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STUDY PLAN FOR DIFFUSION TEST IN THE EXPLORATORY SHAFT

YMP-LANL-SP 8.3.1.2.2.5, R0

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1.0 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose

The diffusivity coefficients for nonsorbing ions in aqueous solutions will be measured in this study under in situ conditions in the exploratory shaft facility (ESF). The data from this study will help in computing accurately the retardation resulting from diffusion of $^{99}TcO_4^-$ and $^{129}I^-$, which are important long-lived radioactive waste species. In addition, the data will be compared with the results of diffusivity coefficient measurements from laboratory experiments that use tuff samples. The comparison will help to indicate the validity of extrapolations from laboratory measurements of diffusivity coefficients to in situ measurements.

1.2 Use of Results

The data from this study will be used as part of the information required by the Yucca Mountain Project (YMP) to calculate releases to the accessible environment. These data will help establish an accurate model of the aqueous transport and retardation of radionuclides in the unsaturated zone at Yucca Mountain.

A second use of the results will be determining the reliability of modeling calculations. The TRACR3D (Travis, 1984) code is being used to help design the diffusion test, and the data that result will help test the diffusive model that forms part of the TRACR3D code. Diffusivity coefficients are being measured in the laboratory with samples of tuff from Yucca Mountain. The data from these measurements will be corrected by means of mathematical models to conditions of lithostatic load and moisture content at the repository depth and below. The corrected data will be compared with the in situ measurements to help validate the computer codes incorporating the mathematical models.

The spatial variations of the geologic media and their geophysical properties at Yucca Mountain may result in requests from the Sandia National Laboratories (SNL) performance assessment division for diffusivity coefficients in materials or in locations that differ from those used for the two in situ determinations. The comparison of laboratory data with field data will permit extrapolations (from laboratory measurements on other tuff samples or extrapolations to different depths along the likely transport paths) to be made with much greater confidence in the accuracy of the results than would be possible without the laboratory and field data comparisons.

1.3 Resolution of Performance Issues

The rationale for the YMP site characterization program is presented in Section 8.1 of the consultation draft of the YMP Site Characterization Plan (SCP)(DOE, 1988). The issue-based strategy was guided by an issue identification procedure to define the activities needed to resolve the issues. The issues were divided into performance issues and design issues; the work in this study plan applies only to performance issues.

The primary issues that will use the data from this study are the following:

Issue 1.2 Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?

Issue 1.1 Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?

The activity described in this study plan to obtain in situ diffusion data is one of the activities being undertaken to meet Information Need 1.2.1: "Determination of doses to the public in the accessible environment through liquid pathways."

1.4 Tie to Regulations

The results of this study are expected to provide supporting information concerning compliance with parts of three federal regulations.

The measured diffusivity coefficients will serve to quantify the extent to which Yucca Mountain satisfies the favorable siting condition specified by the U.S. Department of Energy (DOE) in 10 CFR 960.4-2-2(b) (2):

> "Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides,..."

The TOSPAC code will use the data from this test to calculate compliance with the U.S. Nuclear Regulatory Commission (NRC) regulation 10 CFR 60.112, which states that the geologic repository system performance following permanent closure shall meet the system performance objective for limiting the release of radionuclide material to the accessible environment as required by 40 CFR 191.13.

The comparison of the laboratory and in situ measurements of diffusivity coefficients will help to increase the confidence that laboratory measurements and extrapolations from models give accurate results, as required of the DOE by 10 CFR 60.101(a) (2).

2.0 RATIONALE FOR STUDY

The Project does not presently plan to penetrate the Calico Hills unit with the ESF. However, the requirement for flexibility to sink the shafts and perform site characterization testing in the Calico Hills will be maintained. In the event that the Project decides to penetrate the Calico Hills, the planned diffusion test can be initiated. Therefore, this study plan describes diffusion experiments in both the Topopah Spring and Calico Hills tuff. If the Project is not permitted to penetrate the Calico Hills, the portions of this study plan pertaining to the Calico Hills will not be performed.

The need for this test is based on the observation that two of the long-lived fission products in high-level radioactive waste, technetium-99 and iodine-129, are likely to exist under aqueous flow conditions at Yucca Mountain as the nonsorbing chemical species TcO_4^- (Daniels et al., 1982) and I^- (Wolfsberg et al., 1979). Assessments of the performance of a nuclear waste repository at Yucca Mountain must address the disposition of these species. The SNL performance assessment division considers diffusion to be a potentially important retardation process when the hydrologic flux through the unsaturated zone exceeds 1 mm/yr. Therefore, a complete description of the repository performance is likely to require an understanding of the effects of diffusion.

Measurements of diffusion are under way in laboratory studies (see Study 8.3.1.3.6.2). However, lithostatic load and in situ saturation, which are important characteristics for effective diffusivity data, may deviate in the laboratory from those obtainable in field studies. In situ measurements of effective diffusivity will be undertaken for comparison with laboratory data to provide the most accurate data for the repository performance modeling efforts.

2.1 Modeling Studies and Constraints

An in situ study of diffusion in the saturated granite at the Stripa Mine in Sweden was conducted by Birgersson and Neretnieks (1982). They introduced water-soluble tracers into a borehole and used a pump to counter hydrostatic pressure for 3 months while the tracers diffused in a connected pore system; then they overcored the borehole and analyzed the resulting core for tracer concentrations. An in situ study of diffusion in the tuffs at the Yucca Mountain ESF would be similar in principle to the Stripa Mine work. The unsaturated conditions, however, eliminate the need for a pump and raise questions about the effects of water that might be used to introduce the tracers into the borehole or to cool the overcore bit. Modeling studies were performed to evaluate the feasibility of diffusion measurements in unsaturated tuffs at Yucca Mountain. The results of this modeling are given here. The full report should be consulted for additional details (Birdsell et al., 1987).

The schematic of the borehole and the tracer source used in the modeling studies is shown in Figure 1. The tracer source was taken to be 10 mL of water containing 1 g tracer/mL. The TRACR3D code (Travis, 1984), discussed in the study plan for Retardation Sensitivity Analysis, Study 8.3.1.3.7.1, was used to calculate tracer concentration profiles for times as long as a year in two tuffs. One tuff was assigned porosity, initial saturation, and permeability values characteristic of the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain. The second had values for these three parameters that were characteristic of the tuffs of Calico Hills. In most cases, the diffusion coefficient was given the value 1×10^{-7} cm^2s^{-1}. A diffusion coefficient of 1×10^{-6} cm^2s^{-1} was used for comparison in one set of calculations to determine the effects of a larger diffusion coefficient.

One question that was investigated in the modeling studies was the effect of introducing the tracer in an aqueous solution. The tuff immediately around the emplacement position would be saturated initially. The modeling studies compared tracer movement as a function of time into unfractured, porous tuff from a source whose initial saturation and porosity were the same as those of the surrounding matrix where the tracer was introduced under saturated conditions. For the Topopah Spring tuff, the tracer would diffuse approximately 7 mm farther into the tuff from the aqueous solution, after a year's time, than it would move in the ideal case from a source at the same saturation and porosity as the surroundings. The difference for the tracer movement in Calico Hills tuff is approximately 5 mm, because the Calico Hills tuff is more saturated initially than the Topopah Spring tuff. These calculations indicate that the introduction of tracers in an aqueous solution will affect the measured results to an imperceptible extent.

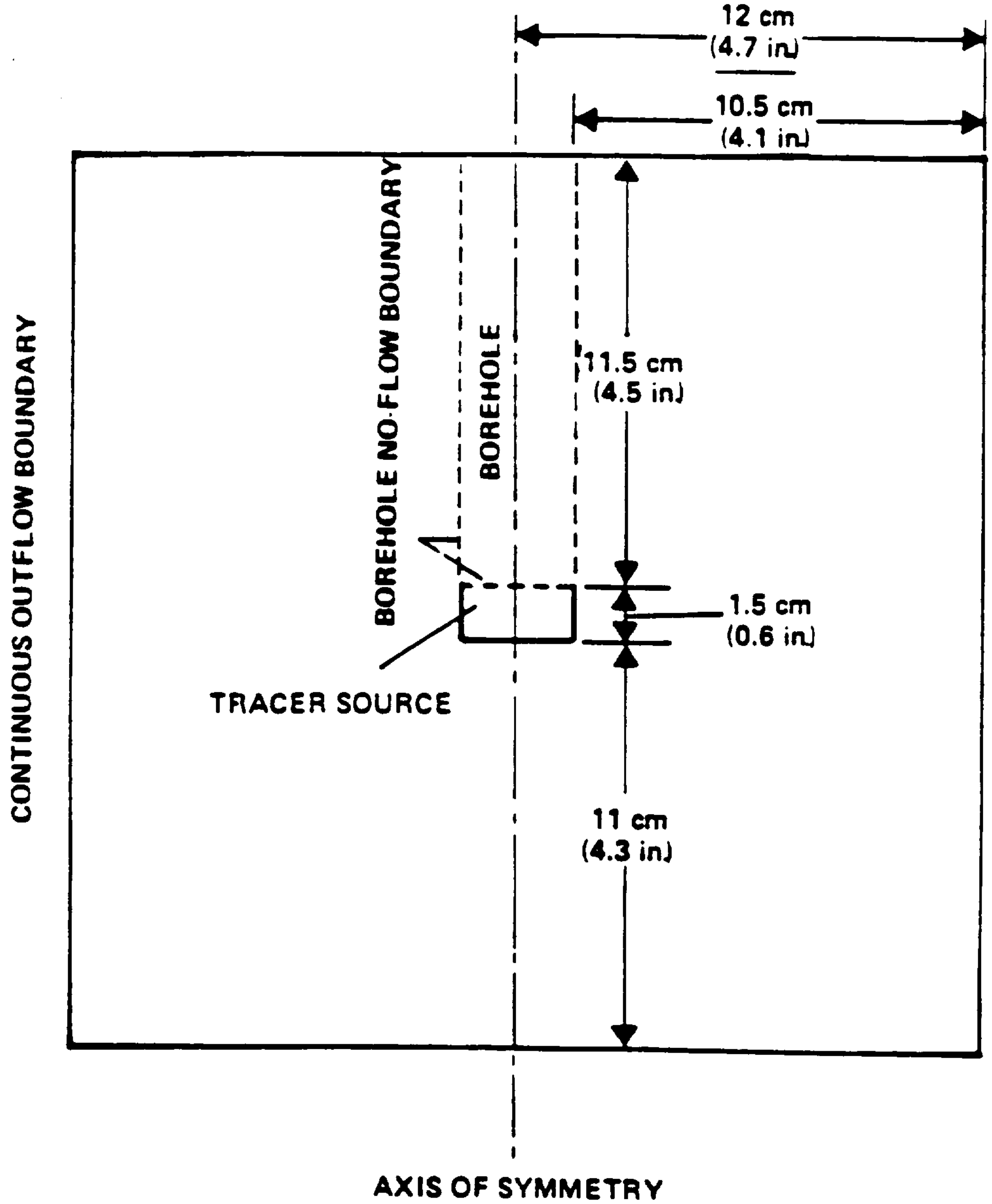

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Figure 1. Diagram of the borehole, the source region, and the surrounding matrix used for the pure diffusion and the diffusion with advection simulations.

Another effect that must be considered is the possibility of advective transport, as well as diffusion, when the tracer is introduced in an aqueous solution. Calculations provided comparison of transport under pure diffusion conditions and diffusion combined with advection in both tuffs. Advection was a minor perturbation in the Calico Hills tuff, but the calculation of the results of the in situ test in the Topopah Spring tuff is likely to include correction for advective transport. The in situ tests will be carried out with a minimum pressure differential between the alcove and the tracer emplacement site to maximize diffusive transport relative to advection.

Another question that was investigated in these modeling studies was the effect of a nearby fracture on the results. Modeling was done with a horizontal fracture 11.5 mm beneath the tracer source. In the Calico Hills tuff, the initial saturation difference between the source and the matrix was too low to force fluid toward the fracture. Consequently, the high permeability of the fracture had little effect on the overall transport after a year's time. The effect of a horizontal fracture in the Topopah Spring tuff was greater than that in the Calico Hills because of fluid flow in the fracture. The effects of the fracture diminished with time. After 6 months, the tracer concentration profiles were shifted only slightly downward and outward near the fractures relative to the computer simulation without a fracture.

The final question investigated in these modeling studies was the effect of a water-cooled overcoring bit operating 147 mm from the center of the tracer source. The calculations indicate that the water from such a bit will not alter the test results significantly, as long as the value of the diffusion coefficient is low.

The modeling studies show that the experimental design proposed for this test is appropriate for determining in situ diffusion coefficients, because the test results will be sensitive to the value of the diffusion coefficient.

2.2 Potential Site Impacts

The potential impacts on the site that result from this test are the construction of alcoves at two locations in the underground test facility and the drilling of two core holes in each alcove. The drilling fluid will be air. Each core hole will be approximately 10 m deep and 0.3 m in diameter when the underground phase of the work is complete. All of the tracers to be used are planned to be removed in the core that is retrieved. The core holes can be backfilled at the conclusion of this test to minimize residual impacts on the underground facilities.

2.3 Need for Simulation of Repository Conditions

The purpose of this test is to determine effective diffusivity values in Yucca Mountain tuffs at the repository level and below under in situ conditions. The field conditions most important for this test are the lithostatic load and the pore saturation. Diffusion can be measured under laboratory conditions using specimens of tuff similar to those employed for the field determinations. However, when the tuffs are removed from their underground locations, neither saturation nor lithostatic load can be duplicated reliably under laboratory conditions. Therefore, this test will be performed under conditions that resemble as much as possible the long-term repository storage conditions so that the data supplied for performance modeling will accurately represent postemplacement conditions.

2.4 Required Accuracy and Precision, Limits of Methods, and Capability of Analytical Methods to Support the Study

The basic measurements in this test are the determinations of the quantities of tracers in segments of the tuff that surrounds the tracer emplacement hole. The initial concentration of a tracer such as Br^- is expected to be 1 g/cm^3. The tests have been modeled (Birdsell et al., 1987) in terms of concentration profiles, with the limit of analytical sensitivity taken to be 10^{-3} g/cm^3. The modeling indicates that useful results can be expected under this assumption. Bromide ion detection has been obtained to 20 ppb by anion chromatography, which is the analytical technique that is planned for use in this test. The analytical sensitivity will not be a limiting factor in obtaining useful results. Additional discussion of experimental tracer measurements and the resulting effective diffusivity is given below as part of the detailed test description.

2.5 Time Required versus Time Available to Complete the Study

This test will require approximately 24 months to complete following the completion and availability of drilling alcoves in the main drift area and at the bottom of the exploratory shaft (ES-1). This test will be carried out concurrently with other tests in the underground facilities. Thus, the duration of this test will not be constrained by the time available.

3.0 DESCRIPTION OF TESTS AND ANALYSES

The Project does not presently plan to penetrate the Calico Hills unit with the ESF. However, the requirement for flexibility to sink the shafts and perform site characterization testing in the Calico Hills will be maintained. In the event that the Project decides to penetrate the Calico Hills, the planned diffusion test can be initiated. Therefore, this study plan describes diffusion experiments in both the Topopah Spring and Calico Hills tuff. If the Project is not permitted to penetrate the Calico Hills, the portions of this study plan pertaining to the Calico Hills will not be performed.

3.1 General Approach

This test will determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of two of the tuffs that ES-1 will penetrate. The two tuffs are the Topopah Spring welded unit at the main underground facility and the Calico Hills nonwelded unit at the bottom of ES-1. Tracers will be introduced into boreholes in each of these tuffs and permitted to diffuse. The emplacement locations will be overcored, and tracer concentrations will be measured as a function of the distance from emplacement. The tracer concentration data will be used to derive the diffusivity coefficients for each of the tuffs in which the tests are performed. The Topopah Spring unit is likely to be highly fractured at the test location. The overcored tuff will be examined to determine whether diffusive transport of nonsorbing species is nonlinear because of fracture boundaries in these unsaturated tuffs. Finally, the in situ measurements will be compared with diffusivity coefficients determined in laboratory measurements of similar tuffs (Study 8.3.1.3.6.2).

3.2 Test Methods

This test requires drilling procedures and apparatus to permit emplacement of the tracer solution in the appropriate location, a method to recover the core into which the tracer has diffused, a technique to section the recovered core, and an analysis procedure for each tracer that is used. The methods required for this test are being developed in prototype tests to be conducted in G-Tunnel at the Nevada Test Site (NTS). An apparatus has been designed to deliver a 10-mL volume of tracer solution to the bottom of a 10-m borehole. Nonvolatile tracers will be used. Overcoring will use air-cooled bits, and sectioning will be performed dry with a diamond-studded wire to preserve the in situ tracer concentrations. The core sections will be crushed and then leached with water, and the tracers will be assayed in the leachate. Procedures for the techniques and analyses that are required will be written at appropriate times. The data resulting from this test will be used in predicting the long-term performance of the site as a nuclear waste repository. These data, then, are classified as YMP Quality Level I. The work will be performed in accordance with the Los Alamos National Laboratory (LANL) Quality Assurance Program Plan, LANL-NNWSI-QAPP. All computer codes will be validated and verified according to procedure. Table 1 lists the detailed technical procedures (DPs) that will be used in this activity.

TABLE I

DETAILED TECHNICAL PROCEDURES TO BE USED

DP Number	DP Title	Effective Date
TBD[a]	Borehole Overcoring	b
TBD[a]	Diffusivity Analysis	b
TBD[a]	Laboratory Tracer Concentration Analysis of Core	b
TBD[a]	REECO Drilling and Coring Procedure--Vertical Holes	b
TBD[a]	Tracer Injection Tests	b
NWM-USGS-GP-10, R0	Borehole Video Fracture Logging (Vertical Holes	4/12/85
TWS-QAS-QP-3.1, R0	LANL YMP Computer Software Control	9/21/88
TWS-MSTQA-QP-14, R1	Research and Development (Experimental) Procedure	2/14/86

a. TBD = to be determined.

b. These procedures will be written after prototype testing is completed at the end of 1989. The prototype diffusion test is being performed as described in the draft Prototype Test Plans, Volume 1, (FY-88 Funded Tests) (May 1988).

3.3 Diffusion Equations and Measured Parameters

The measured tracer concentrations as a function of distance from emplacement will be analyzed in terms of the diffusion equation for solute transport radially through a long cylinder of a porous geologic medium in the absence of fluid flow (Crank, 1975):

$$\frac{\partial c}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(\frac{rD\partial c}{\partial r}\right), \tag{1}$$

where

c = concentration of the tracer,
t = time,
D = diffusivity, and
r = distance from the source.

The use of this equation is predicated on the absence of tracers in the tuff at the start of the experiment and on a constant tracer concentration in the source solution.

The diffusivity (D) can be defined by the following relation:

$$D = D^i \frac{\varepsilon\alpha}{\tau^2} \frac{1}{\left(\varepsilon + K_d \rho_\beta\right)}, \tag{2}$$

where

D^i = ionic diffusivity,
ε = water-filled porosity,
α = constrictivity of the pore space,
τ = tortuosity of the pore space,
K_d = sorption distribution coefficient, and
ρ_β = dry bulk density.

Ionic diffusivity values are tabulated in standard reference sources, such as the Handbook of Chemistry and Physics (Weast, 1984). The water-filled porosity and dry bulk density of the tuff in which the experiment is performed will be measured in pieces of tuff removed from the vicinity of the diffusion measurement. The sorption distribution coefficient will be measured in laboratory experiments for each tracer and each tuff. Thus, the solution of the diffusion equation (Equation 1) in terms of measured tracer concentrations as a function of distance for a given time will result in a diffusivity value that can be interpreted as the ratio of (α/τ^2), which is a physical characteristic of the water-filled pore space in contact with the aqueous solution containing the tracers. Table 2 lists the parameters to be measured in this test.

3.4 Data Analysis and Statistical Sensitivity Analysis

The tracer concentration data from these experiments will be analyzed in terms of computer-derived solutions of the diffusion equation (Equation 1). Numerical integration of the equation is a small-scale computer problem as long as the

TABLE 2

MEASUREMENT PARAMETERS FOR THE DIFFUSION TEST[a]

Measured Data Items	Test Method	Derived Parameters	Expected Values
Distance of tuff sample from borehole	Ruler	--	0 to 5 cm (0 to 6 in.)
Tracer concentrations in tuff samples and source solutions	Analytical chemistry methods	$\frac{C}{C_o}$	1 to 95%
Diffusion time	Calendar	--	3 to 12 mo
$\frac{C}{C_o}$ versus r as f(t)	All of above	D	10^{-7} cm^2/s
Total porosity[b]	Mercury penetrometry	--	5 to 15%
Neutron diffusion and attenuation	Neutron probe	Moisture content	1 to 5 vol%
Dry mass of a measured geometric shape	Ruler and balance	ρ_B	2.0 to 2.2 gm/cm^3
Tracer concentrations in tuffs and equilibrated solutions	Batch sorption measurements	K_d	0 to 10 mL/g

a. All items in this table will be used to derive $\frac{\alpha}{\tau^2}$, Equation 2.

b. Water-filled porosity (ε) will be derived from total porosity and moisture content.

geometry of each experiment is relatively simple and tracer transport depends only on diffusion. If the data show flow associated with fractures in the diffusion volume, solution of the diffusion equation will require finite-difference methods.

The TRACR3D code was used to derive estimates of tracer concentrations that may be obtained in this test. The purpose of these simulations was to determine the sensitivity of the diffusivity values, calculated from the data, to the uncertainties in the measurements. The following assumptions were made. The borehole geometry was that shown in Figure 1. The tracer solution, with a porosity of 0.99 and a saturated water content, diffused into Calico Hills tuff, which was a homogeneous medium with a porosity of 0.33 and a water content of 0.7. At the conclusion of an in situ test, the borehole was overcored. The resulting core, with a diameter ~30.5 cm (12 in.), was cut to obtain a disk that extended 5 cm (2 in.) downward from the bottom of the borehole. The disk was cut in half parallel to the symmetry axis. One of the resulting half-disks was cut parallel to a radius of the

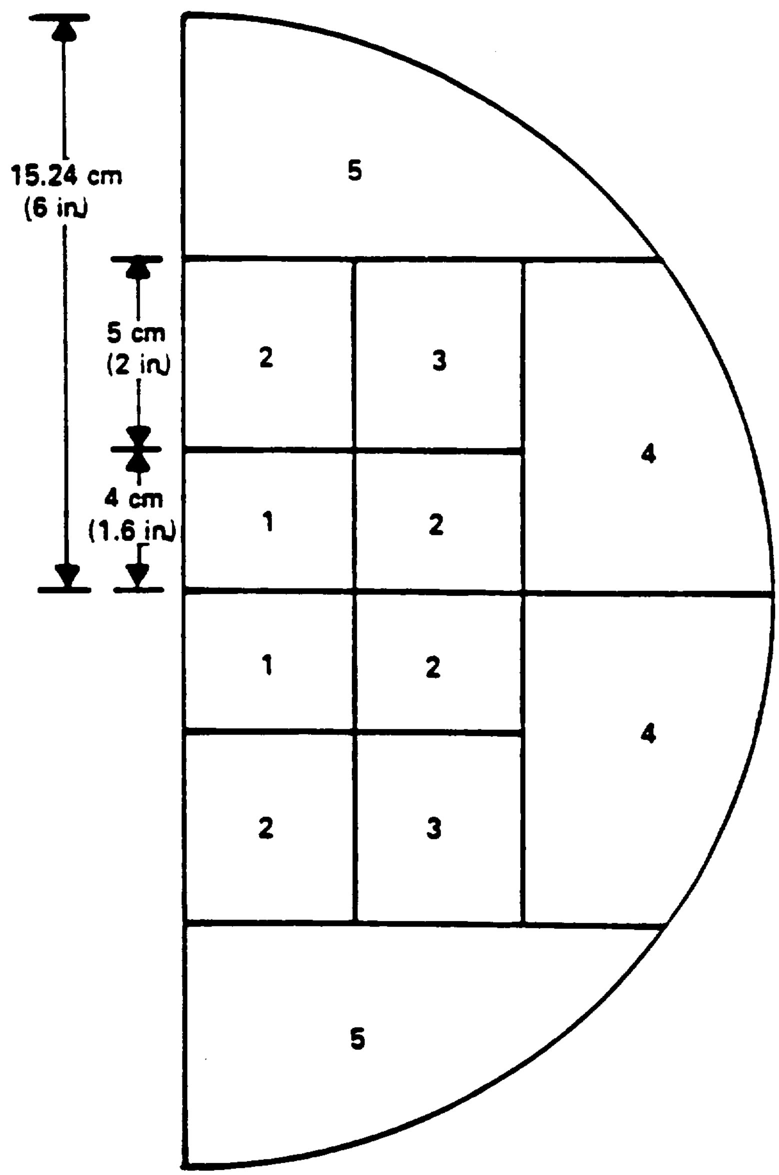

Figure 2. Diagram of sample locations in a half-disk of core immediately below the borehole. Samples labeled with the same number, e.g., 2, are expected to have the same tracer concentrations. In the half-disk of core immediately below that shown, the sample numbers 6, 7, 8, 9, and 10 correspond to the locations in the diagram labeled 1, 2, 3, 4, and 5, respectively.

original right cylinder to form two half-disks, each 2.5 cm (1 in.) thick. Each of these half-disks was subdivided as shown in Figure 2 to produce a total of 24 pieces of core for analysis. The TRACR3D results were integrated over the 10 sample types, of which 5 are shown in Figure 2, and the remainder are located in the half-disk below. The results of the calculations for a diffusion test that lasts 9 months are shown in Figure 3. The abscissa is the $\log_{10}$ of the diffusivity, and the ordinate is the $\log_e$ of the relative expected total amount of tracer in the sample divided by the original concentration of tracer in the source. The curves are labeled with the sample numbers from Figure 2.

The effects of uncertainties in the measurements of tracer concentrations are shown in Figure 4. Both axes show $\log_{10}$ of the diffusivity. The dotted line is the true diffusivity, and the other three curves show the lower bounds on the estimated diffusivity values that could be expected for errors of 15%, 30%, and 50% associated with the individual measurements. The statistical test from which these curves are derived bounds the range of diffusivity values that can be rejected with a probability of 0.95 as a function of the true diffusivity in a test designed to reject the true value only 5% of the time.

The bulge in the curves in Figure 4 near diffusivity values of 10^{-6} can be explained qualitatively by referring to the curves in Figure 3. The curves at the left side of Figure 3 increase so rapidly that diffusivity values can be obtained with very little uncertainty. Around diffusivity values of 10^{-6} the curves flatten, so the measured tracer concentrations cannot be used to determine diffusivity values as precisely as at the extremities. This relative lack of certainty results in the bulges that occur in the curves in Figure 4. Overall, however, the patterns in Figure 3 make different diffusivity values easy to detect in a homogeneous medium, even with large measurement errors.

3.5 Facilities and Equipment

This test requires the drilling of four boreholes, each of which will be about 10 m (33 ft) long. The drilling should be done with air to avoid adding drilling water to the pores, where diffusion will occur. The drill-hole diameter should be 2 to 10 cm (1 to 4 in.). Packers of appropriate size for the drill holes will be required to isolate the diffusion volume from the remainder of the underground environment. The maximum number of diffusion experiments that would be run simultaneously is two; therefore, no more than two packers will be needed. Table 3 summarizes the required items.

3.6 Test Representativeness

The comparison of diffusivity coefficients derived from laboratory measurements with those determined in situ is an important aspect of this site characterization test. The in situ measurements will result in data from two locations beneath Yucca Mountain. The spatial variations of the geologic media may result in requests from the SNL performance assessment division for diffusivity coefficients in materials or in locations that differ from those used for the two in situ determinations. The comparison of laboratory data with field data will permit extrapolations on laboratory measurements to other tuff samples or extrapolations to different depths along the likely transport paths to be made with much greater confidence in the accuracy of the results than would be possible without the laboratory and field data comparisons.

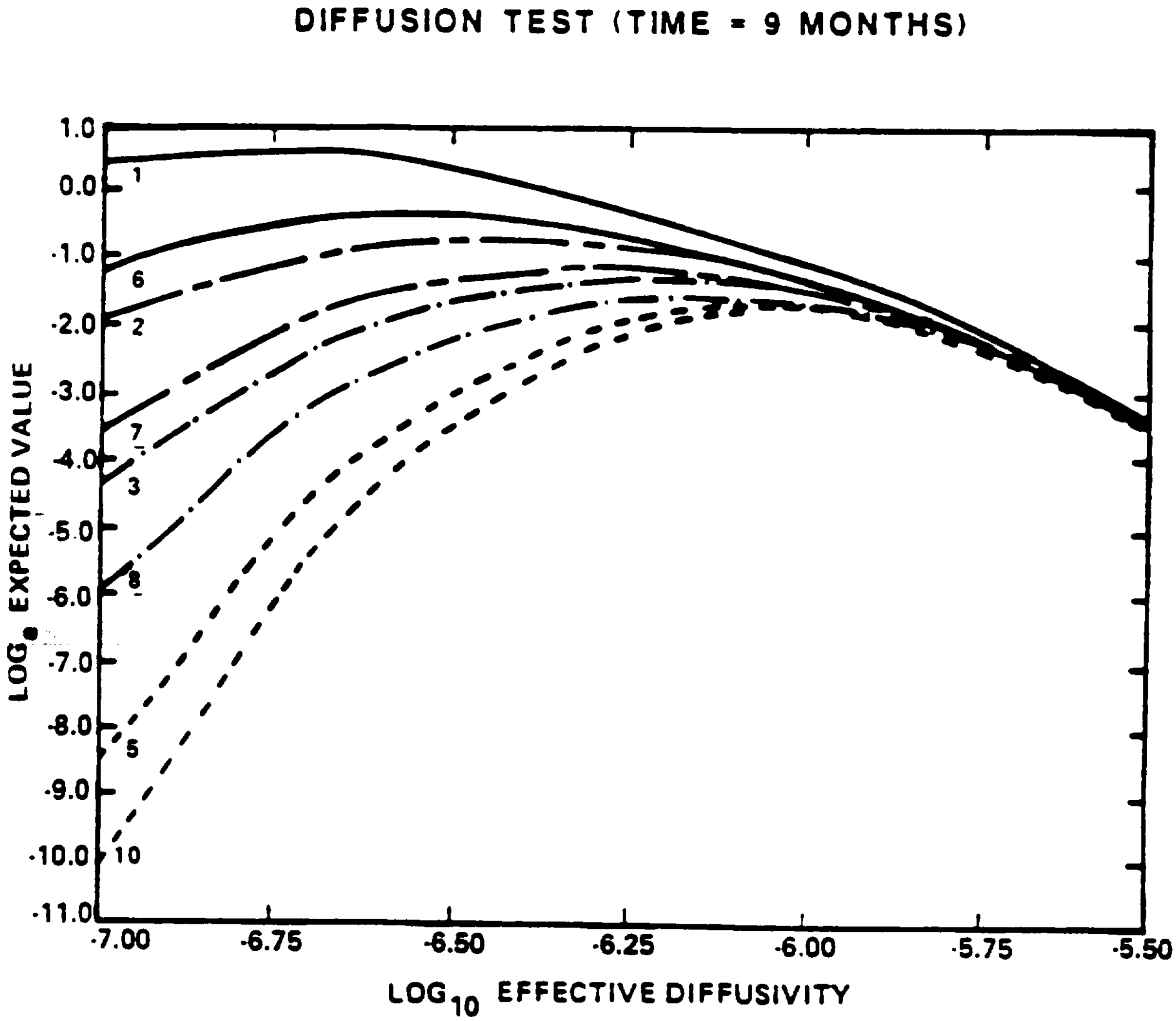

Figure 3. Plots of diffusivity values to be derived from tracer concentration measurements. The curves are labeled with the sample numbers defined in Figure 2.

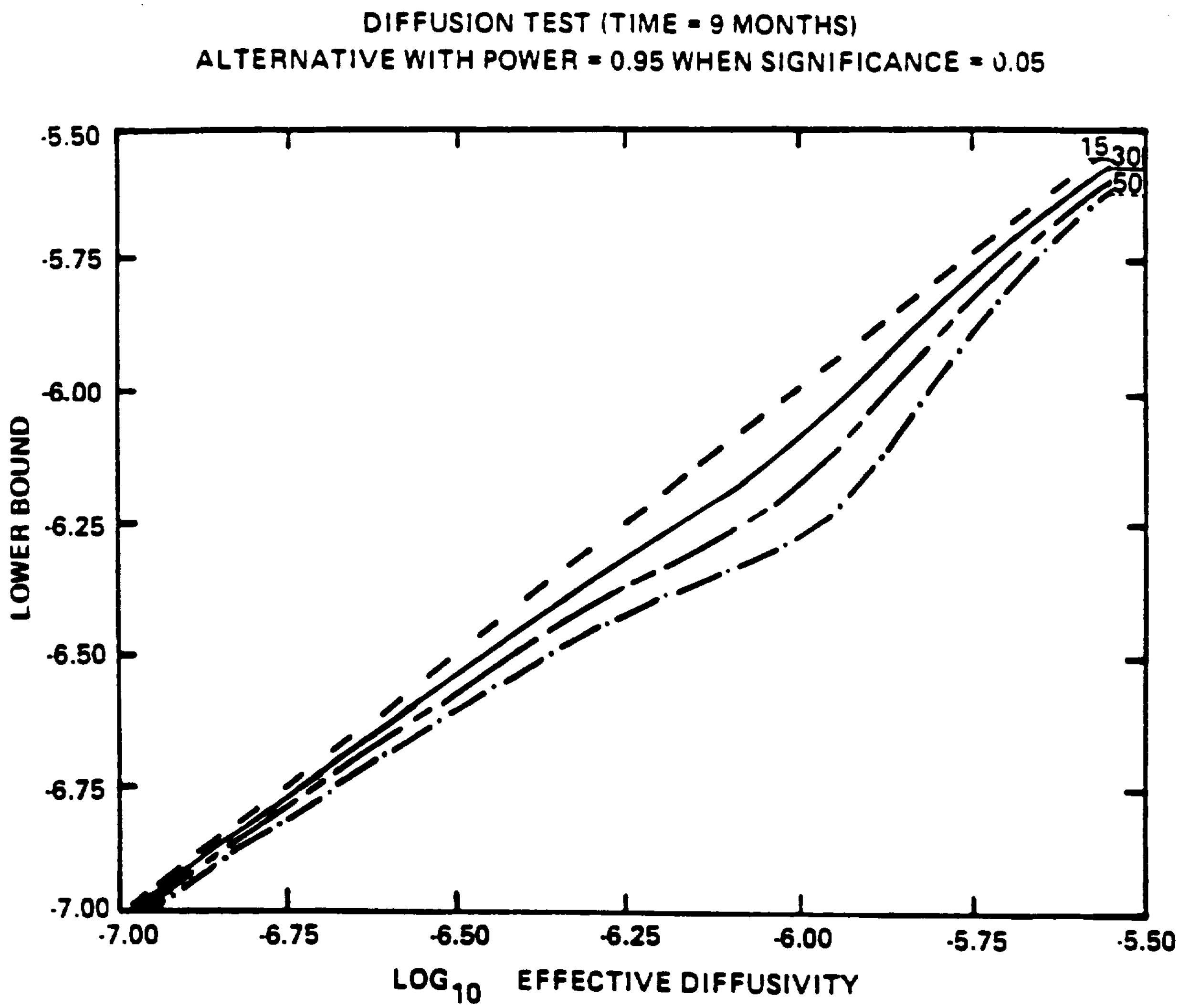

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Figure 4. Plots of the lower bounds on diffusivity values as a function of diffusivity for different errors associated with the individual measurements. The dotted line indicates the true diffusivity. The other curves are labeled with the experimental errors in percentages.

TABLE 3

INSTRUMENTATION, EQUIPMENT, MATERIALS, AND SERVICES
FOR THE DIFFUSION TEST

Item	Quantity*	Description	Procurement Method
Packers	2	Standard	NTS support contractor, purchase, or lease
Pressure transducers (if pressurized packers are used)	2	Standard	Tester's organization purchase order
Air-drilled boreholes, each ~10 m deep, plus overcoring of each	4	To be developed in prototype test	NTS support contractor
Tracer injection apparatus	2	Special	Tester's organization design and fabrication

* Quantities here include Calico Hills testing needs. If Calico Hills testing is not performed, quantities will be half of those shown here.

3.7 Location

One set of diffusion experiments will be performed in the Topopah Spring unit in the main underground facility, and the other set may be performed in the Calico Hills nonwelded unit at the base of ES-1. Important considerations for choosing the exact location of each diffusion experiment in either of the two tuffs include boreholes with segments free from fractures and isolation of the experimental volumes from other experiments that might result in water flow through the diffusion volume or that might vibrate the diffusion volume to the extent that fracturing could occur during the course of the experiment.

4.0 APPLICATION OF RESULTS

4.1 Site Investigation

The data from this study will provide information about the diffusion of aqueous solutes into two unsaturated tuffs at Yucca Mountain. These measurements of diffusivity coefficients under in situ lithostatic load and moisture conditions will aid in characterizing the retardation of $^{99}TcO_4^-$ and $^{129}I^-$ relative to the rate of water flow.

4.2 Resolution of Performance Issues

The application of results in this site investigation study is tied directly to the resolution of a performance assessment issue. That issue is whether the mined geologic disposal system can meet the requirements for limiting radiation doses to the public as required by 40 CFR 191.15. The results of this study will supply quantitative information concerning solute diffusion under in situ conditions. The data will be used to calculate radioactive nuclide transport through liquid pathways for repository system performance.

The comparison of laboratory measurements of diffusivity coefficients, extrapolated to in situ conditions, with measurements made under in situ conditions is an important application of this study. This comparison is expected to help increase the confidence that extrapolations from laboratory measurements result in data that are comparable to those measured under in situ conditions.

5.0 SCHEDULE AND MILESTONES

Schedule components are listed in Table 4. A diagram of the schedule is shown in Figure 5.

TABLE 4

SCHEDULE FOR THE DIFFUSION TEST

Item	Date
Prepare engineering test plan	Before start of study in exploratory shaft
Overcore 3-mo diffusion test in Topopah Spring tuff	3 mo after injection of tracer solution
Draft report of 3-mo results	4 mo after overcoring
Overcore 3-mo diffusion test in Calico Hills tuff	3 mo after injection of tracer solution
Draft report of 3-mo results	4 mo after overcoring
Overcore 12-mo diffusion test in Topopah Spring tuff	12 mo after injection of tracer solution
Draft report of 12-mo results	4 mo after overcoring
Overcore 12-mo diffusion test in Calico Hills tuff	12 mo after injection of tracer solution
Draft report of 12-mo results	4 mo after overcoring
Complete draft final report	24 mo after final overcoring

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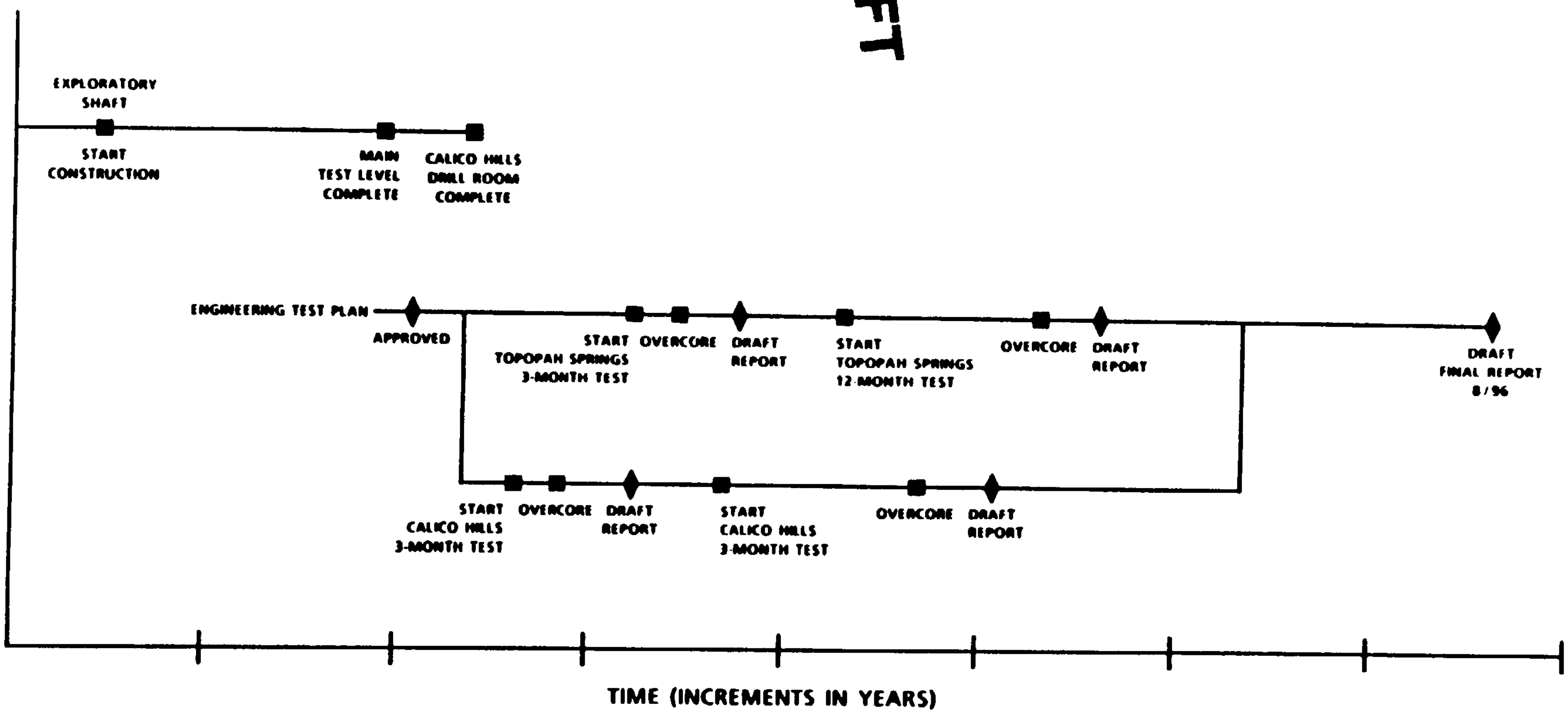

Figure 5. Schedule

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