the sorption parameters is that of probabilistic analysis whereby each parameter is varied and then incorporated into a sorption model. More importantly perhaps is the role of the sorption process coupled with hydrologic flow models allowing for the evaluation of radionuclide plumes. Under this task the research will assess the influence of the sorption parameters (e.g., log K, mineral surface area, and site densities) and their variability on plume geometries. Ultimately, the assessment will provide a stochastic, yet rigorous, analysis in support of performance assessment models for radionuclide retardation and migration in the environment.

5.	*Retardation of Radionuclides in the Environment*			
Priority Score		JCN		Duration
0.6		TBD		4 years

Objectives

(1) Provide radionuclide sorption and desorption data and information for radionuclides in ground waters flowing through soils and fractured rock systems.
(2) Provide radionuclide sorption data for the irrigation-to-soils pathways models in performance assessment computer codes.
(3) Investigate the role of radionuclide sorption in both the saturated and unsaturated zones.
(4) Determine radionuclide sorption behavior under varying groundwater and fracture flow chemistry conditions
(5) Address uncertainties associated with radionuclide mobility and retardation to calculate doses in performance assessment models.

Brief Scope of Work

(1) Determine sorption and desorption coefficients for important long-lived radionuclides in soils and fractured rocks using batch and flow systems. Soil systems are to include wet and arid environments and include alluvial materials.
(2) Study radionuclide sorption in saturated and unsaturated ground water systems.
(3) Determine radionuclide sorption data and information under varying ground water physical (e.g., particle size distributions, various moisture conditions, temperature) and chemical (e.g., pH, carbonate, ionic strength) conditions.
(4) Coordinate results with source term laboratory and modeling studies.
(5) Calculate the important radionuclide chemical species involved in the sorption processes. Attempt to experimentally determine the important chemical species in the sorption processes.
(6) Determine the chemical thermodynamic data to calculate radionuclide sorption coefficients under a varying chemical and physical conditions.
(7) Evaluate capabilities of microorganisms to effect the behavior and mobility of radionuclides in ground water systems.
(8) Participate in field studies to determine radionuclide sorption in soil, fractured rock systems and matrix media.

6.	*Characterization of soil-particle coatings*			
Priority Score		JCN		Duration
0.6		Y640 1		2 years

The RES staff is doing this work in laboratories at the Johns Hopkins University.

Characterize the chemical composition and phases present in coatings of soil particles at the Naturita, CO, site to support surface complexation modeling work done for the NRC by the USGS and Sandia National Laboratories. Following characterization (including synchrotron-based methods), the role of coatings in the retardation of radionuclide movement is to be assessed by laboratory measurements and molecular modeling. The Naturita soil characterization research will assist in demonstrating the effectiveness of surface complexation models for prediction of radionuclide movement through soil. In addition, it will address the role played by soil coatings in retardation and those data will be factored into geochemical codes which can be used for regulatory decisions affecting SDMP sites, uranium mill tailings sites, and waste disposal sites.

7.	*Radionuclide colloid transport*			
Priority Score		JCN		Duration
0.6		Y646 6		3 years

Objectives

(1) Determine the role colloids play in the transport and behavior of long-lived radionuclides in waste disposal facilities.
(2) Provide data and information that could be used to reduce uncertainties in colloid models incorporated in performance assessment computer codes that calculate radionuclide source terms, transport of radionuclides in ground water and the behavior of radionuclides in pathway systems.
(3) Provide data for radionuclides and waste forms for use in colloidal release models.
(4) Evaluate the chemical processes and environmental conditions affecting radionuclide colloid formation in near-field environments and transport in ground water and fractured rock systems.
(5) Evaluate methods used to measure radiocolloids and colloids in aqueous environments.

Brief Scope of Work

(1) Review and evaluate existing laboratory and field data on radiocolloid releases to and transport in groundwater systems.
(2) Conduct experiments to determine the formation of radiocolloids from the combining of ^{239}Pu, ^{241}Am and ^{237}Np and other radionuclides with colloids formed from waste forms, cladding, waste package corrosion products, glass and with colloids present in ground water systems.
(3) Study the formation of reversible and irreversible radiocolloids in laboratory experiments.
(4) Evaluate the chemical (e.g., pH, ionic strength) and physical (e.g., temperature) effects on radionuclide colloid formation.
(5) Determine aqueous sorption coefficients for reversible radionuclide colloids.
(6) Determine radiocolloid mobility in saturated and unsaturated soils and through porous media and rock fractures as a function of water quality chemistry.
(7) Participate in field studies to determine radiocolloid transport in soil, fractured rock systems and reactions in matrix media.
(8) Propose chemical reaction mechanisms to explain radiocolloid behavior in near-field environments, ground water systems and pathway systems.
(9) Assess chemical and physical methods for determining radiocolloid concentrations and characteristics in aqueous systems.

8.	*Testing the validity of ^{14}C transport models*	
Priority Score	0.5	

The NRC studied ^{14}C transport from the point of release at a radioactive waste disposal area to uptake in vegetation at Chalk River Nuclear Laboratories over a two year period in 1995-1996[24]. There is need to update that work by examining the temporal changes that have happened to the ^{14}C plume and to relate that to transport models to rest the validity of their predictions. Some field measurements will need to be taken to determine environmental changes in the ^{14}C plume at Chalk River with time. The Chalk River ^{14}C research will be useful for predictions of ^{14}C transport in the environment. Preliminary results indicate that wetlands are highly effective in sequestering ^{14}C and that the gaseous pathway plays a prominent role in uptake and releases. These data need to be quantified, linked to seasonal changes, and then input into transport models.

9.	*Historical case analysis of plumes*	
Priority Score	0.4	

Historical case analyses of actual contaminant plumes to see what has moved, how far it moved and the factors controlling migration will provide a data base useful for NRC licensing decisions regarding site clean-up and closure. This work will build on similar work done for uranium plumes[25]. The data from the uranium work indicate that with rare exceptions, uranium plumes migrate less than 2 km. There is a need to extend historical case analysis to other key radionuclides to identify dominant transport processes that may be common to all plumes. Future research will be directed toward examining plume migration in both the unsaturated and saturated zones for evaluating ground-water flow and transport models. Under a USGS-NRC MOU, the research will examine multi-phase vapor transport in heterogeneous, partially saturated media at the Amargosa Desert Research site to determine controlling radionuclide migration processes.

5.3.2	Soil Biotic Effects on Radionuclide Transport	
Priority Score	0.5	

5.3.2.1 Technical and Regulatory Background

Vegetation plays a role in enhancing transport through biotic processes operating in the rhizosphere (root zone) of plants. Biotic processes produce organic ligands which can mobilize radionuclides and other metals. This was demonstrated in a scoping study of the effect of rhizosphere processes on radionuclide mobilization[26] that showed that hickory trees were capable of mobilizing Co-60 to a far greater degree than other types of deciduous trees.

To support regulatory decisions, further work is needed on soil biotic processes that affect transport. The preliminary scoping study of the effect of rhizosphere processes on radionuclide mobilization was on a limited number of radionuclides and on a limited suite of trees typical of eastern deciduous forest. This work needs to be expanded to a wider range of radionuclides and metals and on a wider range of vegetation. Because water is more prevalent as a transport vehicle in the eastern U.S., emphasis should be given to vegetation typical of eastern humid region sites, especially those likely to be found in proximity to decommissioning sites.

5.3.2.2 Technical and Regulatory Objectives

The regulatory objective is to assess the magnitude of the impact of soil-biotic factors affecting radionuclide transport with particular emphasis on processes operating in the rhizosphere of vegetation and to estimate its contribution to doses to people.

5.3.2.3 Research to be Performed and Products

Perform focused laboratory studies of the effect of vegetation on the mobilization of key radionuclides. The vegetation studied will be representative of types likely to be employed in site closure of decommissioning, uranium mill tailings, and waste disposal sites. Research results are to be in the form of reports useable by the NMSS staff in PA.

5.3.3	Bioaccumulation of Radionuclides	
Priority Score	0.5	

5.3.3.1 Technical and Regulatory Background

Bioaccumulation of radionuclides can be an early-warning monitoring system at sites contaminated with long-lived radionuclides. Vegetation promises to be a cost effective and highly effective monitoring tool for early detection of radionuclide transport from contaminated sites. Conventional monitoring methods rely heavily on sampling wells. These wells sample only a small portion of the subsurface. However, vegetation acts as an integrator and concentrator of subsurface radionuclides. Tritium in the plant transpiration stream was used successfully in this manner at the Maxey Flats, KY, LLW disposal facility. This is a site in which fracture flow plays a prominent role and monitoring wells were typically dry unless they encountered a fracture. Tritium in trees located several plumes that could not be located by monitoring wells. Because vegetation plays a role as an integrator of contaminants it offers promise in allowing for early detection of radionuclide releases from contaminated sites.

5.3.3.2 Technical and Regulatory Objectives

The regulatory objective will be to demonstrate the effectiveness of vegetative uptake (bioaccumulation) of radionuclides as an early-warning monitoring method for detecting environmental releases from contaminated sites.

5.3.3.3 Research to be Performed and Products

The research is to be conducted at contaminated sites (e.g. Chalk River and/or DOE sites). Field measurements will be taken to characterize the transport rates and transfer coefficients for long-lived radionuclides moving from waste to the surface to determine bioaccumulation rates in vegetation. Monitoring strategies and sampling protocols will be developed for use in assessing bioaccumulation of radionuclides.

The transport rates and transfer coefficients for long-lived radionuclides will be useful for PAs of contaminated sites in that they will provide real data from actual sites. The monitoring strategies and protocols will be of use to regulators and site managers for ensuring protection of public health and safety.

5.4 Performance Assessment

5.4.1 Technical and Regulatory Background

There are many extant computer programs that implement mathematical models of radionuclide transport in the biosphere (collectively called environmental pathways models) and doses to humans exposed to the radionuclides. The NRC has generally accepted these models and used them in its regulatory decision-making. However, most of the existing models use a conservative approach and are not useful for complex sites.

Current PA tools are often criticized for constraints alleged to require oversimplification of complex systems, and are not adaptable for extended applicability beyond the originally-designed problem type without extensive software modification.

5.4.2 Technical and Regulatory Objectives

One objective of the RTE research program's PA element is to examine environmental pathways models and parameters currently used by the NRC in decommissioning and waste decisions.

The other objective is to establish an adaptive PA framework that will integrate tools for:

1. conceptualization of the problem and supporting data;
2. sampling (Monte Carlo) of complex features, events, and process;
3. flexible database access;
4. importing, exporting or reporting of data or results;
5. incorporating additional models into the framework;
6. analysis of data and intermediate or final results; and
7. visualization of intermediate and final results.

The framework will allow the NRC to develop more risk-informed approaches for identifying the most important parameters and models for demonstrating compliance with license-termination requirements and criteria. The framework also would be adaptable to LLW and uranium recovery applications.

5.4.3 Research to be Performed and Products

The RTE research program is currently conducting PA projects to

- benchmark the RESRAD and RESRAD-BUILD codes to ensure the quality and technical defensibility of dose analysis performed for complicated decommissioning cases; and

- identify and prioritize data gaps in RESRAD's and RESRAD-BUILD's parameters to be filled by future research.

Proposed future PA research in the RTE research program is described below.

1.	*Assessment of parameters used in environmental pathways models*			
Priority Score		JCN		Duration
0.8		Y646 9		5 years

Objectives

(1) Investigate the important features, events and processes of the irrigation and food-chain pathways for calculating dose to the average member of the critical group and maximally exposed individual from radioactive contaminated agriculture and animal products near waste disposal facilities and decommissioned sites.
(2) Assess irrigation and food-chain conceptual models, parameters, uncertainty analysis, probability distribution functions, and data sources in performance assessment computer codes
(3) Obtain laboratory and field data for agriculture exposure scenarios involving ground water contaminated with radionuclides for use in irrigation and food-chain pathway models
(4) Evaluate and determine age dependent data and information to assess total effective dose equivalent radiation exposure for the food-chain
(5) Determine the impacts of microorganisms in soils, fractured rocks and ground waters to effect the mobility and overall environmental behavior and transport of radionuclides in ground water systems.

Brief Scope of Work

1. Review and evaluate data and information published on irrigation of agriculture products, crop uptake factors, and animal uptake factors including studies performed by the United Kingdom Ministry of Agriculture, Fisheries and Food and the International Union of Radiologists.
2. Update consumption rates for crops and animal products for children and adults.
3. For important radionuclides, perform laboratory and field experiments to determine, crop intersection fractions, soil-to-plant concentration ratios, crop translocation factions, animal product transfer coefficients, and other important transfer factor.
4. Develop strategies to assess and verify irrigation and food-chain pathways models, parameters, uncertainty analysis, and data sources for performance assessments.
5. Evaluate capabilities of microorganisms to effect the behavior and mobility of radionuclides through solubility and speciation changes, biosorption, bioaccumulation, other transformations, and bioproduct chemical reactions.

2.	*Development of Probabilistic RESRAD-OFFSITE Code.*			
Priority Score		JCN		Duration
0.7		Y602 0		2 years

Objective

The objective of this project is to develop probabilistic version of the U.S. Department of Energy (DOE) sponsored code RESRAD-OFFSITE and associated distributions of input parameters and exposure scenarios to extend the probabilistic RESRAD (onsite) dose assessment methodology to sites that have the potential for off-site migration of radionuclides. This will enable the maintenance of consistency in site-specific probabilistic dose analysis performed for onsite and offsite migration of radionuclides to demonstrate compliance with the license termination rule and with other NRC regulations for waste management, storage and disposal in a risk-informed manner.

Brief Scope of Work

(1) Develop and update a user-friendly probabilistic code version.
(2) Perform analysis to define distributions of input parameters and exposure scenarios.
(3) Develop interface modules for RESRAD-OFFSITE to establish the capability to perform site-specific off-site probabilistic dose assessment.
(4) Develop and document the technical basis for the code.
(5) Perform testing and Quality Assurance(QA) of software and document results.
(6) Prepare user's manual.
(7) Perform and document dose analysis to illustrate the use of the probabilistic approach to identify sensitive parameters and sensitive exposure scenarios.
(8) Perform Technology Transfer to NRC.

3.	*Evaluating the use of the FRAMES system.*			
Priority Score		JCN		Duration
0.7		Y646 0		3 years

Objectives

The primary objective of this work are to provide NRC/NMSS with a dose-assessment tool for licensing decisions with sufficient power, flexibility and utility that it can serve as their primary platform for analyzing the hazards associated with licensing actions at those "complex" sites at which the traditional dose-assessment tools are inappropriate. A secondary objective is to provide NRC/RES with a tool with sufficient power, flexibility and utility that it can be used as: a platform to evaluate the sensitivity and significance to dose from varying conceptualizations of structure or processes within the radionuclide transport and exposure problem, a platform to test the utility of these conceptualizations within a PA context, and a stabile interface design target for "PA-suitable" code produced by RPERWMB research projects.

Brief Scope of Work

The current development of FRAMES is being supported by contracts from DOE, EPA, Corp of Engineers Waterways Experiment Station. With this alliance, we gain the opportunity to leverage others funds and access to a stable development team. The scope of NRC-specific work is under development as we evaluate the current system and on-going work sponsored by the other federal agencies.

NRC-specific components will be minimized as our focus is quite similar to the current focus of the other participants. The EPA's HWIR brings to FRAMES a more comprehensive consideration and treatment of uncertainty and an increased dimensionality in the ground-water pathway. The DoD's ARAMS implementation and future plans bring added sophistication to a number of the pathways and an emphasis on meeting the regulatory requirements for risk assessment (documentation of data pedigree, etc.). The DoD is anxious to link FRAMES with input to and output from their Groundwater Modeling System (multi-model and multi-dimensional analyses of flow and transport), Surface-Water Modeling System and Watershed Modeling System codes.

4.	*Support for interagency cooperative research*			
Priority Score		JCN		Duration
0.6		Y633 0		2 years

Objectives

The U.S. Departments of Defense (DOD) and Energy (DOE), the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and other federal and state agencies share responsibility for protecting human health and the environment from adverse impacts resulting from the production, use, and disposal of radioactive materials. In carrying out their radiation protection work, regulators and those whom they regulate frequently must make sophisticated and complex site and risk assessments. There are considerable differences among the various tools that they traditionally have employed for these purposes, however, and this has often led to inconsistent results. Such discrepancies may cause confusion and disagreements among the regulatory agencies, or between the agencies and the regulated community. This work is to provide support for an interagency effort to harmonize transport and exposure modeling within the federal government.

Brief Scope of Work

The cooperative program is currently being developed by the members of the Interagency Steering Committee on Radiation Standards. RES anticipates that the scope will involve selecting and perhaps modifying computer code and methodologies to be consistent with the needs of the cooperating federal agencies.

5.	*Testing the validity of performance assessment computer codes.*	
Priority Score	0.4	

Research is needed to assess available DOE data and information on radionuclide migration in the environment for use in testing the validity of models implemented in PA computer codes. An evaluation of the available data and information on radionuclide migration in the environment (e.g., soils and plumes) from releases at DOE facilities will be performed to determine the suitability of the data and information for use in evaluating PA computer codes to predict radionuclide source term releases and migration in soils. If the data and information are of sufficient quality, a study will be performed to compare the field data with results calculated by the PA computer codes in an effort to improve the PA codes' ability to predict radionuclide migration in soils and ground-water systems.

5.5 Cooperation with Other Organizations

The RTE research program leverages its resources through cooperative interactions and special research agreements (e.g., Memoranda of Understanding (MOU) and Interagency Agreements (IAA)) with other national and international research organizations that are pursuing similar work. The technical objective is to gain access to technologies, databases, computer software, and methodologies useful to the NRC's regulatory activities. The RTE program cooperates with other Federal Agencies (e.g., the USDA's Agricultural Research Service, U.S. Geological Survey, NIST, EPA, U.S. Army Corps of Engineers), DOE national laboratories, universities (e.g., Johns Hopkins University), National Academy of Sciences (NAS), National Academy of Engineers (NAE), and international organizations (e.g., OECD/Nuclear Energy Agency (NEA), Swedish Nuclear Power Inspectorate, IAEA and AECL). These cooperative ventures help to identify important research findings, datasets (e.g., Chernobyl and Mayak site data through the American Institute of Hydrology and Lawrence Berkeley National Laboratory), and lessons learned for use in evaluating and testing multi-media environmental models.

5.5.1 Participation in Phase 2 of the NEA Sorption Project

RES, NMSS, the Center for Nuclear Waste Regulatory Analyses, and the US Geological Survey have formed teams to participate in Phase 2 of the NEA Sorption Project, an international cooperative effort on sorption modeling. In Phase 1 of the NEA Sorption Project, the participating organizations concluded that practical alternatives to modeling sorption with linear isotherms are within reach[27]. Phase 2, which started in 2000, will test that conclusion. Phase 2's Technical Direction Team has defined several test cases that the participating teams will use to test their sorption models. The Technical Direction Team will evaluate the results of the teams' modeling exercises and issue a report on which models are the best for estimating sorption.

5.5.2 Interagency Cooperation on Integrated Environmental Transport Modeling

NRC has entered into an agreement with the Environmental Protection Agency, the Department of Energy, and the Army Corps of Engineers on issues integrated environmental transport modeling methods and software that all of the involved agencies have to deal with. An MOU has been developed that will establish policies and administrative practices to facilitate cooperation and coordination among the involved agencies, and possibly other federal agencies, in research and development of multimedia environmental models, software, and related databases. The intent of this MOU is to provide a mechanism for the cooperating federal agencies to pursue a common technology in multimedia environmental modeling with a shared scientific basis. The work cited in Section 5.4 on FRAMES is part of this cooperation.

5.6 Stakeholder Involvement

The RTE research program has pursued several avenues of stakeholder involvement. The technical objective of these "outreach" activities is to transfer timely research results to stakeholders, and in return obtain periodic reviews of ongoing research studies. This public outreach takes many forms: publication of research results as NUREG's and NUREG/CR's; convening public meetings and site visits, research symposia held at NRC Headquarters or at cooperating Federal Agency locations (e.g., USGS and ARS), and special sessions at professional meetings (e.g., American Geophysical Union meetings). In the area of hydrology research, RES has held annual research reviews attended by federal agencies (EPA, DOE, USGS, ARS, NWTRB), universities (University of Arizona, Pennsylvania State University, University of Southern Illinois), DOE national laboratories (PNNL, SNL and ANL), the Center for Nuclear Waste Regulatory Analyses, and Agreement States regulators and consultants. Input received from these "outreach" activities has benefitted both the individual research projects reviewed, and research users (i.e., the NRC licensing staff and Agreement State regulators).

RES will continue ongoing discussions with the National Academy of Sciences (NAS) on the role of Engineered Barrier Systems in waste disposal. The NAS has scheduled a Workshop, to be held in mid-July 2001, on the performance of and credit to be taken for engineered barriers in waste disposal PAs.

Recommendations from the workshop proceedings as applicable to NRC will be included in a revision to this RTE research plan.

5.6.1 Archival and Conference Publications and NUREG Reports

All work published under the auspices of the RTE research program is publicly available. The staff and contractors publish their results in archival and conference publications and NUREGs and NUREG/CRs. Journals such as *Water Resources Research*; conferences such as those of the American Geophysical Union, American Chemical Society, and the Geological Society of America; and more specialized conferences such as the annual *Waste Management* conference in Tucson, AZ, and the international *Migration* conferences have published work from the RTE research program.

5.6.2 Advisory Committee on Nuclear Waste

The RTE research program regularly briefs the ACNW on its ongoing activities and on the details of specific projects and solicits feedback the committee's feedback.

Appendix A: Strategic Plan Context

The NRC's Strategic Plan provides direction for the staff to embrace in accomplishing the agency's mission.

A.1 Strategic Arenas Supported by RTE Research

The "U.S. Nuclear Regulatory Commission Strategic Plan" (NUREG-1614, September 2000) organizes its mission-specific goals and strategies into four strategic arenas: Nuclear Reactor Safety, Nuclear Materials Safety, Nuclear Waste Safety, and International Nuclear Safety Support. For each strategic arena, NUREG-1614 defines a strategic goal and performance goals, strategies, and measures to be employed in achieving and assessing accomplishment of the performance goals. In the sections that follow, those goals and strategies that the RTE research program is addressing will be listed and discussed briefly.

The RTE research program mainly supports the Nuclear Waste Safety strategic arena, which includes the regulation of decommissioning and low- and high-level radioactive waste facilities. The RTE research program also supports the regulation of aspects of the Nuclear Materials Safety arena that deal with uranium recovery and the disposal of uranium mill tailings. The goals, strategies, and measures applicable to the regulation of nuclear waste also are applicable to the regulation of uranium mill tailings. The RTE research program also supports the International Nuclear Safety arena through its participation "in international safety cooperation, information exchange, and cooperative safety research."[1] Aspects of this participation are described below in the context of Nuclear Waste Safety.

A.2 *Strategic Goal for Nuclear Waste Safety: Prevent significant adverse impacts from radioactive waste to the current and future public health and safety and the environment, and promote the common defense and security*

To support this goal, the NRC "... will use domestic and international research, technical studies, and risk information to ensure that the regulatory framework is based on technically sound and realistic information." The NRC will conduct and support domestic research, follow the results of relevant domestic and international research, and leverage its resources through cooperative projects with other federal agencies and other countries. The specific Performance Goals and related *strategies* are discussed below.

A.2.1 *Performance Goal: Maintain safety, protection of the environment, and the common defense and security*

The RTE research program supports this performance goal by providing a technical basis to support regulatory decisions. This technical basis is expressed through existing regulatory guidance and review procedures that are supported by "the body of technical information, obtained from research performed by the NRC or by others and from evaluation of operational experience." The RTE research program supports the following strategies for meeting this performance goal.

> "We will continue developing a regulatory framework to increase our focus on safety, including the incremental use of risk-informed and, where appropriate, less prescriptive performance-based regulatory approaches to maintain safety."

> "We will evaluate potential new information from research, new safety issues, changing external factors,

[1] Quoted and italicized text in this appendix is from NUREG-1614.

international programs, and licensee operational experience so that improvements can be made to maintain an adequate regulatory framework."

A.2.2 *Performance Goal: Make NRC activities and decisions more effective, efficient, and realistic*

The RTE research program supports this performance goal by providing a technical basis for more realistic regulatory assessments. The conventional regulatory response to uncertainty is to attempt to over-predict consequences from regulatory decisions so that the final choice is always protective of safety. However, for complex natural systems, the bounding assumptions and simplified models used in regulatory decision-making have been shown in some cases to under-predict consequences. The uncertainties that cause such anomalies can be dealt with only by employing data and models that yield more realistic assessments of performance. The RTE research program will support the following strategy to meet this performance goal.

> "We will continue to improve the regulatory framework to increase our effectiveness, efficiency and realism."

NUREG-1614 states that, in meeting the goal of more realistic activities and decisions, "The NRC will ensure that its decisions are scientifically-based; risk-informed; and shaped by operational experience, new information, and research, including cooperative international activities. As a result, the NRC's decisions will be realistic, will be systematic, and will appropriately treat areas of uncertainty." The RTE research program will provide new data and models from NRC-supported research and information derived from cooperative national and international activities. "We will pursue international cooperative research in order to leverage our resources, share research facilities wherever possible, and maintain an environment in international committees and working groups which can best further our interests and minimize unnecessary duplication of effort... NRC [will make its] decisions more realistic by eliminating excessive conservatism. Realism is supported by risk information, research results, and operational experience."

A.2.3 *Performance Goal: Reduce unnecessary regulatory burden on stakeholders*

Unnecessary regulatory burden can increase costs with no significant reduction in risk or result in no significant improvement in the protection of the public health and safety. The NRC strategy to address unnecessary burden as outlined in NUREG-1614 is to "... use domestic and international research and technical studies to evaluate new information in order to identify areas in our regulatory programs where unnecessary burden and duplication can be reduced." The RTE research program will provide much of the domestic research, and through international cooperation, provide the NRC with access to research in other countries that it can use to reduce unnecessary regulatory burden. The RTE research program supports the NRC's strategy to "continue to improve [its] regulatory framework in order to reduce unnecessary regulatory burden" by reducing uncertainty in regulatory judgments so that they are more realistic.

A.2.4 *Performance Goal: Increase public confidence.*

The RTE research program supports this goal in two ways. Its primary contribution comes from providing a sound technical basis for NRC decisions and a clear articulation of how its results affect the existing regulatory framework. In order to assure the proper incorporation of research results into the regulatory program, RES will provide summaries of all significant products or results and the implications and potential uses for these products in regulatory analyses. These summaries also will become available to the public through the NRC's electronic systems, thereby improving public awareness of new information and its significance.

The second way the RTE research program supports this goal is by proactively seeking to provide increased access to both the planning and implementation aspects of its research activities. By seeking stakeholder input on this plan, RES will ask stakeholders for comment on those topics already suggested for further study and to suggest areas that they think should be examined. By opening program reviews of ongoing research to public attendance and providing opportunities for public participation at these program reviews the NRC is increasing the opportunity for concerned parties to have an impact on the ongoing execution and focus of funded research. As a result of these interactions, RTE research products should more fully address the full range of stakeholder concerns and improve confidence in the results and their application to the regulatory process.

Appendix B: RES Prioritization

Table B-1 shows the current (FY 2002) RES prioritization criteria. These criteria differ from those used in previous years in that specific changes have been made for use with projects in the Nuclear Waste Safety Arena.

Table B-1: RES Prioritization Rating Factors

Safety/Environmental Contributors		Max Score	Multiplier
For Use in Reactor and Materials Activities		2	
1	Addresses significant new safety challenges		1
2	Maintains or assures current level of safety		0.6
3	Monitors safety performance		0.4
For Use in Waste Activities		2	
1	Addresses significant environmental challenges		1
2	Addresses technologies to control, mitigate or prevent degraded isolation performance		0.6
3	Addresses monitoring or long-term institutional control		0.4
Scope of licensees		Max Score	Multiplier
		1	
1	>50% of all licensees		1
2	>10% of all licensees		0.6
3	<10% of all licensees		0.4
Efficiency and Effectiveness Contributors		Max Score	Multiplier
Realistic Decision Making		1	
1	Realistic tools or data to confirm safety		1
2	Realistic tools or data to reduce margins, burden		0.6
3	Maintain capabilities for independent verification and identification of issues		0.4
Industry or International Participation / Leverage		1	
1	Major external participation/NRC < 25% support		1
2	NRC and ext. part. / NRC ~ 50% support		0.6
3	Minor external support / NRC > 75% support		0.4

Table B-1: RES Prioritization Rating Factors			
Burden Reduction Contributors		Max Score	Multiplier
		1	
1	Cumulative savings > $10M / year		1
2	Cumulative savings > $1M / year		0.6
3	Cumulative savings > $0.1M / year		0.4
Public Confidence Contributors		Max Score	Multiplier
		1	
1	Responds to a public concern		1
2	Contributes to resolution of an issue before the public		0.6
3	Provides information to the public		0.4
Composite score = Sum {multiplier x maximum score}			

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