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March 23, 1993

NOTE TO: Norman Eisenburg, Leader
Repository Performance Assessment Section

FROM: Rex G. Wescott

SUBJECT: COMMENTS ON RESEARCH PROGRAM PLAN (NUREG 1406)

Attached are comments relayed to me verbally by Dick Codell.

Additional comments from Dick have been incorporated into my reviews of the Hydrology and Performance Assessment Sections.

These comments have not as yet been resolved with RES.

- THM studies under DECOVALEX reports, CY93 - CY94
- Thermohydrologics research results, CY93 - 94

A.0.1.4. Hydrology

The hydrology research program will address key technical uncertainties (see Appendix A.4.2) in the areas of climatology, surface and ground-water flow and transport, and coupled effects. Specifically the hydrologic studies will provided technical bases for evaluating DOE's predictions of; (1) the upper bound of precipitation (and subsequent infiltration) over the next 10,000 years, (2) the effects of combined conditions (human activities, climate changes, and tectonic changes) on the hydrologic system, (3) the relative proportion of fracture versus matrix flow in the unsaturated zone, including identification of the conditions under which fracture flow will dominate, and (4) the potential for future perched water bodies. Fundamental knowledge on how to collect unsaturated hydrologic property data for fractures and how to model unsaturated fracture flow will need to be independently determined in these hydrologic studies.

Too positive

The hydrology program will assess ground-water flow and transport using a systems approach. Specifically, ground-water contributions to the degradation of waste package containment, radionuclide release from the engineered barrier system, and where transport to the accessible environment will be examined. The hydrology research program will independently test DOE concepts of infiltration, percolation and recharge (both distributed and focused) in unsaturated porous media and fractured rock under varying climatic conditions. Due to the paucity of hydrologic experience in low-permeability unsaturated fractured rock, detailed field test evaluations and experiments will be conducted to test DOE's assertions as described in their SCP and accompanying Special Study Plans. Methods for measuring and estimating large-scale effective pneumatic, hydrologic and transport parameters for unsaturated fractured rock will be evaluated [R186].

The following activities will be pursued to resolve the key technical uncertainties in hydrology:

- Apache Leap Pneumatic and Hydraulic Field Tests (FY93-94)
- Apache Leap Laboratory and Field Tracer Experiments (FY95-98)
- Field Infiltration, Percolation and Recharge Studies (FY93-94)
- Field Hydrochemical Studies for Confirming Ground-Water Recharge Fluxes and Travel Times (FY93-94)
- Theoretical Large-Scale Parameter Estimation Studies (FY93-95)
- Regional Hydrogeologic Studies to Assess Conceptual Flow and Transport Models as Input to Coupled Effects Models (FY93-97)

A.0.1.5. Geochemistry

Geochemistry relates to key technical uncertainties throughout the HLW repository

1A.1 Controlled Release, *Phillip R. Reed, William R. Ott, George F. Birchard,*

A.1.1 <u>Introduction</u>

A.1.1.a <u>Background</u>

To assess compliance with the requirement for controlled release from the engineered system in the event of waste package containment failure, the NRC must have a model of radionuclide release for the complete period of regulation, which is assumed here to be 10,000 years. The HLW regulation 10 CFR Part 60 does not include the host rock in the definition of the engineered system for the controlled release compliance assessment. At present, no engineered backfill materials are planned for the Yucca Mountain site. Available controlled release models would assess the performance of the waste form in the repository environment for 10,000 years, assuming various scenarios of waste package containment failure. The NRC now uses a set of simple assumptions on release rates in its performance assessment calculations [R137, R133]. For licensing, the NRC needs a defensible model of radionuclide release in unsaturated fractured rock to assess compliance with 10 CFR Part 60.

Poorly worded

The requirement limiting the rate of release of radionuclides over the 10,000 year lifetime of the repository is found in 10 CFR Part 60.113. Determination of compliance with this requirement will require knowledge of inventories degradation mechanisms for spent fuel, HLW glass, and any other wastes that might be disposed in Yucca Mountain, such as greater-than-Class-C wastes. The study of interactions between the waste form and its environment is a key area for future waste package research because the rate of waste form dissolution and the solubility of waste form leachates will be strongly affected by components of the engineered system and their degradation products, groundwater chemistry, and host rock mineralogy. The release of carbon-14 and other volatile components from spent fuel as a source for vapor or gas phase transport is a concern for Yucca Mountain. The change in rates of leaching over time, including the effects of potential wet and dry cycling on the rates of leaching and dissolution, is a major concern. Extrapolation of laboratory data to actual site conditions and the testing and validation of leaching, solubility, and source term models is a priority research concern. The radionuclide source term under unexpected conditions such as volcanic intrusion or saturated groundwater flow is a concern. The NRC needs to be able to assess the importance of worst-case radionuclide release scenarios.

A.1.1.b <u>Research Interfaces</u>

<u>Waste Package Research</u>

The near field environment is critical to how the waste form degrades and the time period over which it degrades. The manner of container breach determines the conditions inside the waste container and thus the initial conditions for any effort to model the degradation of the waste form and migration of radinuclides into the environment. The waste package design and sacrificial components are critical to assessing the combined effects of design and natural environment on the degradation processes.

Closely related investigations in the engineered system performance area include investigations on interactions among water, rock, and vapor in tuff and on mathematical modeling of possible waste package environment conditions. The thermodynamic data base for chemical species and minerals that affect the waste package environment is being evaluated. In the performance assessment area, the NRC HLW research program is participating in natural analogue studies on the Koongarra uranium ore body in Australia [R066, R067, R168, R169]. The primary purpose of this research is the validation of radionuclide transport models, but models related to assessing controlled release will also be tested. Models of the long-term behavior of uranium (and spent fuel) in the environment will be tested by comparison with the chemistry of the groundwater and the mineralogy of the host rock at the Koongarra Ore Body. The models that will be tested by modeling the Koongarra source term are the same thermodynamic and reaction path models that the DOE is using to model the behavior of spent fuel at Yucca Mountain. Research on modeling the release and transport of carbon-14 in the repository environment is being undertaken in the geochemistry area of the NRC HLW research program.

Natural Analogues

overstated

Under those scenarios in which the waste package fails prematurely, excess heat may cause rapid oxidation of spent fuel and accelerate dissolution of the waste form and transport of radionuclides. This and other scenarios which result in degradation of the waste form and exposure to transport mechanisms may result in conditions analogous to those encountered in the formation and dissolution of uranium ore bodies. Research on these natural systems must be compared with laboratory work on irradiated reactor fuel to determine the degree to which the analogue studies caan be used to bound long-term predictions of transport of radionuclides.

International/National Cooperative Research/Review Activities

The elevated temperature planned for the US repository may limit the usefulness to the NRC program of work on spent fuel in other countries. Work undertaken by the DOE and industry groups within the US on characterizing spent fuel, waste glass, and "greater than Class C" wastes will form the largest portion of relevant data and will be reviewed as it becomes available. Specific work is being funded by the DOE to study the oxidation of irradiated fuel at Pacific Northwest Laboratory and leaching of irradiated fuel at Argonne National Laboratory. Add Canadian Fuel Projects

A.1.2 Systematic Regulatory Basis

A.1.2.a Identification of Key Technical Uncertainties

CDS/CDM

The Compliance Determination Strategy and Compliance Determination Methodology enc 5

March 23, 1993

NOTE TO: David Brooks, Leader
Hydrologic Transport Section

FROM: Rex G. Wescott Rex

SUBJECT: COMMENTS ON RESEARCH PROGRAM PLAN (NUREG 1406)

Attached are my comments on the RES Program Plan, specifically Appendices A.4, Hydrology and A.7 Performance Assessment.

My comments on Chapters 1 and 2 have already been incorporated into the comments transmitted by Joe Holonich.

All of these comments have been discussed with RES and resolved.

A revised Appendix C which was given to RES earlier is still under discussion.

A.4 Hydrology, Thomas J. Nicholson

A.4.1 Introduction

a. Background

Hydrology in this plan refers to surface and ground-water (i.e, both the unsaturated and saturated zones) flow systems and the related climatological forcing functions on those systems. The scale of the systems discussed vary from small-scale (i.e., 10's cm to meters) to the regional scale (i.e., kilometers). Hydrologic issues addressed in this research plan are ~~derived~~ three regions ~~directly from~~ (1) the performance objectives for ground-water travel time and radionuclide release to the accessible environment, and (2) the siting criteria of 10 CFR Part 60 [R002]. Ground-water flow and transport research is needed to support the 10 CFR Part 60 licens~~ing analysis~~ review of ground-water travel time and rates and amounts of radionuclide release to the accessible environment because of large ~~technical and regulatory~~ uncertainties in assessing compliance with these requirements.

understanding to evaluate compliance with

Ground-water research efforts can be divided into studies of flow and transport through saturated and partially saturated (i.e., unsaturated) media. With the elimination of the Hanford, Washington, and Deaf Smith, Texas, sites from current consideration, the program emphasis has shifted primarily to flow and transport concerns for unsaturated fractured rock.

The NRC staff needs to be capable of evaluating DOE's hydrologic site characterization program, conceptual models, and data bases used to model the Yucca Mountain Site. In addition, the NRC staff will assess DOE's hydrologic performance modeling and model validation efforts. ~~that address~~ Critical issues in the assessment expected to ~~such as~~ infiltration and ground-water recharge, preferential flow through persistent discontinuities, conceptual models for fracture/matrix flow, parameter estimation and radionuclide transport in both the liquid and vapor phases.

A significant percentage of ongoing hydrologic research in low-level radioactive waste (LLW) on characterizing and modeling flow and transport in unsaturated heterogeneous porous media [R184, R188, R189, R286, R287, R288, R281, R256, R284] is also applicable to HLW issues. Similarly, earlier hydrology research studies for nuclear reactor siting and for disposal of uranium mill tailings can also be useful for assessing HLW issues such as flooding potential and ground-water recharge rates.

~~The~~ Hydrology ~~area~~ is central to HLW licensing due to the fact that ground water is the most likely agent to cause degradation of waste package containment, radionuclide release from the engineered barrier system, and transport to the accessible environment. The DOE has asserted in the Yucca Mountain Site Characterization Plan [R156] that the arid climate and unsaturated conditions in the engineered barrier system will be favorable for maintaining containment and limiting radionuclide release and transport. These assertions will be very difficult for the NRC to assess due to a paucity of hydrologic experience in low-permeability unsaturated fractured rock. Adequate methods for measuring and estimating large-scale effective pneumatic, hydrologic and transport parameters for unsaturated fractured rock have yet to be developed [R186].

Theories about ground-water flow and radionuclide transport in unsaturated rocks [R075, R185] have been developed but have not been rigorously tested against field conditions similar to those at Yucca Mountain. The Fickian dispersion model commonly used in predicting transport in saturated media and used for many years in HLW performance assessments has been shown to be incorrect [R212]. Evaluation of numerous field tests done at different spatial scales showed the inadequacy of advection-Fickian-dispersion theory and provided a basis for proposing a new theory [R075, R185]. This process of extensive field testing of theories and models provides a way to develop a practical understanding of the limitations of flow and transport theories. This practical understanding of the precision, accuracy, limitations, and uncertainties of data and models provides a basis for establishing regulatory conservatism. Because there is very limited testing of parameter measurement methods and estimation techniques, site characterization approaches, conceptual models, and fundamental theories for flow and transport in unsaturated fractured rocks, there is little no scientific basis for establishing regulatory conservatism for Yucca Mountain's hydrogeology. Therefore, because hydrogeology is a key technical concern to each performance objective, uncertainties in the hydrogeology of unsaturated fractured rocks are critical uncertainties.

Provided that acceptable hydrogeologic parameter measurements, theories, and conceptual and mathematical models are developed for application to Yucca Mountain, the issues of applying them to the period of regulatory concern (i.e., currently EPA's 10,000 years) and the spatial scales of the local and regional hydrologic systems of Yucca Mountain would remain to be addressed. The stability of Yucca Mountain's present-day flow system could be affected by climate change and geologic activity such as faulting, earthquakes and magmatic intrusion. Research by NRC is needed to assess possible alternatives to scenarios models favored by DOE ~~for~~ to determine the effects of climatic change and geologic activity on ground-water flow in and around Yucca Mountain. Ground-water flow rates in unsaturated fractured rocks may be very sensitive to climate change and ~~variable~~ spatial ~~distributions of~~ variations in infiltration. Even if DOE or others in the scientific community develop acceptable mathematical models of ground-water flow and radionuclide transport in Yucca Mountain's unsaturated fractured rocks, the problem will remain of estimating effective parameter values from small-spatial-scale measurements, which may be the only feasible measurements at Yucca Mountain, to large-spatial-scale applications required for performance assessment. NRC research is needed to ~~examine the~~ assess ~~uncertainties involved in~~ possible approaches (particularly their inherent uncertainties) to using parameters measured on small spatial scales to estimate flow and transport over much larger scales of unsaturated, fractured, heterogeneous rock.

b. Related Technical Interfaces/Considerations

Research into hydrologic processes and conditions are related to other research studies dealing with coupled thermal, chemical, tectonic and mechanical processes. The considerations and technical interfaces of hydrology with related studies are provided below.

b.1 Coupled Processes

As discussed in the Engineered System discussion of section A.3, thermal perturbations arising from radioactive decay may have significant affects on the local repository hydrologic system. The role of fractures to either impede or accentuate preferential vapor and liquid flow and transport from the waste canister to the surrounding natural flow system will need to be assessed. The coupling of geologic, hydrologic, rock mechanical and geochemical processes and conditions will be needed in the performance assessment models. Development of stochastic flow and transport theory and improved numerical methods for solving highly non-linear flow and transport problems are being conducted in the low-level waste research program [R282, R283, R256, R292].

(including boundary conditions)

Similarly, research on tectonics, volcanism, and seismology that could affect hydrologic conditions needs to be undertaken in the geology area. The effects of volcanism and tectonic processes ~~and conditions~~ on the regional and sub-regional scale hydrologic systems are discussed in ~~the Geology discussions of~~ section A.6 (Geology). The analysis of coupled effects due to natural tectonic and volcanic events on radionuclide transport will require a regional and sub-regional ground-water flow model. ~~This work is anticipated following review of DOE's regional conceptual hydrogeologic models.~~ The role of earthquake events on ground-water levels and flow conditions are discussed in ~~the~~ section A.3.1 (Engineered System) ~~(A.3.1)~~. The results of this analysis will provide the licensing staff with technical bases to review DOE's regional hydrogeologic model.

Natural Analogues

need to be understood.

Analysis of ground-water pathways and conditions at natural analogue sites under investigation (e.g., Pena Blanca) are discussed in the Geochemistry section (A.5). The role of hydrologic and hydrochemical processes and conditions to interpret the evolution of a natural ore body as an analogue to regional scale transport has been pursued in the joint Alligator Rivers Analogue Project (ARAP). Radionuclide mobility studies are being done in the geochemistry area.

In order

This is ignored

recently,

International/National Cooperative Research/Review Activities

The international projects HYDROCOIN and INTRAVAL studied ground-water flow and transport modeling for a variety of rock types (e.g., fractured tuff, clay and granite cores, and heterogeneous desert soils) and flow conditions (e.g., shallow and deep unsaturated flow, hydrothermal rock core studies, and matrix diffusion and channeling in saturated fracture media) [R150, R148, R149, R151, R152, R180]. NRC staff and contractor results showed that it is possible to model saturated flow and transport in porous and fractured media [R183]. Radionuclide transport modeling, testing the validity of transport models (done in part under INTRAVAL), and comparing transport models are being investigated in the performance assessment area. A data set from unsaturated tuff at Yucca Mt is now an INTRAVAL test case and is being studied.
In 1992, the NRC staff signed a cooperative agreement (MOU) with the U.S. Geological Survey in the area of geoscience research related to radioactive waste management (excluding Yucca Mountain site studies). NRC research projects are actively reviewed during the biennial Tucson Workshops (I-VI) on

The purpose of this MOU with the USGS is to provide a forum for exchanging personnel in [illegible] geosciences dealing with waste management. (However [illegible] mountain studies are explicitly outside this MOU).

Unsaturated Flow and Transport Through Fractured Rock and before select National Academy of Sciences panels and subcommittees.

A.4.2 Systematic Regulatory Basis

a. Identification of Key Technical Uncertainties

a.1 CDS/CDM's

The fully developed "Compliance Determination Strategy" (CDS) narratives requiring research technical bases (i.e., levels 4 & 5) in hydrology are:

a.1.1 Potentially Adverse Condition: Changes to Hydrologic System from Climate

Precipitation and temperature change will affect the flux of water in the vadose zone which, in turn, dominates the likely consequences of adverse effect on canister degradation, radionuclide release, and radionuclide transport to the accessible environment. ~~Even though~~ the consequences of severely increasing the precipitation (doubling or more) do not appear to produce severe effects on performance when considered individually, at this time, the nature and timing of climatic change ~~may~~, when considered in the context of all other adverse effects on the performance of the repository, has yet to be proven to have little or no adverse consequence on performance.

However

The staff has identified a key technical uncertainty in this regulatory requirement as the;

> technical inability to predict the upper bound of precipitation (and subsequent infiltration) during the course of the next 10,000 years.

The staff believes that it not possible, at the present, to reliably determine precipitation and temperature in the 10,000 year future.

limits and combinations

a.1.2 Favorable Condition: Mineral Assemblages

Thermal alteration of mineral assemblages is a process which has the potential for causing noncompliance with the performance objectives. For example, drying could cause mineralogic changes to the less hydrated and potentially less sorptive phases (e.g., smectite alteration to illite). Changes in the capacity to inhibit radionuclide migration which may result from thermal alteration of mineral assemblages (e.g., dehydration, precipitation, and volume change, among others) are extremely hard to quantify and are the source of the uncertainty and risk associated with this key technical uncertainty.

The staff has identified a key technical uncertainty in this regulatory requirement as the;

> relationship between thermal environment and alteration of mineral assemblages comprising the host rock.

The staff believes that the identification, characterization, interpretation, and quantification, of the integrated results of such changes are extremely uncertain and currently beyond the state-of-the-knowledge.

a.1.3 Potentially Adverse Condition: Human Activity Affecting Ground Water

Future large-scale ground-water withdrawals near the site may accelerate the migration rates of radionuclides in the saturated zone along paths to the accessible environment. This may lead to violations of the three performance requirements 10 CFR Part 60.112, ~~since~~ (it will be very difficult to predict future ground-water withdrawals over the next 10,000 years.) It should be noted that if "special sources" of ground water are confirmed not to exist in the vicinity of Yucca Mountain, then there can be no violations of the ground-water protection requirements. Although drawdowns in unconfined aquifers do not propagate laterally as rapidly as those in confined aquifers, it should be noted that very small horizontal hydraulic gradients east and southeast of ~~the~~ Yucca Mountain would require little perturbations to significantly change ground-water travel times. Limited information to date from DOE indicates that very small reductions in hydraulic heads southeast of the site could significantly accelerate ground-water fluxes away from the site.

The staff has identified a key technical uncertainty as;

> adverse effects of future ground-water withdrawals on the ground-water flow system.

The staff believes that it may be impractical to predict the locations and extent of future ground-water withdrawals that may adversely affect the saturated leg of the ground-water flow system in the controlled area. Therefore, assessment of the existence of "special sources" of ground-water in the vicinity of Yucca Mountain needs to be fully addressed.

Other partially developed CDS narratives requiring research technical bases in hydrology are:

a.1.4 Nature & Rates of Hydrogeologic Processes Operating During the Quaternary, when Projected, Would Not Adversely Affect or Would Favor Isolation

The key technical uncertainty identified is that;

> there is no consensus on the nature of and the interpretation of paleohydrological evidence from the Quaternary that may have resulted in extraordinary recharge rates and locations during the Quaternary.

Reoccurrence of ~~similar~~ historical recharge rates and locations in the future ~~that~~ could adversely affect the saturated content of the vadose zone leg of the ground-water flow system in the controlled area.

The staff believes that a positive factor with respect to isolation is the climatic change since the Pliocene due to the formation of the "rain shadow" Sierra Nevada and Transverse Ranges of California. Also, the continuing subsidence of Death Valley is further lowering the basal altitude for the

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regional hydrologic flow system that terminates in the basin. The coupling of these geologic and hydrologic changes over time will need to be assessed to determine their potential effects on the site to isolate the waste.

a.1.5 <u>Potential for Changes in Hydrologic Conditions that Would Affect Radionuclide Migration</u>

This CDS has associations with other hydrologic CDS's dealing with climatic change, human activities, and tectonics. The effect of some or all of these conditions occurring together can be addressed under this CDS. Specifically, changes in the hydraulic gradients, ground-water velocities, storage, hydraulic conductivities, recharge and discharge fluxes and locations will need to be assessed.

The key technical uncertainty is defined as;

> the ability to predict the effects of combined conditions (human activities, climate changes, and tectonic changes) on the hydrologic system.

a.1.6 <u>Assessment of Compliance with Ground-Water Travel Time Performance Objective</u> Provide introductory ¶

Explanation of GWTT performance objective

Associated with this CDS are three technical uncertainties:

(1) There is great uncertainty in determining effective hydrologic characteristics (e.g., effective porosity, hydraulic conductivity) as a function of scale for the saturated zone.

(2) There is great uncertainty in determining or projecting infiltration rates as a function of time.

(3) There is great uncertainty in determining the relative proportion of fracture vs. matrix flow in the vadose zone, including identification of the conditions under which fracture flow will dominate.

a.1.7 <u>Potential for Perched Water Bodies to Form and Saturated Parts of a Repository in the Vadose Zone</u>

DOE data from borehole UZ-1 suggests that a persistent perched zone may exist at the bottom of this borehole, which was never intended to penetrate a saturated zone. Nearby borehole G-1 lost a tremendous amount of water when drilled. If the water encountered in UZ-1 is proven to be perched, then G-1 is the likely source of the water. One scenario of concern involves the creation of a perched zone within the repository at future time when waste may have been released but is still near the engineered barrier. The perched water could wash out these contaminants producing a slug of recharge to the water table.

The key technical uncertainty identified is that;

> to satisfy this regulatory requirement, the potential for future perched

water bodies must be predicted. To accomplish this, future climates must be predicted. Such predictions contain many uncertainties regarding method and approach. In addition, predictions would depend on a knowledge of the flow behavior of unsaturated fractured rock for different flux rates through Yucca Mountain. At present there is much uncertainty about how to collect unsaturated hydrologic property data for fractures and how to model unsaturated fracture flow. The NRC will therefore need to conduct independent research and modeling of climate prediction and unsaturated zone fracture flow.

a.2 User Needs Statement

The identified Research Needs (RN) in hydrology from the NMSS User's Need Statement are:

401 Discrimination between near surface and deep subsurface approaches for determining ground water flow paths and fluxes in unsaturated fractured rock at a variety of scales

402 Criteria to evaluate the appropriateness and accuracy of pneumatic tests (use of air or gases) for determining hydraulic parameters of water flow in the unsaturated zone

403 Evaluation of mathematical flow and transport models applicable to unsaturated fractured rock and the application of these models over a range of scales and heterogeneities

404 Experimental confirmation, over a range of scales, of the current concepts and modeling approaches of fracture/matrix flow in unsaturated fractured rocks

405 Appraisal of the applicability of existing mathematical models of hydrologically and chemically coupled flow and transport to model performance of a proposed HLW repository at Yucca Mountain

406 Assessment of climate models (general circulation models, GCMs) for a recommendation of the most appropriate one for long term future climate prediction

407 Evaluation of alternative conceptual models of the regional ground-water system (including saturated and unsaturated zone interactions) and the process of developing corresponding mathematical/numerical models

502 Appraisal of methods for using anthropogenic contaminants such as tritium, carbon-14, technetium-99, iodine-129, and chlorine-36 (bomb-pulse radioisotopes) directly to assess pre-waste-emplacement groundwater travel time (and resolution of fracture vs. matrix flow components) in the vadose zone

503 Knowledge of how the physical and chemical parameters of macroscopic groundwater samples compare with those for groundwater in the microscopic pores in unsaturated fractured rock

703 Validation of mathematical models

> It should be noted that these Research needs are just beginning to reflect key technical uncertainties identified from the SRA process. As more KTU's are developed the User need statements may be modified.

b. <u>Approach to Addressing Key Technical Uncertainties</u>

In response to the Nuclear Waste Policy Amendments Act (NWPAA) [R159], NRC-supported ground-water research has been redirected from an emphasis on flow and transport in saturated fractured rock to unsaturated fractured rock. Physical processes affecting radionuclide transport in tuffaceous rocks ~~will~~ is now being ~~be~~ investigated. The research will ~~should~~ identify processes that may affect radionuclide transport at Yucca Mountain, strive toward improved models of such processes, evaluate their relative importance under various radionuclide transport scenarios, and determine ~~decide~~ how they should be incorporated into performance assessment. The research will be performed to develop an understanding of fundamental processes that affect unsaturated flow and transport [R176] through field and laboratory study and numerical simulation. Numerical simulations will consider the possible environments from dry to fully saturated within which the processes may operate, the possible modes of multiphase transport under isothermal and nonisothermal conditions [R175], anticipated geochemical effects on the hydrologic system, and a range of temporal and spatial scales.

The general research approach will be to (1) do theoretical and experimental assessments of the physical processes that affect radionuclide transport and rank the processes in terms of their importance to radionuclide transport at various scales, (2) identify the uncertainties associated with the descriptions and predictions of these processes at laboratory scales and relatively small field scales, for ~~use in large-scale (i.e., Yucca Mountain) and long-term simulations~~, and ~~rank the uncertainties by their relative importance to licensing~~, (4) reduce these uncertainties through sharply focused theoretical and experimental studies in the laboratory and the field on scales ranging from decimeters to hundreds of meters, and (5) assess problems peculiar to large-scale flow and transport phenomena and identify large-scale research and site characterization that DOE needs to ~~be~~ do. ?

ok

3) Further uncertainties arise from the use of small scale measurements in large scale models

First, major physical and chemical processes affecting radionuclide transport need to be understood qualitatively and quantitatively on small scales; those scales at which laboratory and field experiments can be conducted within a reasonable time frame. Next, some insight into the sensitivity of these processes to the complex nature of the host rock can be derived from small-scale field experiments [R175]. Finally, large-scale studies will be necessary to address whether it is appropriate to apply information obtained in experiments that encompass at most a few decimeters and a few years to the real geologic environments at the scale of a repository at Yucca Mountain (i.e., regional scale). The research will assess the extrapolation, or scaling up, of information from small space and time scales to the full repository scale. The issue of measuring flow and transport parameters on small spatial and temporal scales and applying them to predictions on larger scales within a low-permeability environment is extremely difficult to resolve experimentally, but it can not be ignored because it is central to performance assessment. Research on natural analogues and ground-water flow and transport theory, in combination with small-scale field methods and statistical and fractal analyses, will determine the extent to which extrapolation is possible.

A.4.3 Research Activities, Accomplishments and Schedules

a. Continuing and Planned Research

Ongoing research on flow and transport in unsaturated fractured rock has provided information and guidance to the NRC staff. The Apache Leap Tuff

Site, located near Superior, Arizona, is a specially designed field experimental facility for examining flow and transport phenomena in unsaturated fractured tuff over a range of scales and hydrologic conditions [R289, R291].

The field and related laboratory studies at Apache Leap are part of an International Study on Validation of Geosphere Transport Models, INTRAVAL [R180, R289]. INTRAVAL provides an international forum for the comparison of different approaches to transport modeling, the validation of transport models, and the identification of uncertainties in hydrologic flow and transport modeling. Theories that enable one to predict the distribution of ground-water travel times, dispersivities, and other transport properties from measurements of hydraulic conductivities, in boreholes are being studied at the University of Arizona. Neuman [R212] ~~has developed a new~~ is developing theory (ies) for universal scaling of hydraulic properties in geologic material. Research will continue to test the applicability of this (ese) theory (ies) to HLW site characterization and performance assessment. RES continues to support National Science Foundation-directed cooperative work involving a number of agencies and contractors on understanding and modeling past and future climatic change. RES has recently help fund a National Research Council, Geotechnical Board's Panel on Fracture Characterization and Fluid Flow which addresses issues related to the ongoing Apache Leap Tuff site studies.

and other hydrologic properties

b. Key Accomplishments, Publications

Previous research, primarily at the University of Arizona, focused on testing site characterization methods and theoretical modeling studies. A field site in fractured welded tuff, known as the Apache Leap Tuff Site, has been developed to test field techniques and instrumentation for characterization of unsaturated flow conditions [R177, R289, R291] and to develop a better understanding of liquid and vapor flow and transport [R177, R076, R187, R190, R285]. Data sets for evaluating various fracture-matrix models at various scales are being developed [R257, R291].

Research results have shown that fracture flow can be a significant pathway [R176]. A modeling approach for discrete fracture flow was developed [R075, R185]. Examination of field instrumentation techniques and down-hole imbibition experiments indicated that fracture orientations, correlations, connectivities, in situ permeability measurements, and flux rates can be measured [R186, R289, R285, R291]. The studies indicated that matrix flow was extremely slow, and matrix flow and transport properties could be measured in blocks. Field studies have proven the existence of convective vapor movement through unsaturated fractured media and certain mechanisms that affect it [R285, R291].

b.1. University of Arizona accomplishments

Specific examples of key accomplishments at the University of Arizona studies at the Apache Leap Tuff Site are:

(1) Examination and evaluation of state-of-the-art characterization techniques for identifying physical and chemical properties in rock core samples (Haldeman, W.R., Y. Chang, T.C. Rasmussen and D.D. Evans, "Laboratory Analysis of Fluid Flow and Solute Transport Through a

Fracture Embedded in Porous Tuff," Water Resources Research, Vol. 27, No. 1, pp. 53-65, American Geophysical Union, Washington, DC, 1991);

(2) Evaluation of conceptual models and computer simulation codes related to near-field fluid and solute transport using laboratory data, discovery of important deficiencies and development of strategies for upgrading existing models [Neuman, S.P., S. Orr, O. Levin and E. Paleologos, "Theory and High-Resolution Finite Element Analysis of 2-D and 3-D Effective Permeabilities in Strongly Heterogeneous Porous Media" in Mathematical Modeling in Water Resources, Vol. 2, (Edited by T.F. Russell, R.E. Ewing, C.A. Brebbia, W.G. Gray and G.F. Pinder), Computational Mechanical Publication, Boston and Elsevier, New York, pp. 117-136, 1992; Rasmussen, T.C. and D.D. Evans, "Nonisothermal Hydrogeologic Transport Experimental Plan," NUREG/CR-5880, U.S. Nuclear Regulatory Commission, Washington, DC, September 1992];

(3) Application and evaluation of laboratory techniques for estimating rock properties for a range of thermal regimes (Rasmussen, T.C. and D.D. Evans, "Nonisothermal Hydrogologic Transport Experimental Plan," NUREG/CR-5880, U.S. Nuclear Regulatory Commission, Washington, DC, September 1992);

(4) Evaluation of earlier DOE-conducted field heater tests dealing with coupled processes effects including development of a strategy for conducting a field heater test at the ALTS (Rasmussen, T.C. and D.D. Evans, "Nonisothermal Hydrogologic Transport Experimental Plan," NUREG/CR-5880, U.S. Nuclear Regulatory Commission, Washington, DC, September 1992);

(5) Identification of important deficiencies in earlier field heater tests including evaluations of these earlier tests and scientific recommendations for conducting future tests (Rasmussen, T.C. and D.D. Evans, "Nonisothermal Hydrogeologic Transport Experimental Plan," NUREG/CR-5880, U.S. Nuclear Regulatory Commission, Washington, DC, September 1992);

(6) Development of a testing strategy for estimating pneumatic properties of in situ fractured rock as a precursor for estimating vapor phase flow and transport properties, and as an efficient method for examining fractured rock properties (e.g., fracture connectivity) over a range of scales (Guzman, A.G., M.J. Sully, S.P. Neuman and C. Lohrstorfer, "Determination of Pneumatic Permeability in Unsaturated Fractured Rock Using Steady State Analysis," Abstract H31E-10, AGU 1991 Fall Meeting Program and Abstracts, p. 184, 1991);

(7) Development of a universal scaling law for estimating ground-water dispersivity in various geologic media (Neuman, S.P., "Universal Scaling of Hydraulic Conductivities and Dispersivities in Geologic Media," Water Resources Research, Vol. 26, No. 8, pp. 1749-1758, American Geophysical Union, Washington, DC, 1990);

(8) Collection of statistically significant datasets of in situ rock

properties for use in stochastic models for estimating flow and transport parameters (Guzman, A.G., M.J. Sully and S.P. Neuman, "Spatial Structure of Air Permeability Estimates in Unsaturated Fractured Tuff," Abstract H51B-7, AGU 1991 Fall Meeting Program and Abstracts, p. 127, 1992; Vickers, B.C., S.P. Neuman, M.J. Sully and D.D. Evans, "Reconstruction and Geostatistical Analysis of Multi-scale Fracture Apertures in a Large Block of Welded Tuff," Geophysical Research Letter, Vol. 19, No. 10, pp. 1029-1032, 1992);

(9) Examination of field instrumentation and methods for sampling ground-water chemistry in the unsaturated and saturated zones;

(10) Evaluation of geochemical analytical methods for determining diagnostic chemical indicator values useful in confirming ground-water flux and travel times estimations; and

(11) Examination of validation issues associated with ground-water flow and transport assessment models and suggestions on formulating strategies for rigorous testing [Neuman, S.P., "Validation of Safety Assessment Models as a Process of Scientific and Public Confidence Building," Proceedings of the Third International High-Level Radioactive Waste Management Conference, Las Vegas, Nevada, April 12-16, 1992, pp.1404-1420, 1992; Tsang, C-F and S.P. Neuman (Editors), "Studies of Tracer Experiments in a Fractured Zone at the Finnsjon Research Area, Phase 1, Test Case 5," The International INTRAVAL Project, OECD, Paris, 221 pp., 1992].

Title 5.2. Climatic Studies Accomplishments

The NRC has supported (in part) studies concerning the use of general-circulation models to identify and evaluate causes and mechanisms of climate change and to evaluate the potential of general size circulation models for predicting future climates, including the impacts of such changes on the hydrologic regime. Results of these studies [R145, R146, R147] have shown that:

(1) Paleoclimatic data could be systematically evaluated to reconstruct coherent global paleoclimates at 3,000 year increments back to 18,000 years B.C.;

(2) Climate simulation models can successfully simulate, on the coarse grid scale, past climatic conditions as derived from paleoclimatic data;

(3) Climate simulation models can be used to synthesize paleoclimatic data to reproduce past climates in terms of global vegetative patterns that can be used as temperature, rainfall, and evapotranspiration proxies to estimate hydrologic regimes; and

(4) Climate simulation models are now capable of investigating potential future climatic conditions that might be caused by changes in the Earth's orbit around the sun, changes in the earth's albedo or from anthropomorphic changes in the atmosphere such as increased carbon dioxide levels.

A.7 Performance Assessment, *John D. Randall, Timothy J. McCartin*

A.7.1 Introduction

a. Background

Through NMSS, NRC will regulate and make licensing decisions concerning the disposal of HLW as dictated by the Nuclear Waste Policy Act of 1982 [R001] and its implementing regulations, 10 CFR Part 60, issued by NRC [R002], and 40 CFR Part 191, issued by the Environmental Protection Agency (EPA)) [R003]. EPA's regulation is a standard that sets limits on the total releases of radioactive material from a repository of HLW over a 10,000-year period following emplacement of the waste and sets groundwater protection and individual dose requirements on a repository for the first 1,000 years after HLW emplacement. NRC's regulation, 10 CFR Part 60, is a set of mandatory guidelines that DOE must follow in demonstrating compliance with the generally applicable environmental requirements of the EPA standard. NRC's regulation contains additional performance requirements and repository design and siting criteria to which DOE must adhere. Because of the long performance period of a repository, NRC expects DOE to base much of its demonstration of compliance with regulatory requirements on estimated predictions of repository performance using mathematical models of the phenomena that will affect repository performance.

The performance assessment calculations will require the ~~abstraction~~ incorporation of the current conditions as well as future conditions into mathematical models with which to represent repository behavior. These complex models will then be abstracted into models or modules which will be part of a total systems performance assessment code to calculate repository performance on a probabilistic basis. This ~~abstraction~~ process will contain a number of uncertainties due in part to an inability to completely characterize the site, extrapolation to future states of nature, incomplete understanding of repository phenomena and processes, and limitations of modeling approaches and implementations. Key technical uncertainties in performance assessment arise from the conceptual model representations of the natural and engineered systems, variability (temporal, spatial, etc.) in model parametric values, appropriateness of assumptions and simplification in the abstracted ~~mathematical~~ models, validation of mathematical models, ~~and~~ prediction of future system states (i.e., disruptive scenarios).

In addressing these uncertainties the NRC's long-range programmatic approach to research supporting modeling of HLW repository performance has three aspects: identification of modeling needs, development and implementation of models, and evaluation of the models. In this endeavor the performance assessment research program will make use of nearly all of NRC's HLW research projects to assist the development of conceptual models that describe repository behavior. The objectives of NRC's HLW performance assessment research program is to integrate results from the HLW research program's more specialized projects into mathematical models that can be used in HLW performance assessments, evaluate the validity of the mathematical models, and evaluate the affect of the models and their assumptions on repository performance (accomplished partly through participation in the Iterative Performance Assessment effort), and development and improvement of techniques for analyzing system behavior (i.e., sensitivity and uncertainty techniques).

The performance assessment of an HLW repository will place significant reliance on these mathematical models for arriving at conclusions with respect to the controlling phenomena to be considered, justification for simplifications made in performance assessments, and ultimately compliance with numerical regulatory criteria. The critical issue in the application of the models is whether or not their predictions over the long performance periods of HLW disposal will be realistic at best or conservative at worst. If the models' predictions are neither realistic nor conservative, there will be no basis for confidence in using them.

The models used must also have sufficient flexibility to provide NRC with the capability to assess DOE's demonstrations of compliance with all of NRC's quantitative regulatory criteria. Given the NRC HLW research program's emphasis on repository performance after closure, the types of determinations that have to be kept in mind while conducting the HLW performance assessment research program include but are not limited to: 1) waste package containment, 2) controlled release of radionuclides, 3) ground-water travel time, 4) anticipated response of the geomechanical, hydrogeologic, and geochemical systems to the maximum design thermal loading, and 5) releases of radionuclides to the accessible environment, 6) individual dose and groundwater protection requirements for the first 1,000 years after HLW emplacement.

b. Related Technical Interfaces/Considerations

Because a repository for HLW has never been constructed, information needed to support NRC's licensing decisions about HLW disposal has no direct experience as a base. The information is needed in order to reduce uncertainty (i.e. provide a basis for confidence) in making HLW licensing decisions. The NRC HLW research program is endeavoring to assemble as much of this new information as possible so that the NRC staff will be able to use it in its licensing decisions. Nearly all of NRC's HLW research projects have some impact on the development of conceptual models that describe repository behavior and the implementation of the mathematical models that will be used to estimate repository performance. As mentioned above a primary objective of NRC's HLW performance assessment research program is to integrate results from the HLW research program's more specialized projects into mathematical models that can be used in HLW performance assessments. abstracted

A.7.2 Systematic Regulatory Basis

a. Identification of Key Technical Uncertainties

a.1 Compliance Demonstration Strategy

NMSS through its Compliance Demonstration Strategy (CDS) has described the regulatory basis for performance assessment as follows:

"The overall system performance objective (10 CFR 60.112) stipulates that DOE provide, through tests, data, and analyses, reasonable assurance that the overall repository system (i.e., the geologic barrier provided by the site together with the engineered barriers incorporated in the system by design) will meet the "generally applicable standards for protection of the general environment from off-site releases from radioactive material in repositories" as set by the U.S. EPA in 40 CFR Part 191. This is the highest level of performance placed on the geologic repository and DOE is expected to utilize great amounts of site characterization and design data, in addition to some subjective information obtained through expert elicitation, to show compliance with this requirement. Moreover, DOE's compliance demonstration methods are expected to be based largely on predictive mathematical models of varying complexity.

The individual protection portion of the total system performance requirement focuses on the radiation dose received by any future individual for the 1,000 years following permanent closure. As stated in the existing EPA standards, such doses would be calculated considering "undisturbed performance of the disposal system." In its proposed conforming amendments to 10 CFR Part 60, the staff determined that for the purposes of compliance demonstration with the individual protection requirements, "undisturbed performance" is equivalent to consideration of "anticipated" processes and events under 10 CFR Part 60."

Based on the above requirements for determining cumulative releases and compliance with individual protection, the CDSs document the following key technical uncertainty topics:

1) Conceptual Model Representations

Conceptual model representations of the site are uncertain regarding the presence and origin of tectonic and magmatic/volcanic features, the flow and transport paths which are possible through the variably saturated, fractured, heterogeneous rock of Yucca Mountain, and the long-term stability and behavior of the engineered barriers.

2) Variability in Model Parametric Values

Modeling of natural heterogeneous systems like Yucca Mountain, require the assignment of parameters which vary both temporally and spatially.

3) Appropriateness of Assumptions and Simplifications in the Abstraction Proce

From the CDS: "To perform analyses of overall repository system performance, mathematical models and numerical computer codes will be developed to represent a conceptual understanding of the important processes operative at the site. Various assumptions and simplifications will be required in these models and codes so that the important processes (e.g., ground-water flow through unsaturated, fractured rock) can be represented as realistically as possible and yet not be so detailed as to be unworkable."

and the sensitivity of the CCDF to the particular mode

confidence in

4) ~~Validation of~~ Mathematical Models

degree of confidence in

The ~~validity of~~ the performance assessment models depends upon, but not limited to, the scales of representation, the processes under consideration, the type and extent of measurements available from the site. Provisions of 10 CFR 60.21 require that models be validated with data from an appropriate combination of such methods as field tests, in-situ tests, laboratory tests, and natural analog studies.

5) Prediction of Future System States (i.e., Disruptive Scenarios)

The identification and analysis of disruptive scenarios will be based on an understanding of processes that have operated and the events that have occurred in the past within the geologic setting of the site. Reasonable projections about those potential processes and events which could affect a geologic repository during the period of performance will place substantial reliance on expert opinion and result in substantial uncertainty.

a.2 User Needs Statement

701 Means to identify and screen scenarios

This user need addresses the key technical uncertainties related to conceptual model development (Key Technical Uncertainty (KTU) #1) and the prediction of future states of nature (KTU #5).

702 Efficient integration of mathematical models into HLW performance assessment methodology

This user need addresses the appropriateness of simplifications and assumptions that are used to allow complex processes to be evaluated in the context of a "total systems code" for application in sensitivity and uncertainty analysis (KTU #3).

703 Validation of mathematical models

This user need is synonymous with the technical uncertainty on the validity of mathematical models (KTU #4).

403 Evaluation of mathematical flow and transport models applicable to unsaturated fractured rock and the application of these models over a range of scales and heterogeneities

The uncertainties associated with spatial and temporal variation of natural systems (KTU #2) is addressed by this user need.

405 Appraisal of the applicability of existing mathematical models of hydrologically and chemically coupled flow and transport to model performance of a proposed HLW repository at Yucca Mountain

The appropriateness of assumptions and simplifications (KTU #3) are addressed by this user need.

b. Approach to Addressing Key Technical Uncertainties

In order to provide information that will be useful to NRC's HLW performance assessment capabilities, the specialized NRC HLW research projects need to continue to identify the relevant controlling phenomena. associated with a performance assessment of Yucca mountain. In its HLW performance assessment research program, NRC will approach the development of a computational methodology for evaluating repository performance and addressing the technical uncertainties by performing in three areas. These areas are: 1) identification of the disruptive scenarios applicable to the Yucca Mountain site and conceptual models for the dominant processes of the identified scenarios, 2) development or acquisition of computer programs that implement mathematical models for quantifying performance, and 3) evaluation of the models used through efforts to validate them with laboratory and field tests, natural analogue studies, and continued participation in such international programs as HYDROCOIN, INTRAVAL, and ARAP.

As mentioned above, the specialized NRC HLW research projects will contribute to the performance assessment research by identifying controlling phenomena in their respective areas. DOE funded research in these same specialized areas and DOE site characterization studies will further contribute to the identification of controlling phenomena.

In addition to the specialized areas, work is currently underway at both NRC and DOE with respect to conducting preliminary performance assessments of the Yucca Mountain site. One primary objective of this effort at NRC is to provide ~~demonstrate~~ the staff the capability to conduct and evaluate a total system-performance assessment. Secondary objectives, of direct benefit to the research effort, of the NRC Iterative Performance Assessment (IPA) effort are: 1) perform an evaluation of the adequacy of analytical tools, both methodologies and computational methods; and 2) obtain insights onto the need for further development of methodologies and computational tools (Codell, 1992). The IPA effort provides an invaluable "testing" ground for computational tools developed under performance assessment research in addition to providing a feedback mechanism to the specialized areas as to the importance of various scenarios and processes. The DOE also is conducting preliminary performance assessment analysis (Barnard, 1992) which should also provide insights for the performance assessment effort.

A.7.3 Research Activities, Accomplishments and Schedules

a. Continuing and Planned Research

NRC is continuing to develop a far-field HLW performance assessment methodology for analyzing HLW isolation in unsaturated fractured tuff. The current work can be divided into the following three subject areas:

1) Conceptual Model Development

Conceptual models will be identified for the physical processes which are anticipated to affect the ability of the HLW repository to safely contain the nuclear waste when subjected to the effects of the four disruptive scenarios. Activities will include the identification of important performance assessment issues related to scenario identification, and conceptual model formulation, implementation and solution. At this time the disruptive scenarios to be considered include seismo-tectonic and volcanic events, the climatic change scenario, and deliberate or inadvertent human intrusion. In addition to these disruptive scenarios, fracture-matrix interactions and two-phase flow in high temperature regimes are processes which have already been identified for examination.

[illegible], relatively simple, abstracted models must still be designed for efficient computation in the Total systems code, and revised to aid the abstraction process is still required

2) Computational Model Development

Recent advances in computer technology (~~i.e.~~ e.g., massively parallel machines) as well as advances in computational techniques (~~i.e., adaptive grid construction)~~ provide a means for increasing the complexity of current models and thereby reduce the uncertainty inherent in simplifying assumptions. ~~Reactive transport and colloids have already been identified as topics for further investigation.~~

3) Model ~~Validation~~ confidence

Effort is currently underway to develop a methodology for evaluating ~~or "validating"~~ the long-term predictive models that will be used to make licensing decisions. Data sets from a variety of sources (i.e., laboratory and field investigations and natural analog studies) will be explored to support the methodology and to be used to demonstrate the utility of the developed methodology.

Additionally, the ~~validity of~~ degree of confidence fluid flow and contaminant transport models applied to radioactive waste disposal is being investigated through INTRAVAL. The ARAP has developed an extensive hydrological, geochemical, and geological data base and models of physico-chemical processes occurring at the Koongarra ore body. Alternative approaches for modeling radionuclide transport will be compared with standard approaches in the ARAP.

overstatement of value

b. Key Accomplishments

- Development of Sampling Methods for Sensitivity and Uncertainty Analyses (NUREG/CR-3624, A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and

Random Samples for Use With Computer Models, 1984)

- Evaluation of Vapor-Phase Transport (NUREG/CR-4693, Assessment of Radionuclide Vapor-Phase Transport in Unsaturated Tuff, 1986)

- Development of a Performance Assessment Methodology (NUREG/CR-5701, Performance Assessment Methodology for High-Level Radioactive Waste Disposal in Unsaturated, Fractured, Porous Media, 1991) The methodology provides a calculational framework for the iterative performance assessment effort.

- Development of a Ground-Water Flow Model (NUREG/CR-5536, A Dual-Continuum, Three-Dimensional, Ground-Water Flow Code for Unsaturated, Fractured, Porous Media, 1991) The DCM3D computer program provides a conceptual model for analyzing the fracture matrix interaction.

- Development of a Radionuclide Transport Model (NUREG/CR-5618, User's Manual for the NEFTRAN II Computer Code, 1991)

- Conceptualization of the Processes in Unsaturated, Fractured Tuff (NUREG/CR-5495, Conceptualization of a Hypothetical High-Level Nuclear Waste Repository Site in Unsaturated, Fractured Tuff, 1991) The NEFTRAN II computer program provides an efficient calculational tool for simulating radionuclide transport for sensitivity and uncertainty analysis.

- Development of a Two-Phase Flow and Radionuclide Transport Model (NUREG/CR-5991, PORFLOW: A Multifluid Multiphase Model for Simulating Flow, Heat Transfer, and Mass Transport in Fractured Porous Media, 1993) The PORFLOW computer program will provides a capability for analyzing near-field, transient transport effects.

c. <u>Schedules</u>

- Identification of relevant performance assessment issues (April 1993)
  This information will be used to guide the development and/or acquisition of computer models for incorporation into the performance assessment methodology to assure that the methodology has the sufficient capability to examine the relevant issues for the Yucca Mountain site.

- NUREG/CR report on advanced computational methods in performance assessment (August 1994)
  Improvements will be made to the computational tools of the methodology to allow for incorporation of more complex phenomena and the relaxation of modeling simplifications, thereby, reducing uncertainty in performance assessment calculations.

- NUREG/CR report on the formation and transport of radiocolloids (December 1994)
  This report will provide information on the importance of colloids in relationship to its inclusion in the calculation of overall performance.

- NUREG/CR report on model validation methodology (December 1994)
  This report will provide a methodology for building confidence in the conceptual models being used to evaluate repository performance. The methodology will identify how various types of information (i.e., field and laboratory data and natural analog studies) could/should be used to support models used for making regulatory decisions.

- NUREG/CR report which documents models used for analyzing disruptive scenarios (1996)
  Models used for modeling disruptive scenarios will be documented for use in the iterative performance assessment effort.

A.7.9 Schedule

Table A.7: HLW Performance Assessment Research Schedule

Products	User Needs	CY93	CY94	CY95	CY96	CY97	CY98	CY99	CY00	CY01
<u>Repository Schedule</u> Surface testing ESF Operation Insitu testing										
Identification of relevant performance assessment issues	701, 702	X								
Incorporation of existing mathematical models into performance assessment methodology	702	X	X							
Evaluation of advanced computational methods	702	X	X							
Incorporation of NRC-supported research results into performance assessment methodology	702	X	X	X	X					

Table A.7: HLW Performance Assessment Research Schedule										
Products	User Needs	CY93	CY94	CY95	CY96	CY97	CY98	CY99	CY00	CY01
<u>Repository Schedule</u> Surface testing ESF Operation Insitu testing										
Methodologies for validation of models	703, 403, 405	X	X							
INTRAVAL Participation	703, 403, 405	X	X							
Evaluation of formation and transport of radiocolloids	701, 702, 405	X	X							

Additional References

Codell, R., et al., "Initial Demonstration of the NRC's Capability to Conduct a Performance Assessment for a High-Level Waste Repository," NUREG-1327,United States Nuclear Regulatory Commission, Washington, D.C., May 1992.

Barnard, R.W., et al., "TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain," SAND91-2795, Sandia National Laboratories, Albuquerque, New Mexico, September 1992.