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PROGRAM PLAN: FIELD RADIONUCLIDE MIGRATION STUDIES IN CLIMAX GRANITE

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ABSTRACT

This Program Plan describes the field radionuclide migration studies we plan to conduct in the Climax granite at the Nevada Test Site. Laboratory support studies are included to help us understand the geochemical and hydrologic processes involved in the field. The Program Plan begins with background information (Section 1) on how this program fits into the National Waste Terminal Storage Program Plan and discusses the needs for field studies of this type. The objectives stated in Section 2 are in direct response to these needs, particularly the need to determine whether laboratory studies accurately reflect actual field conditions and the need for field testing to provide a data base for verification of hydrologic and mass transport models. The technical scope (Section 3) provides a work breakdown structure that integrates the various activities and establishes a base for the technical approach described in Section 4. Our approach combines an interactive system of field and laboratory migration experiments with the use of hydrologic models for pre-test predictions and data interpretation. Section 5 on program interfaces identifies how information will be transferred to other related DOE projects. A schedule of activities and major milestones (Section 6) and the budget necessary to meet the project objectives (Section 7) are included in the Program Plan. Sections 8 and 9 contain brief descriptions of how the technical and program controls will be established and maintained and an outline of our quality assurance program. This program plan is an initial planning document and provides a general description of activities. An Engineering Test Plan containing detailed experimental test plans, an instrumentation plan and equipment design drawings will be published as a separate document.

1.0 BACKGROUND

To evaluate the potential of granite as a host rock for a nuclear waste repository, information is needed on fluid flow and radionuclide transport through fractures. Current research on rock/waste/water interactions emphasizes laboratory studies of sorption and radionuclide migration. Field tests are now needed to determine whether laboratory studies accurately reflect in situ conditions, to develop measurement techniques that can be used for in situ testing at candidate repository sites, and to provide experimental data for model development and verification required for long-term risk assessment. This experimental basis for model development and verification is an important part of the National Waste Terminal Storage (NWTS) Program Plan as outlined in the Waste Confidence Rulemaking Document (DOE/NE-0007). The Earth Science Technical Plan (ESTP)(DOE/TIC-11033), a document designed to guide earth science research related to deep geologic disposal of nuclear waste, also cites the need for field testing in the areas of geochemistry and hydrology to provide a data base for model verification of both near-field and far-field flow systems.

In response to the research objectives cited by both the NWTS Program and the ESTP, Lawrence Livermore National Laboratory plans to study radionuclide migration in fractured Climax granite at the Nevada Test Site (NTS). Our approach combines an interactive system of field and laboratory measurements of radionuclide transport and sorption in fractured rock with the use of existing hydrologic models for pre-test predictions and data interpretation. This project will provide state-of-the-art field measurement techniques for radionuclide migration studies, field test data on radionuclide migration, and a comparison of field and laboratory measured retardation factors. The field test data will be available to the Waste Isolation Performance Assessment Program (WIPAP) for the verification of mass transport models designed to describe radionuclide release scenarios and their consequences.

In order to keep costs relatively low, the Climax field tests are designed to be limited in scope. The fracture flow experiments will not give a regional picture of flow characteristics in fractured granite, however, they will provide scaling factors of several orders of magnitude over laboratory tests, and provide a better understanding of radionuclide migration in fractured rock.

There are several advantages to using the Climax granite: (1) access exists to a drift complex 400 meters below the surface thus requiring little site preparation; (2) a great deal of geologic and geophysical data, as well as core samples, are available; (3) NTS is one of the few locations in the United States where field tests using radioactive tracers can be quickly and conveniently made and where radiation safety procedures and equipment are already in place.

Finally, the study of granite as a waste repository host-rock has international importance. Results from the field study in the Climax granite will provide information of value to the Swedish, French, and Canadian waste programs and, in turn, will make information from those programs more meaningful to the U.S. effort.

The accumulation of a sufficient technological data base for the safe disposal of nuclear waste requires that many experiments be conducted on a laboratory and field scale. Recognizing this need, the Office of Nuclear Waste Isolation is planning various field experiments in several candidate media. The specific requirements of individual experiments will vary depending on the technical issue to be addressed. Concurrent with this project, Los Alamos National Laboratory, Sandia National Laboratory, and Argonne National Laboratory will jointly conduct a similar migration experiment in tuff at the Nevada Test Site. Cooperation between the two projects including the sharing of problems, techniques and data will enhance both studies and provide a solid base for future migration experiments.

2.0 OBJECTIVES

2.1 General Objectives

The work described in this Program Plan has the following objectives:

- To study radionuclide migration in fractured granite.
- To compare retardation factors measured in the field with laboratory results.
- To develop a reliable in situ retardation testing system and methodology that can be used at any candidate repository site.
- To model the fracture flow experiment using an existing flow model and calibrate the model using field parameter values. This will give us the ability to make pre-test predictions and aid in data interpretation.

Meeting these objectives will contribute to: (1) the NWTS Program which calls for in situ testing as part of its experimental basis for model development (see section II.F.2.2., DOE/NE-0007), and (2) the ESTP which describes the need for geochemical and hydrologic field studies to understand the scale dependence of geologic interactions and to improve long-term risk analysis.

2.2 Specific Design Objectives

To achieve the general program objectives listed above, we must reach specific design objectives. To study radionuclide migration in fractured rock, we must first design and construct a system that will:

- Establish and monitor a constant flow of water along a single fracture between an inlet and outlet hole.
- Inject a radionuclide solution as a single pulse into an existing flow system.

- Monitor for the presence of radionuclides as the water exits the outlet hole.

- Collect samples automatically over an extended period of time.

- Notify the operator if the system malfunctions.

- Meet appropriate industrial and radiation safety standards and provide radiation monitoring as required.

Other design objectives include the design and construction of a:

- Water collection apparatus needed for taking samples of groundwater seeps in a closed environment. This will allow us to determine the composition of the actual groundwater and provide a basis for preparing a synthetic groundwater to be used in the migration experiments.

- Laboratory mock-up of the field experiment using parallel plastic plates to test equipment and study fracture flow patterns.

- Core sorption apparatus that can be used to study migration along fractures in the laboratory and provide retardation factors that can be compared to the field results.

3.0 TECHNICAL SCOPE

The baseline management plan and the various program activities that must be conducted to achieve the program objectives are outlined below. Figure 1 shows the work breakdown structure (WBS) that describes the four major tasks which are necessary to meet the objectives of the project. The WBS diagram, along with the network chart (Fig. 2 and Appendix), show the relationship and interface between the various technical elements. Figure 2 is an abbreviated version of the network charts showing only major groups of activities. The Appendix contains a detailed network chart showing the interrelationship of the activities and a brief description of how network charts are used as a

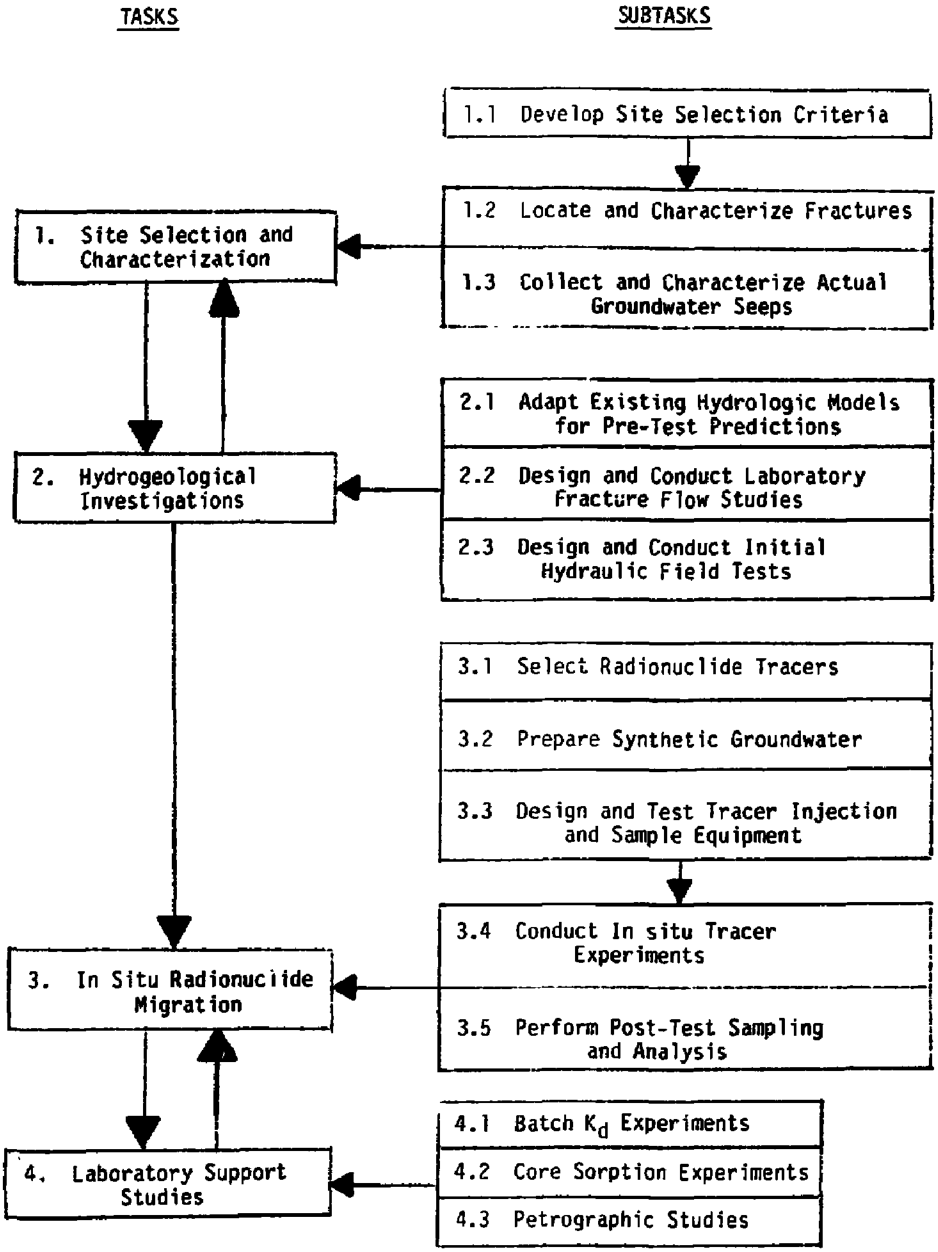


Fig. 1 The Basic Work Breakdown Structure (WBS) shows the relationship and interface between the various technical elements of the project.

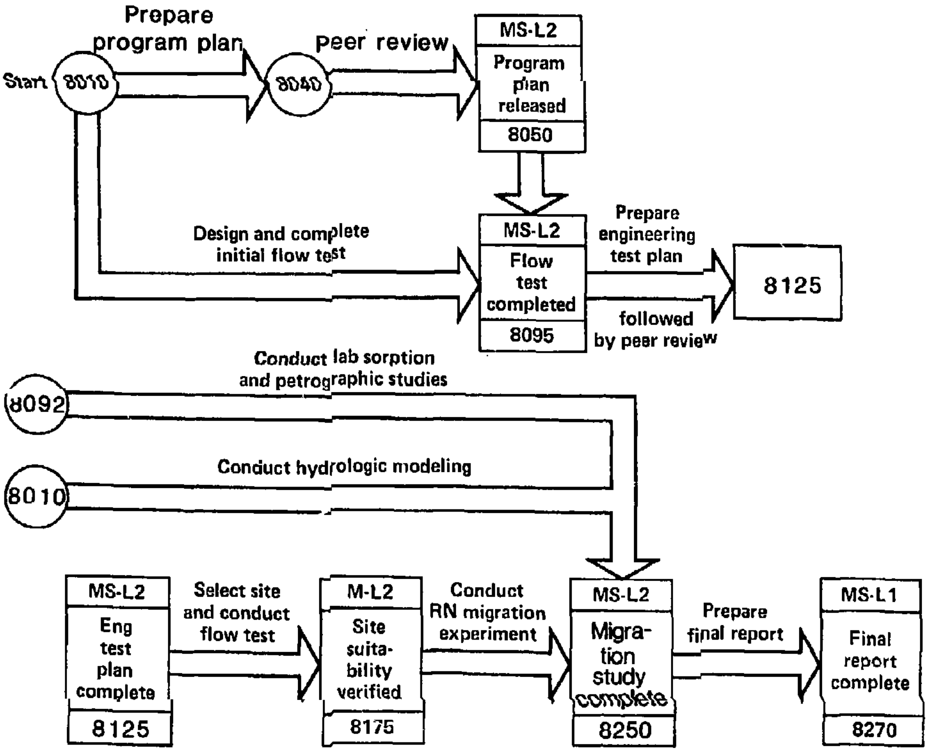


Fig. 2 Abbreviated Network Chart showing the major project activities.

management tool. This section gives a brief description of each task including: (1) task goal and (2) the scope of work for each of the elements in the WBS. Section 4 on the technical approach provides a more complete description of the activities related to each task.

TASK 1: SITE SELECTION AND CHARACTERIZATION

GOAL

Identify and characterize sites with fracture systems suitable for conducting in situ radionuclide sorption experiments.

SCOPE OF WORK

Subtask 1.1 - Develop Site Selection Criteria

The workings in the Climax Stock at the spent fuel test level, shaft 1501, NTS, will be studied for potential sites to conduct the field radionuclide migration experiments. Criteria will be established (i.e., geological, engineering and safety) before an exact location is chosen.

Subtask 1.2 - Select and Characterize Fractures

Sites will be characterized by careful mapping of major fractures at the drift wall. Drill hole locations will be decided on the basis of these studies. Cores will be logged and saved so that internal fracture structure, mineralogy and chemistry can be carefully studied and suitable fractures for the tracer experiment can be located. In the borehole, fracture orientation and the general appearance of the fracture will be determined by visual inspection using a borescope.

Subtask 1.3 - Collect and Characterize Groundwater Seeps

Since groundwater flow in the fractures occurs only at a few locations and at a very slow rate, simulated groundwater will be needed to conduct both the field (Subtask 3.4) and laboratory (Subtasks 4.1 and 4.2) sorption experiments. To determine the composition of the actual groundwater present at equilibrium with the rock, a collection/ characterization apparatus must be designed and built. This apparatus will collect small volumes of water in an equilibrium environment. Appropriate analytical techniques will be evaluated for both field and laboratory measurements.

TASK 2: HYDROGEOLOGICAL INVESTIGATIONS

GOAL

Model fracture flow in granite and calibrate the model using field parameters obtained from hydraulic testing. This will allow for the pre-test predictions and engineering design specifications necessary in Task 3.

SCOPE OF WORK

Subtask 2.1 - Adapt Existing Hydrologic Models for Pre-Test Predictions

The flow models will be derived from the basic equations of fluid mechanics applied to flow between parallel plates and will relate the flow velocities to the fracture permeability. This will enable us to make pre-test predictions and aid in equipment design for the field tracer experiments. The steady state flow model combined with the mass transport model will describe the mass transport of nuclides and their dilution as a function of dispersivity.

Subtask 2.2 - Design and Conduct Laboratory Fracture Flow Studies

A Laboratory mock-up of the field experiments will be conducted to simulate the field test conditions. This will be done using parallel plastic plates which will allow us to study fracture flow patterns, test proposed tracer injection/collection equipment designs, and develop operational procedures to be used in the field.

Subtask 2.3 - Design and Conduct Initial Field Hydraulic Tests

Initial hydraulic testing without tracers is necessary to determine parameters which may affect the success of the radionuclide studies. It is important that we successfully isolate a fracture within the borehole and establish a suitable flow field. Modifications of conventional water packer tests in the boreholes will be performed to obtain information on the hydraulic conductivity of the individual fractures. Test data, (i.c., injection pressures and flowrates) will enable us to effectively design equipment for the injection and sampling of the radionuclide tracers.

TASK 3: RADIONUCLIDE MIGRATION TESTS

GOAL

Obtain field radionuclide retardation factors in fractured granite and develop a new technology for determining sorption characteristics at potential repository sites.

SCOPE OF WORK

Subtask 3.1 - Select Radionuclide Tracers

A suite of radionuclides must be selected for the field tracer experiment (Subtask 3.4). These tracers will be chosen for their relevance to actual nuclear waste and convenience of analysis. If retardation factors for the initial radionuclide suite are successfully obtained within the time period allowed for the experiments, a second experiment using a more complex mixture may be attempted.

Subtask 3.2 - Prepare Synthetic Groundwater

Based upon the groundwater analyses described in Subtask 1.3, a simulated groundwater will be prepared for both the field and laboratory support sorption studies. This simulated groundwater is important since 1) sorption characteristics are partially controlled by the chemical properties of the solution and 2) the experiments are designed to simulate radionuclide migration in actual groundwater conditions.

Subtask 3.3 - Design and Test Tracer Injection and Sampling Equipment

A water injection and automatic collection system must be designed to permit tracer-spiked water to be pumped through the fracture without significant modification of the tracer water by the equipment. A packer unit, used to isolate the fracture at the inlet and outlet holes, must be modified to allow injection of a radionuclide spiked groundwater solution into an existing flow system as either a single pulse or in a continuous injection. The sampling system must be capable of monitoring for the presence of radionuclides as the water is collected.

Subtask 3.4 - Conduct In Situ Tracer Experiments

Information obtained from previous tasks will be used to design the field radionuclide migration experiments. In these experiments, tritium will be used as a nonreactive tracer to measure water movement and permit quantification, by mass balance, of the radionuclide transport data. The experiment will be run as a function of time in order to define a breakthrough curve and establish retardation factors for the various radionuclides.

Subtask 3.5 - Perform Post-Test Sampling and Analysis

At the completion of the tracer experiments, an array of cores will be drilled between the injection and outlet holes to determine the location of sorbed or precipitated radionuclides and estimate their retardation factors.

TASK 4: LABORATORY SUPPORT STUDIES

GOAL

Compare field retardation factors with laboratory measured values.

SCOPE OF WORK

Subtask 4.1 - Batch K_d Experiments

Batch K_d experiments will be conducted on crushed core and fracture fill materials using simulated groundwater containing the same radionuclides used in the field. These data will then be compared to the field data and laboratory core data (Subtasks 3.4 and 4.2).

Subtask 4.2 - Core Sorption Experiments

A core sorption apparatus will be designed and constructed to study migration along both natural and artificially fractured cores in the laboratory and provide retardation factors that can be compared to the field results. Small cores containing fractures will be taken from the larger cores obtained during the drilling work. As with the batch K_d work, simulated groundwater containing radionuclides will be used (Subtask 3.4).

Subtask 4.3 - Petrographic Studies

Petrographic studies are necessary both before and after field and laboratory sorption tests to determine if mineralogical changes have occurred. Increasingly more sensitive techniques may be necessary to determine the quantities and spatial distributions of the radioactive solute species along the flow path. Autoradiography, neutron activation and electron microprobe analysis will be used where appropriate to further understand and interpret the migration data.

4.0 TECHNICAL APPROACH

The technical approach to the four tasks briefly described in the WBS of the previous section includes an outline of the procedures to be used, design criteria and supporting information. This section is not as complete as the Engineering Test Plan to be released at a later time.

TASK 1: SITE SELECTION AND CHARACTERIZATION

Subtask 1.1: Develop Site Selection Criteria

The Climax Stock is a composite granitic intrusive body located at the northern end of the Nevada Test Site (Fig. 3). The advantages of conducting the migration experiments in the Climax Stock have been described in the previous background section. The underground workings at the spent fuel test level, shaft 1501, provide an access to this granitic mass at a depth (400 m) comparable to that being considered for geologic disposal of nuclear waste materials. Figure 4 shows a map of the spent fuel test level and the location of potential experimental sites for this study.

The Climax granitic stock is composed of two main units, granodiorite and quartz monzonite, and contains numerous fractures and local faults. The level at which this experiment will be conducted is apparently above the regional water table. The granite appears to be unsaturated, although several fractures in the excavation are the source of very slow seeps of water into the drift. However, due to the extreme impermeability of the granite, it is difficult to exclude the possibility that the test level is below the water table.

The physical properties of the Climax Stock rocks are similar to those of other granitic rocks (Ramspott, et al., 1979) and should allow the results of this test to be generally applicable elsewhere. A comparison of laboratory results with appropriate field measurements will aid in the verification of existing transport models.

The following criteria for the selection of appropriate fractures have been developed to allow us to select a site for the initial hydraulic test (Subtask 2.3). Additional criteria will be developed in the Engineering Test Plan.

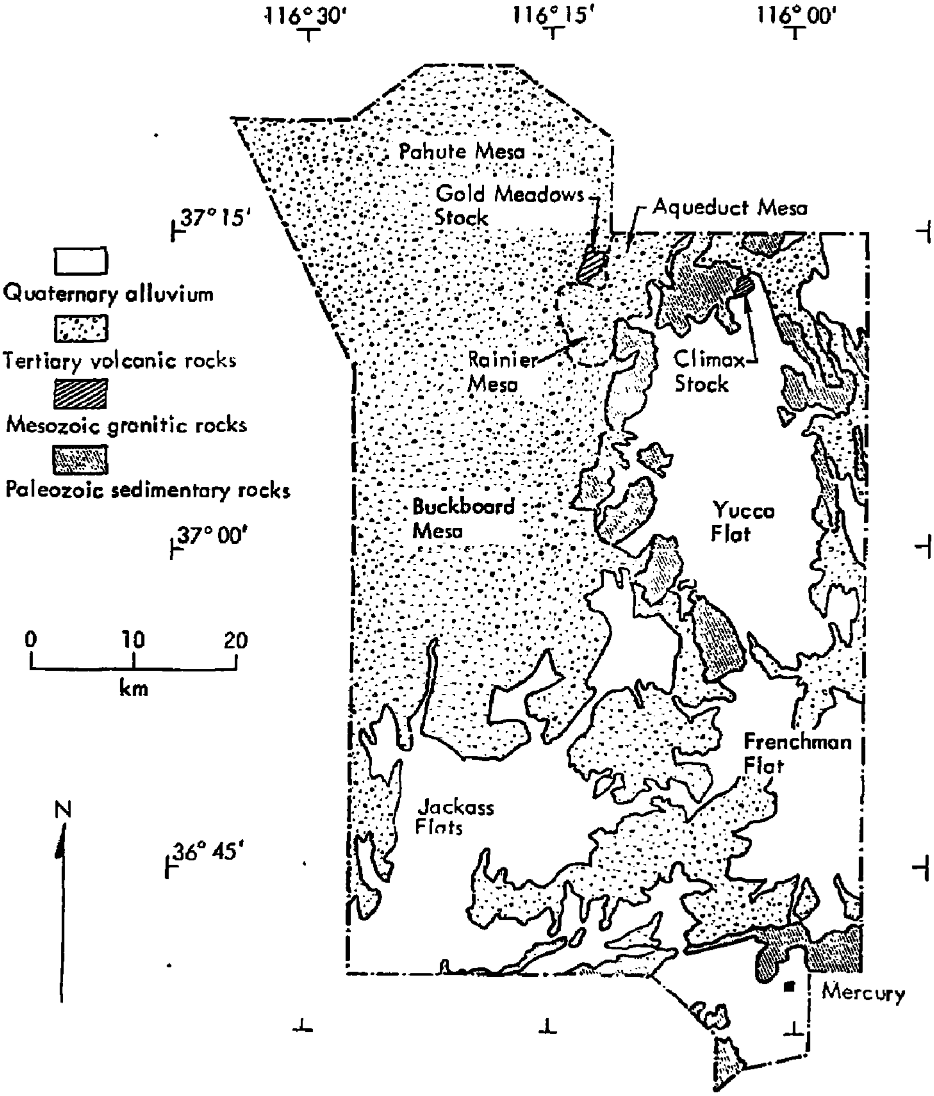


Fig. 3 Principal rock types and test areas at the Nevada Test Site (Ramspott and Howard, 1975)

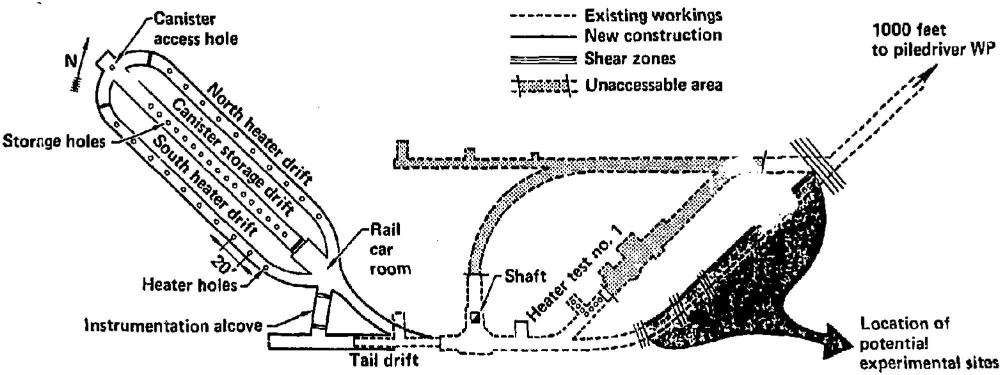


Fig. 4 This map of the underground workings at the spent fuel test level, shaft 1501 in the Climax Mine, NTS shows the location of potential experimental sites for the Field Migration Studies.

1. The fracture must be nearly vertical so that the placement of the inlet and outlet holes fits the experimental design concept. That is, the horizontal holes will intersect the fracture normal to the fracture plane.

2. The fracture must show extensive linearity such that it can be traced across the crown to the opposite drift wall.

3. The fracture must be relatively clean, although it can contain some fracture filling.

4. The fracture must appear to be a single fracture and must not be associated with a major shear zone.

To select the drill site for the boreholes a second set of criteria was also developed. The drilling locations of sets of inlet and outlet holes will be selected such that:

1. The fracture will be intersected at a high angle (this assumes the fracture is linear) to minimize the distance between the straddle packers.

2. The intersection of the fracture and the drill holes are a) greater than 3 m from the drift wall to avoid the fracture zone induced by mining the drift, b) greater than 3 m from the intersection of individual fractures, and c) greater than 3 m away from the drift wall along the fracture plane to avoid fluid flowing out of the fracture into the drift.

3. At each site, the inlet and outlet holes will be drilled 1-3 m apart. Three meters is the maximum distance possible for horizontal holes considering the 3 m height of the drift. This distance could be increased in future experiments by drilling slanted holes, but first, we need to understand the flow characteristics of the

fractures and calculate an estimated time of arrival for the nuclides we will be using. It may not be practical to increase the path length if the time needed to "see" the nuclides is then greater than the time allowed for the experiment.

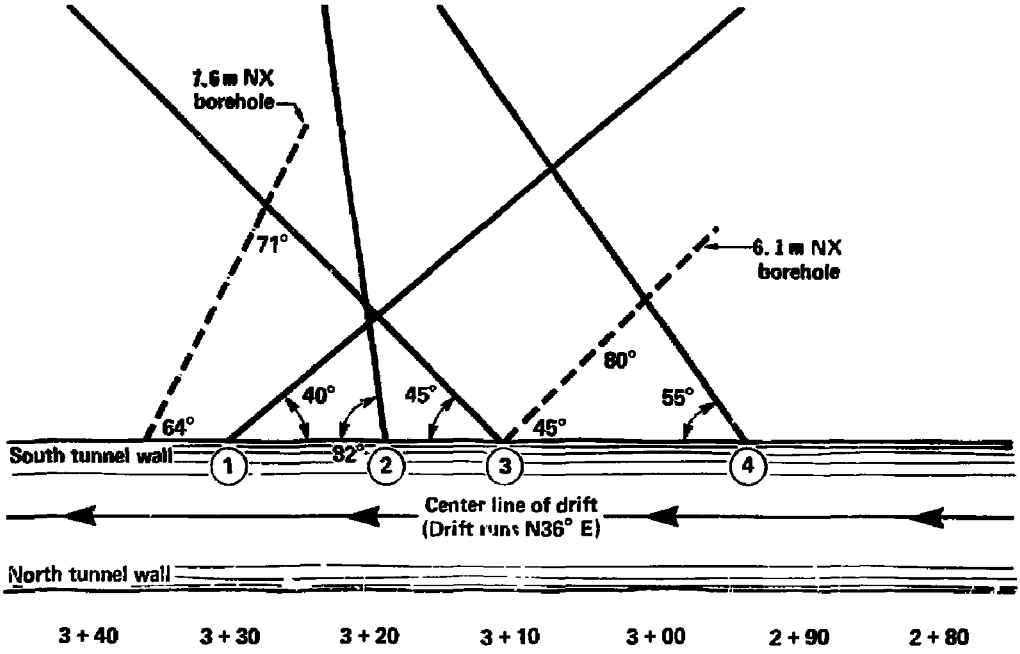
Subtask 1.2 - Select and Characterize Fractures

Potential experimental sites will be selected based upon the criteria described in the previous Subtask. Fractures will be carefully mapped with respect to fracture angle, dip and drift location and preliminary rock samples will be taken.

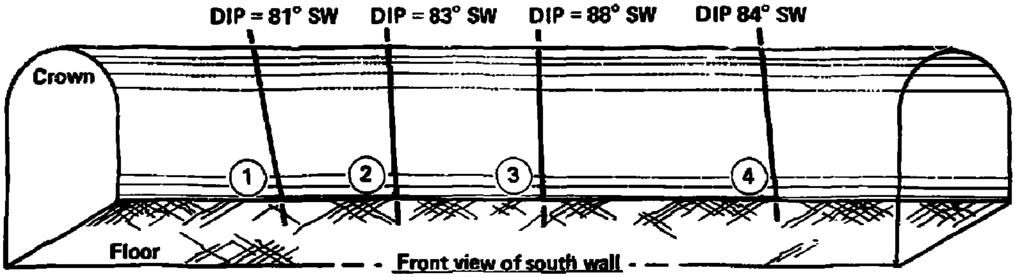
In the first site selection phase, four fractures were identified as candidates for the initial field hydraulic tests (Subtask 2.3). Figure 5 shows the area map of the four potential fractures selected and the locations of the first two sets of boreholes drilled. In general, fractures 1 and 4 are relatively clean with minor alteration. Fractures 2 and 3 have some calcite deposition. Based upon the site selection criteria previously described under Subtask 1.1, fractures 3 and 4 were chosen for this initial flow experiment.

Predominately, this area of the Climax Stock is in a transition zone of quartz monzonite and granodiorite dominated by large potassium feldspar phenocrysts. Accessory minerals present include chalcopyrite, apatite, magnetite, zircon, zoesite, muscovite, sphene and epidote. Fracture alteration material tends to be montmorillonite, chlorite, and sericite with precipitation of calcium carbonate and some amorphous silica.

During drilling, cores will be logged and saved so that internal fracture structure, mineralogy and chemistry can be carefully studied and the fracture for the tracer experiment can be identified. Fractures will be correlated between the upper and lower boreholes. A borescope will be used to identify and photograph the fractures. The scope is scribed in measured intervals to accurately determine the fracture location within the borehole. In addition, it may be possible to measure the width of



Plan view
Scale: 1 cm = 1 m



Front view of south wall
Scale: 1 cm = 1 m

Fig. 5 Climax Mine Area Map showing the potential fractures selected and the locations of the sets of boreholes drilled.

the fractures by using an ocular millimeter grid and comparing the fracture width to photographs of scales taken at varying lengths of borescope. This camera attachment will also provide documentation of the borehole wall. Impression packers may be used to obtain further detailed information concerning the microsctructure of the borehole.

Lastly, the gamma radiation from the rocks in the boreholes used for the migration experiments will be measured by spectral gamma logging. The importance of these measurements is to determine the background level of gamma radiation for correction of later measurements after the tracer experiments.

Subtask 1.3: Collect and Characterize Actual Groundwater Seeps

One of the fundamental parameters controlling radionuclide migration is the geochemistry of the groundwater. To assure that the radionuclide migration experiments reflect field conditions, we should use the groundwater present in the Climax Stock. This would allow us to maintain the geochemical integrity of the subsurface experiment site. However, water inflow into the workings occurs only at a few locations and at a very low rate. The predicted volume of water needed to conduct the tracer tests is large compared to the inflow rate. As a result synthetic groundwater will have to be made. In order to establish the composition of the existing water, a special water collection apparatus has been designed (Figure 6) that will allow for the continual collection of water which drips from the crown of the drift.

The apparatus will first be installed against the crown where the greatest inflow rate occurs. Previous to this installation, the crown will be shaped to fit the viton coated urethane rubber gasket and funnel in such a way as to assure complete sealing. This preparation will also minimize the air space between the funnel and crown. (Air which comes in contact with the groundwater sample may oxidize chemical species and change the groundwater composition.) The air within the container will be replaced by purging the system with argon or other inert gas. The argon inlet line will be closed and the system allowed to fill with water. The time required to fill to overflowing will be observed. The collector will be allowed to operate for at least three times the fill period. We estimate this will require about 1 month of uninterrupted operation. At that point, the water contained in the vessel should be nearly identical in all respects with the water in the granite fractures. Conductivity, pH and Eh will be measured periodically during the collection period to ascertain whether the water character has stabilized. When a stabilized point has been reached, detailed in situ analysis will commence.

Many groundwater parameters are best determined in the field. This can be done by using the appropriate electrodes in the electrode cell (Figure 6) of the collector. Those which cannot be obtained with electrodes will be analyzed at the site using field chemistry techniques. Analysis for stable constituents will be conducted at LLNL. Table 1 lists the parameters to be determined both in the field and the laboratory and the methods we expect to use for their analysis.

The water analyses will provide information for modeling the equilibrium state and chemical evolution of the groundwater. LLNL will use its geochemical modeling codes EQ3 and EQ6 for this purpose. EQ3 will determine the solute species distribution in the samples and calculate the saturation state of these samples with respect to both the primary minerals in the Climax granite and their secondary alteration products. The saturation state computations quantify the thermodynamic driving forces for precipitation and dissolution of the mineral phases. We will use the EQ6 program to make reaction-path models of ground water evolution to compare with the ground water analyses.

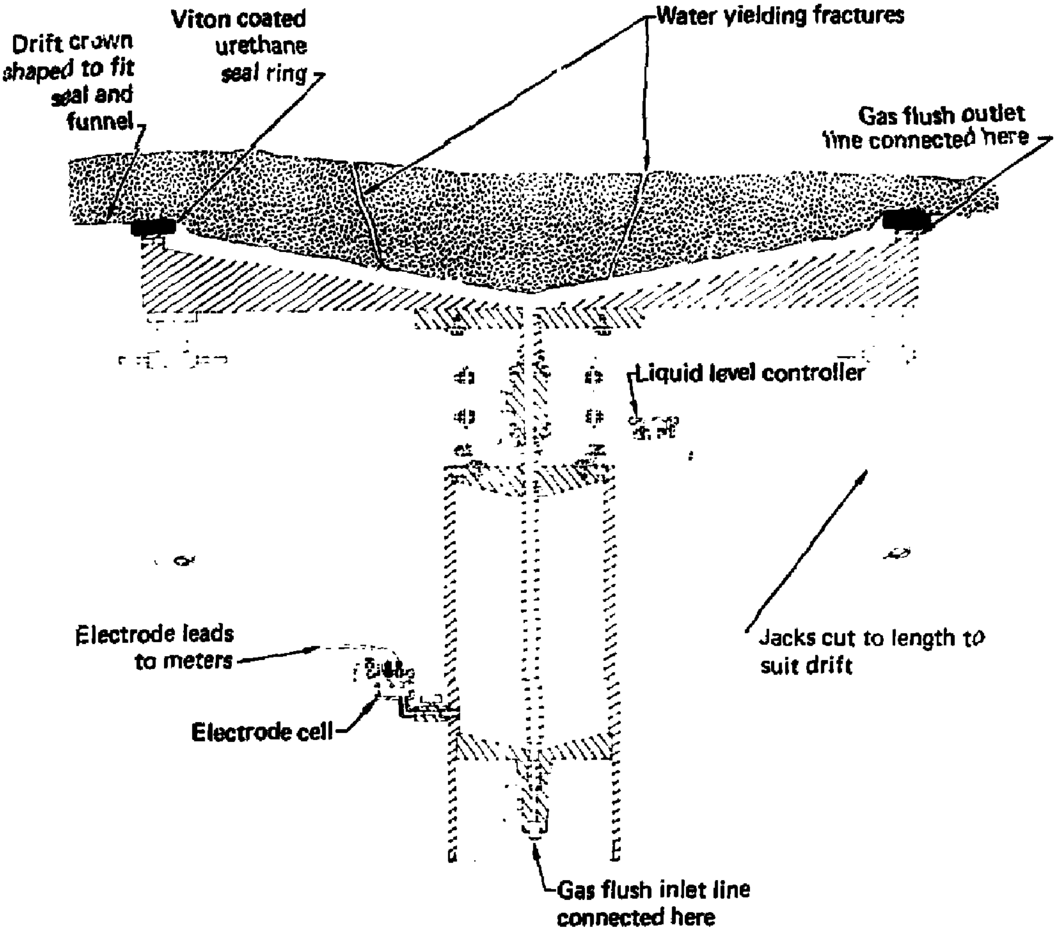


Fig. 6 Water Collection Apparatus which will allow for collection and characterization of the natural groundwater.

TABLE 1 METHODS OF WATER ANALYSIS

PARAMETER	METHOD OF ANALYSIS
	FIELD TESTS
pH, temperature	Standard pH meter and electrodes in collector electrode cell; thermometer
Conductivity	Standard conductivity meter with electrode in collector electrode cell
Alkalinity ($CO_3^{2-}/HCO_3^-/CO_2$)	Titration using commerical kit
Chloride	Titration by $Hg(NO_3)_2$ method using commerical kit
Iron	Colorimetric measurement using a commerical kit; these data will be compared to spectrometric analysis at Livermore
Hardness (Ca+Mg)	Titration using commerical kit
Sulfide	If levels are above 0.1 ppm use a commerical kit; if below, laboratory analysis is needed
Dissolved O_2 (DO)	A commerical kit is good from levels above 0.03 ppm to air saturation (8 ppm). If the DO content is <0.03 ppm, then Eh measurements are more important.

TABLE 1 METHODS OF WATER ANALYSIS (Con't)

PARAMETER	METHOD OF ANALYSIS
REDOX Potential (Eh)	Pt electrode and SCE reference electrode measurements with electrodes in the electrode cell of the collector. A sample will be taken back to Livermore immediately for As speciation analysis. REDOX potential by both methods will be compared.
LABORATORY TESTS	
Total dissolved salts (TDS)	Evaporation
Trace elements including uranium	The ICP-OES technique will be used which is good for up to 22 elements. This technique will be backed-up by the capability of the XRF and INAA methods.
Sulfate and chloride	Technicon Autoanalyzer; chloride data will be compared to field data.
Fluoride	Ion specific electrode
Total organic carbon	Analyses to be performed by Dr. J. Means at Battelle - Columbus (BCL)

TASK 2: HYDROGEOLOGICAL INVESTIGATIONS

Subtask 2.1 Adapt Existing Hydrologic Models for Pre-Test Predictions

Water flow and nuclide transport will be modeled mathematically using models consistent with the fracture geometry and experimental design. These models will relate the flow and transport parameters (permeability and dispersivity) to the fluid pressure, flow geometry, fluid flow rate and solute breakthrough. When used to analyze flow and tracer test data, the models will determine permeability (and hence, the fracture aperature) and dispersivity. The models will provide pre-test predictions of dilution and solute transport that will aid in the final design of the migration experiments.

The Engineering Test Plan will describe the modeling activities and identify the level of effort required to support the experimental phases of the project. Negotiations are underway to make this subtask a cooperative effort between LLNL, Intera Environmental Consultants, Houston, Texas (a SCEPTER contractor), and Pacific Northwest Laboratory's AEGIS Program (see Section 5).

Subtask 2.2: Design and Conduct Laboratory Fracture Flow Studies

Laboratory investigations of fluid flow and mass transport through a parallel plate apparatus (Fig. 7) will be conducted to simulate the proposed field conditions. These simulations of the field tracer experiment will enable testing of proposed equipment design for water and tracer injection and collection; development of operational procedures to be used in the field; and investigation of the charateristics of the flow and mass transport to aid in the analysis of the field data. By conducting laboratory experiments prior to the field tracer experiments, unexpected problems may be revealed which can be solved by design alterations, hence avoiding their occurrence in the field. The probable fracture flow behavior (albeit greatly simplified) can also be observed and our understanding of expected field results will be greatly enhanced.

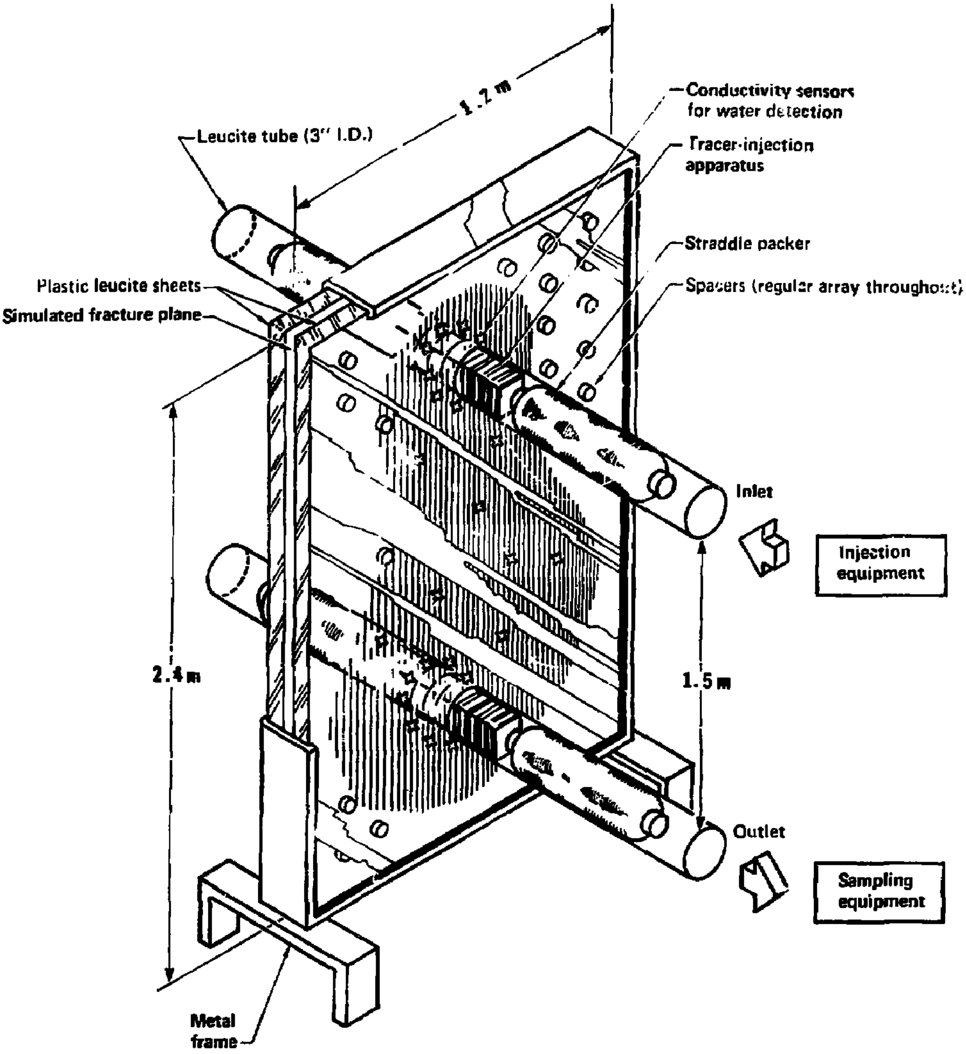


Fig. 7 The Parallel Plate Apparatus for laboratory testing of the injection-collection equipment will use a variety of spacer thicknesses to simulate different fracture apertures.

Fracture flow simulations will be conducted to:

1. Test the proposed method of producing a steady state flow field between the injection and collection holes. Water injected between the plates will tend to migrate vertically downward under the influence of gravity. To ensure that most of the injected fluid is collected at the outlet, a vacuum will be applied to the collection hole. Fluid pressure and flow rate will be monitored at both the injection and collection holes. Flow rates will be adjusted to establish a steady state flow pattern.

2. Test the tracer injection-collection equipment described in Subtask 3.3. An injection of a brightly colored synthetic dye will be used to determine whether the tracer is being injected into the water flow as a single pulse, study dispersion effects between the inlet and outlet holes and check out the effectiveness of the sample collection method. If the equipment is working correctly, we should produce a series of samples that when analyzed give a concentration versus time distribution curve similar to the one described in Subtask 3.4 and shown in Fig. 10.

Subtask 2.3: Design and Conduct Initial Hydraulic Field Tests

An initial field test is necessary to understand the hydrogeologic characteristics of the fractures in the Climax Stock. The purpose of this inital field test is to evaluate the hydraulic properties of the selected fractures (Subtask 1.2) and to determine whether fracture sites are suitable for radionuclide migration tracer tests. The two most critical parameters in the experiment are (1) the successful isolation of a fracture within the borehole and (2) the establishment of an adequate flow field between two boreholes.

Various hydraulic testing techniques have been employed at the Nevada Test Site (Walker, 1962; Dolan, 1957; and Amman, 1960). Unfortunately, no investigations included hydraulic testing of single isolated fractures. Some futher insight into the groundwater hydrology of the Climax Stock can be gained by reference to Walker (1962). Walker reviewed drilling histories on 11 test holes at the Climax Stock and conducted informal bailing and injection tests. The holes ranged from 215 to 610 meters in depth. Walker states in his abstract that "the evidence shows that groundwater is present, but only locally in isolated bodies or pockets where the rock is highly fractured." One hole drilled with air to 277 meters showed an equilibrium water level about 130 meters below the ground surface. Less reliable evidence from another hole suggests the possibility that a water-filled fracture system was penetrated at about 110 meters below the surface and that an unsaturated system was encountered at 358 meters. Still another hole drilled with air to 301 meters apparently did not even tap a saturated fracture system.

Pumping tests for hydraulic measurements in the direction of a particular discontinuity, such as a fracture, involve drilling two boreholes each perpendicular to the fracture as shown in conceptual design (Figure 8). It is assumed that most of the flow will be primarily concentrated within this one fracture and that cross-flow through other fractures, past the packers and through the intact rock surrounding the hole is relatively small. A section of the uncased borehole which contains the fracture is isolated between straddle packers and water is pumped into and out of the straddled intervals.

A variety of borehole packers are commercially available. However, leakage past packers is one of the most serious sources of error in pumping tests and every effort must be made to ensure that an effective seal has been achieved before measurements commence. The most feasible method of testing multiple-fracture boreholes is through the use of inflated straddle packers. Advantages of inflatable packers include sealing lengths many times longer than the mechanically actuated packers. Also, inflatable packers can be run with significantly greater hole clearance than the mechanically actuated

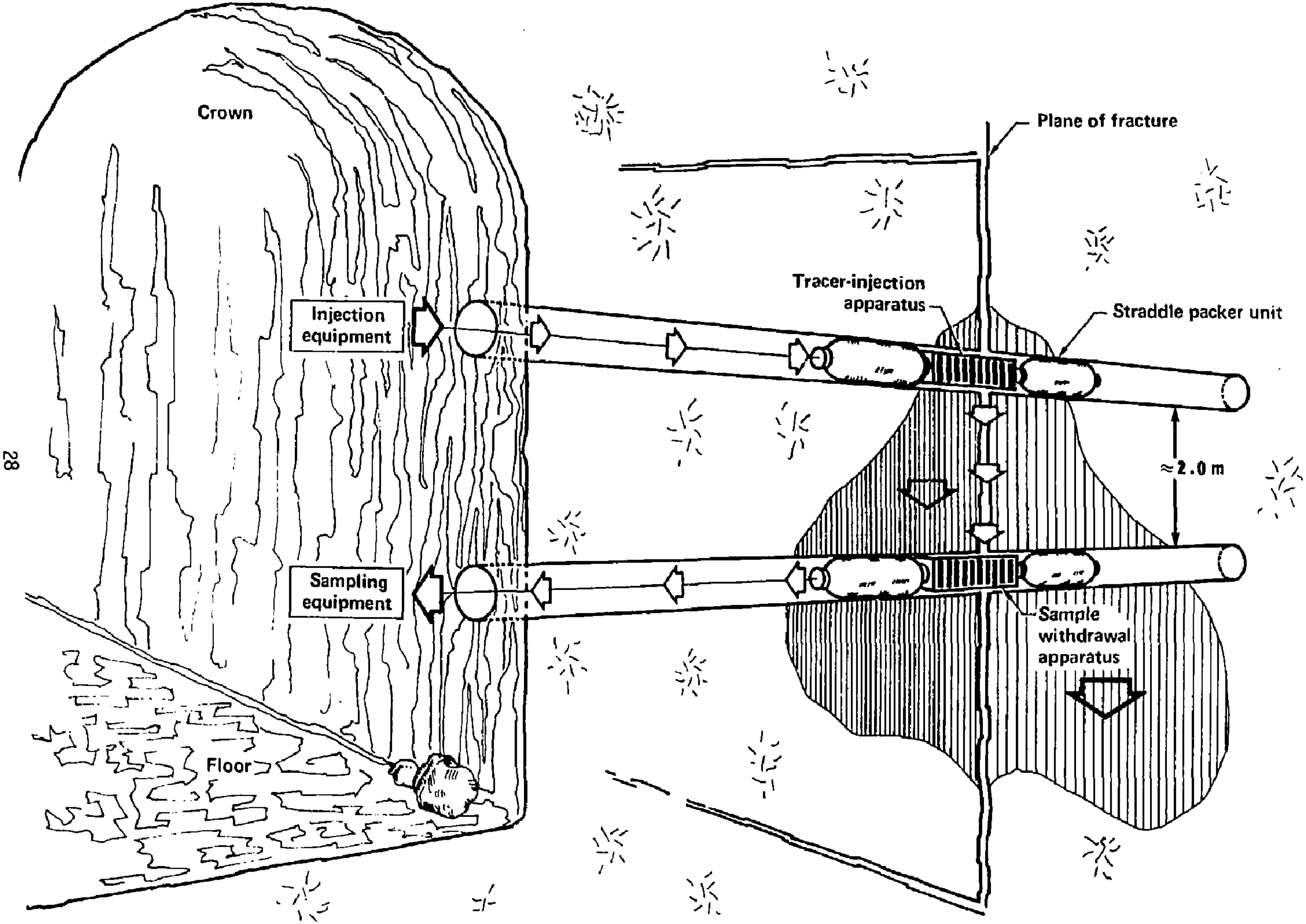


FIG. 8 Conceptual Design for Field Migration Studies.

rubber packers used on standard drillstem testing tools (Shuter and Pemberton, 1978). Given the disadvantages of the mechanical packers, we are planning to use inflatable packers, although we will also test the relative merits of a hydraulically inflated mechanical packer, specifically designed for horizontal boreholes (Cobbs, 1972).

The packers and associated testing equipment to be used in this experiment will be modified from commercially available equipment. However, only a few commercial companies could provide straddle packer units for 3.0 inch NX boreholes which would be acceptable for modification.

Specifications for the straddle packer unit include the following:

1 Straddled interval spacing will be limited to permit adequate isolation of a single fracture.

2 Access transmission tubes will be through the packer elements, permitting monitoring of pressure changes in the packed off zone and the zone below the bottom packer if needed during the experiment.

3. Experimental set up will be a gas or gas powered hydraulic system and will not be dependent on electrical power. An auxiliary DC power supply will be available for instrumentation.

4. Flowrates will be measured by mass balance at both the inlet and outlet holes utilizing alternating load cells.

5. Straddle packers will be assembled as an entire unit, to allow for installation in a 3.0 m wide tunnel.

6. Unit will be lightweight and able to be manually installed.

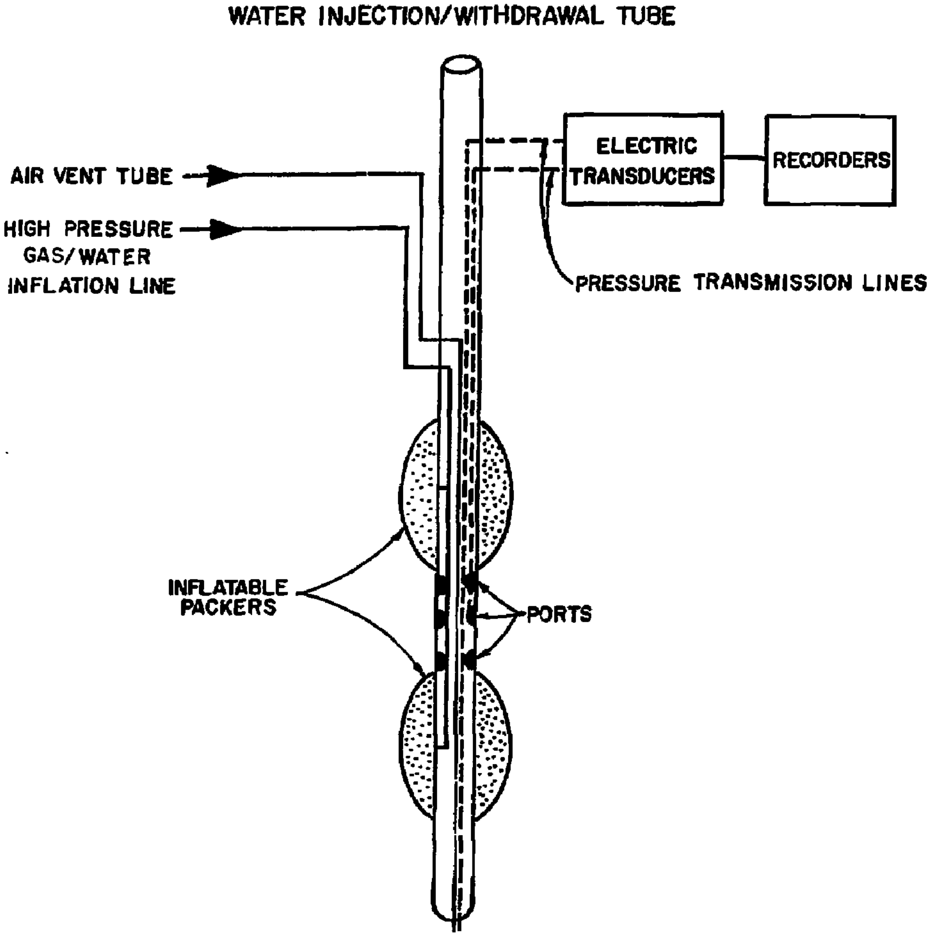


Fig. 9 Modified Straddle Packer Units

7. Water will be prefiltered (suspended solids >0.1 μm) before injection into the fracture. This should alleviate any plugging due to suspended particulates or colloids.

Three types of hydraulic tests are being considered to determine the flow characteristics of the various fractures 1) constant pressure versus flow rate, 2) constant flow rate versus pressure, and 3) pressure pulse tests. The first series of tests will be directed at establishing flow between the upper and lower boreholes as shown in Figure 8 and with measuring the percentage of water recovered in the outlet hole. A second series of tests will consist of one or more of the hydraulic tests listed above to gather data for determining permeability and fracture aperture.

Information from the various hydraulic tests will be used in models to make pretest predictions for the radionuclide migration experiments. However, considering the variability that exists in the physical characteristics of different fractures or even within the same fracture (e.g., aperture), we cannot hope to reproduce the exact results in different locations. We can expect to gain an understanding of the most likely conditions that we will encounter in the migration experiments. This understanding will help us to design the injection-collection equipment and develop the experimental procedures.

In addition to the variability in fracture characteristics, there are other unknowns. For example, we assume that the fractures are unsaturated and that we can saturate them prior to the injection of radionuclides. We also assume that the flow field will be continuous between the inlet and outlet holes and that the boundary conditions can be defined. We need to test these assumptions. It may be that instrumentation of the flow path can be designed to monitor the flow conditions without disturbing the flow. It's been suggested by several reviewers of the draft version of this Program Plan that large scale block tests would assist in scaling up from the laboratory to the field and help us to define the flow path. We plan to examine the feasibility of both instrumentation and block tests and include our recommendations in the Engineering Test Plan.

TASK 3: IN SITU RADIONUCLIDE MIGRATION

Subtask 3.1: Select Radionuclide Tracers

We have tentatively selected seven radionuclides for use in the initial tracer migration tests. They are ^{3}H, ^{85}Sr, ^{99}Tc, ^{131}I, ^{137}Cs, ^{144}Ce, and ^{226}Ra. An estimate of the amounts needed cannot be determined until we have the results from the initial hydraulic field tests. These tests will provide an indication of how much injected water is recoverable at the outlet hole. For planning purposes, we have assumed a worst case situation where approximately 1 mCi of each would be injected. This is the maximum amount that can be conveniently handled at the site. The selected tracers are generally available from commerical sources at a cost of approximately $50.00 to $300.00 per mCi. Strontium-85 is the most expensive tracer. Table 2 lists the pertinent information for each of the nuclides. Other nuclides may be included or substituted for those initially selected depending on their availability at the time of the experiments and the amounts required.

In an attempt to keep the nuclear chemistry as simple as possible, we have not included the actinides in these initial migration experiments. Plutonium in particular was not selected since laboratory studies have shown it to be so easily sorbed by most rocks and minerals that it is essentially immobile. As it is not expected to move, the extra experimental problems it generates make its use impractical for an initial test. Until we can prove that the migration experiments are feasible, safe, and give valid results, the use of actinides is not warranted. The increased costs related to actinide production and radiation safety requirments would pull funds away from our primary mission of developing techniques for studying radionuclide migration in the field. At the successful completion of this project, we will propose a second series of experiments designed to handle actinides.

Tritium was selected as the non-reactive tracer whose detection in water from the outlet hole provides a measure of the dilution and transient time of the tracer through the inlet apparatus, the fracture and the outlet apparatus. With this information, retardation of sorptive tracers can be quantitatively determined by comparison of arrival times. Since liquid scintillation analysis of ^{3}H is so sensitive and no sorption is expected, lesser quantities of this tracer can probably be used. Initial flow tests with just ^{3}H will provide the necessary dilution information for selecting the activity levels required for the other radiotracers. Preliminary data show background values for ^{3}H in seep water at the Climax Stock of about 200 pCi/ml.

Strontium-85 was chosen to represent the behavior of the important waste component ^{90}Sr. The use of ^{85}Sr allows for direct gamma-counting. This avoids the need for expensive radiochemical techniques required for the analysis of ^{90}Sr. Strontium-85 has been used extensively for both our laboratory batch and core sorption studies.

Technitium-99 was chosen since it is a very important long-lived component of nuclear waste. Its geochemical behavior is interesting because it can either be mobile as the TcO_4^- anion or precipitate as TcO_2 given reducing conditions in the groundwater (Bondietti and Francis, 1979). In the laboratory under atmospheric conditions, ^{95m}Tc has been observed to migrate with ^{3}H through rock cores. However, a small component (approximately 1%) stayed with the core. It was probably reduced to TcO_2 by ferrous iron in the rock. Its in situ behavior will be important in determining its groundwater geochemistry. Although ^{95m}Tc can be gamma counted directly, it is expensive and often difficult to obtain. We chose ^{99}Tc because it is inexpensive and can be analyzed by liquid scintillation.

Iodine-131 was chosen to represent iodine-129, an important long-lived radionuclide in nuclear waste. Since any isotope of iodine is expected to exist in natural waters as the negative ion, iodide, ^{131}I should travel with tritium in the groundwater and act as a second tracer. Iodine-131 is commercially available and can be easily gamma counted.

TABLE 2

Selected Radiotracers

Radionuclide	Half Life	Decay Mode	Analysis Method
^{3}H	12.3 y	β^-	Liq Scin[1] 18.6 KeV β^-
^{85}Sr	64.8 d	EC	γ-count 514 KeV γ
^{95m}Tc	61.2 d	EC	γ-count 204 KeV γ
^{99}Tc	2.14×10^{5} y	β^-	Liq Scin[1] 292 KeV β^-
^{131}I	8.02 d	γ	γ-count 364.4 KeV γ
^{137}Cs	30.17 y	β^-	γ-count 661.6 KeV γ
^{144}Ce	284.5 d	β^-	γ-count 133.5 KeV γ
^{226}Ra	1602 y	α	γ-count 186.2 KeV γ

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[1] Liq Scin = liquid scintillation technique

Cesium-137 is an important short-lived component of waste. It has shown moderate sorption in laboratory experiments and its behavior in the field is of interest for comparison to the large amount of laboratory data available. Its analysis is very easy by direct gamma counting and it is a very available and inexpensive isotope. Another optional Cs isotope is the shorter lived ^{134}Cs which can also be gamma counted directly. However, it would be difficult to count with our low background Compton-suppressed equipment.

Cerium-144 is of interest only as a convenient stand-in for the actinides, particularly amercium, curium, and rare earth fission products found in waste. For the first tracer test it will provide a good approximation of actinide and rare earth behavior. Laboratory studies indicate generally high sorption for both actinides and ^{144}Ce. It is also easily analyzed, inexpensive, and generally available.

Radium-226 is included since it is the daughter of ^{238}U decay. Radium-226 generates much activity by its decay to short-lived daughters. Uranium is an important component of nuclear waste and so its contribution (from ^{226}Ra and daughters) to the risk associated with waste disposal needs to be studied. Radium can be analyzed by direct gamma counting of the 186 KeV gamma-ray emitted after ^{226}Ra alpha decays to ^{222}Rn. If the sample is allowed to set sealed for about a month, activity from other daughters can be used to assist in the analysis since secular equilibrium will have been established between ^{226}Ra and all of its daughters. The noble gas ^{222}Rn is released by ^{226}Ra decay, however this is not a special problem. One millicurie (approximately 1 mg) of ^{226}Ra will produce at secular equilibrium, (at 25^{0}C and 1 atm) 5×10^{-15}l of the noble gas ^{222}Rn. If this volume of gas were to all leave the fracture and uniformly enter a 10 meter section of a <u>non-ventilated</u> underground drift at the Climax, the amount of airborne ^{222}Rn would be about 70 pCi/l. The maximum permissible concentration of ^{222}Rn for workers in a DOE controlled environment is 1×10^{5} pCi/m^{3}. Therefore, the maximum amount of ^{226}Ra we expect to use would contribute no ^{222}Ra gas pressure problems to our experimental apparatus nor, under the worst possible scenerio, would it generate a health hazard to people conducting the test.

Half-lives for the selected tracers vary from 65 days to 2×10^{5} years. Strontium-85 has the shortest half life and ^{99}Tc the longest. Since there is little choice but to use ^{3}H, ^{99}Tc and ^{226}Ra, there is no reason to complicate the experiment by picking short half-life isotopes of Cs and Ce (i.e. ^{134}Cs and ^{141}Ce). Strontium-85 is analytically a convenient tracer as well as having a short half-life. However, longer half-lives will simplify experimental scheduling and will allow for follow-up experiments to be performed on both the water samples and the in situ fracture materials.

Subtask 3.2: Prepare Synthetic Groundwater

Based on the groundwater analysis from Subtask 1.3, a synthetic groundwater will be prepared using distilled water and the appropriate constituents. This groundwater will be prepared and stored in polyethylene-lined steel drums. The synthetic groundwater will be analyzed and the data compared to the composition of the actual groundwater. If the synthetic groundwater character does not match the actual, several adjustments can be made. The addition of finely divided Climax granite and fracture material should provide the solution an opportunity to adjust its composition to better match the actual groundwater. After an appropriate equilibrium period (approximately 1 month) the solution will be analysed again and a determination made concerning its suitability as a synthetic groundwater. A more difficult adjustment could be the pH and Eh. The pH and carbonate species distribution will be difficult to maintain if the buffer capacity of the water is low. Also, a low dissolved oxygen and redox potential will probably be the most difficult parameter to reproduce regardless of the values observed in the groundwater.

We recognize that it will be difficult to simulate all the measured parameters perfectly. However, we can evaluate the differences between actual groundwater and the simulated groundwater. We need to assess whether the parameters which are observed to differ the most will effect the geochemistry of the tracers. If so, the retardation factors from the radionuclide migration experiments may not be representative of in situ conditions

Subtask 3.3: Design and Test Tracer Injection and Sample Equipment

A mechanical engineering design is necessary for a water injection and collection system to permit tracer-spiked water to be pumped through the fracture without significant modification of the tracer water by the equipment. This entire assembly will be part of the straddle packer units which will be placed in the inlet and outlet boreholes. Many of the actual equipment design specifications such as injection pressures, inlet flow rates and outlet sampling flow rates will have to be finalized after values are obtained from the initial field hydraulic tests (Subtask 2.3). However, to conduct an effective and meaningful experiment, design criteria must include the following:

1. Effective isolation of a single fracture with a constant sheet flow of water between an inlet and outlet hole. This will be evaluated during the initial field hydraulic tests described in Subtask 2.3 using modified commercial straddle packer units. Constant pressure must be maintained in the packers to insure a continuous seal.

2. Pressure must be monitored and recorded in the interval between the packers as explained under Subtask 2.3.

3. The injection packer system and sampling packer system will each be a single straddle packer unit that can be manually installed into the drift wall.

4. The inlet system must be capable of injecting a radionuclide solution either as a single concentrated pulse or as a continuous injection into an existing flow field. This system must allow subsequent tracers to be injected without contamination or dilution problems. Furthermore, the time the tracer enters the borehole must be accurately known.

5. Samples must be collected automatically over an extended period of time. The capability must exist for monitoring the presence of radionuclides as the water exits the outlet hole. A time history of concentration is necessary.

6. Contamination of dilute tracer samples coming from the outlet hole must be avoided.

7. The system (i.e., packer units, injection and collection apparatus) must be made out of chemically inert materials that have ideally no sorption capacities for the various radionuclide tracers.

The following criteria concerned with the safety of the experiments will be employed in our equipment design:

1. The system will be a gas powered hydraulic system so that electric power, although convenient, is not essential to keep the experiment running.

2. The system will meet appropriate industrial and radiation safety standards as required. The experimental design must prepare for concentrated tracer loss or packer leaks. Packer blowouts could be avoided by using hydraulically inflated packer boots.

3. There will be a fail-safe system with an alarm to notify the operator of malfunctions (i.e., pressure test and leak check systems). A TV monitoring system from the surface is an option we plan to investigate.

There exists no commercially available system that meets all of these requirements. Commercial packer units may be adapted to incorporate the tracer injection and sampling equipment. However, a materials problem does exist, since metal should not come in contact with the tracer-spiked solution to avoid oxidation-reduction reactions.

Natural and neoprene rubber, which are usually used as packer boot material have high sorption capacities for various radionuclides (Morgan, et al., 1964). It is important that we chose our fabrication materials to understand and minimize these effects. Although some studies of sorption phenomena on polymeric materials have been done, the literature is inconclusive and inadequate. Most of these studies were done in Japan and the Soviet Union (F. Ichikawa, 1975; F. Ichikawa and T. Sato, 1971; J. Dennis and J. Lucas, 1978; A. Skal'skii and A. Lyubimov, 1969; A. Skul'skii and A. A. Lyubimov, 1971).

To test the suitability of the various materials, we plan to evaluate plastics, rubbers, and elastomers in the laboratory by batch K_d experiments using the radionuclides described under Subtask 3.1. Materials to be evaluated include: FEP teflon, hycar (nitrile-acrylic), Kel-F (chlorotrifluoroethylene), PFA teflon, Polypropylene, Polyethylene, Vyton (fluorocarbons), 3M urethane, neoprene and natural nitrile rubber (standard packer material). From the results of these laboratory studies, we can choose materials for tubing, valves, packers, etc. which minimize the effects of sorption.

This entire system will be designed by a qualified mechanical engineer at LLNL. If "off the shelf" equipment cannot be modified to meet the requirements specified previously, we can fabricate the system at LLNL. The completed injection and sampling units will be tested with inert tracers or chemical dyes in the laboratory situation described under Subtask 2.2.

Subtask 3.4: Conduct Field Tracer Experiments

The radionuclide migration tests will be conducted only after: (1) the specific fracture selected for the test has been characterized in a series of tests similar to those conducted in the initial flow test (Subtask 2.3); (2) the injection-collection equipment has been tested in the laboratory and checked out in the field; and (3) the completion of pre-test predictions using both the mass transport model selected to model the experiment (Subtask 2.1) and the results of the laboratory core sorption studies(Subtask 4.2). The migration experiments will be done in two phases. The first will be a series of injections of radionuclide solutions into the fracture followed by sample collection and analysis. The second will be a post-mortem test analysis of the fracture material between the inlet and outlet hole that has been recovered by back-coring into the fracture at the completion of the migration experiments (see Subtask 3.5). The following discussion of the planned sequence of events in phase one is based on preliminary plans which will need to be revised and expanded in the Engineering Test Plan based on information gained in the initial flow test:

1. A steady state flow will be established along the fracture using synthetic groundwater.

2. A solution of groundwater containing tritium will be injected into the flow. Samples will be collected at regular intervals and analyzed at LLNL within the next few days. When the tritium peak has passed, we will know both the time of travel between the inlet and outlet holes and the amount of dilution and dispersion. This will allow us to make an informed estimate of the amounts of Sr, Cs, Tc, etc. to be injected so that the collected samples are above the level of dilution at which they can be analyzed given the sensitivity of the analytical method. For the retarded nuclides, we will need to adjust the concentrations to account for a larger dilution factor caused by increased dispersion.

3. A solution of groundwater containing a suite of radionuclides (see Subtask 3.1) will be injected into the flow. Samples will be collected over a period of time to be decided upon in later planning based on the results of the core sorption work. During this time, it is expected that radionuclides with the smallest retardation will pass through the fracture. The time each peak is eluted relative to

tritium will give us a direct measure of the retardation factor as illustrated in Figure 10. The peaks shown in Figure 10 are highly idealized. It's possible that the single pulse injection will produce a poorly defined peak due to dilution by mixing, dispersion, poor recovery at the inlet hole, loss into connecting fractures or non-equilibrium sorption kinetics. A second alternative is a continuous injection where a spiked solution of constant concentration is injected for a period of time equal to the travel time of a non-reactive tracer. The ratio of the concentration at the outlet to the original concentration (C/C_0) plotted against time should produce an S-shaped curve starting at $C/C_0 = 0$ and ending at $C/C_0 = 1.0$. The time at $C/C_0 = 0.5$ is equivalent to the peak time in Figure 10 and can be used to calculate a retardation factor in a similiar way. Before the field experiments begin, we will try both methods in the laboratory and determine which one gives the best results.

In addition to analyzing the eluent from the fracture to determine the retardation factor, it may be possible to monitor the radionuclide migration using a nondestructive measurement method. Two such methods have been developed at Battelle Pacific Northwest Laboratories and the NASA Johnson Spacecraft Center (R. J. Serne, personal communication). Both methods employ neutron sources and downhole detectors. Further study will be needed to assess the applicability of these methods to field tracer studies.

4. At the end of the first experiment, there will be a second injection of radionuclides. This time only those that have been eluted will be injected again. This will give us duplicate retardation factors for some radionuclides while allowing the experiment to continue to run with the hopes of eventually eluting the radionuclides that have higher retardation. If time permits, we will do a third injection and analysis. A second fracture might also be studied, if the first set of experiments have gone smoothly and in a relatively short period of time. We have allowed approximately 9 months for the injection-collection phase of the study.

Subtask 3.5: Perform Post-test Sampling and Analysis

At the end of phase one we will back-core into the fracture between the inlet and outlet hole. Samples containing the fracture will be studied to detect the presence of radionuclides which have either precipitated or are still in the process of migrating through the fracture (see subtask 4.3). The position of radionuclides remaining in the fracture will allow us to calculate a retardation factor provided a peak concentration can be found and the material is not simply distributed somewhere along the fracture. This might occur if precipitation rather than sorption takes place as could be the case with technetium.

At the end of the migration experiments and the supporting subtasks a final report will be written which compares the field and laboratory work, discusses the capabilities of the pre-test predictions, and makes recommendations for the use of similar tests on other rock types.

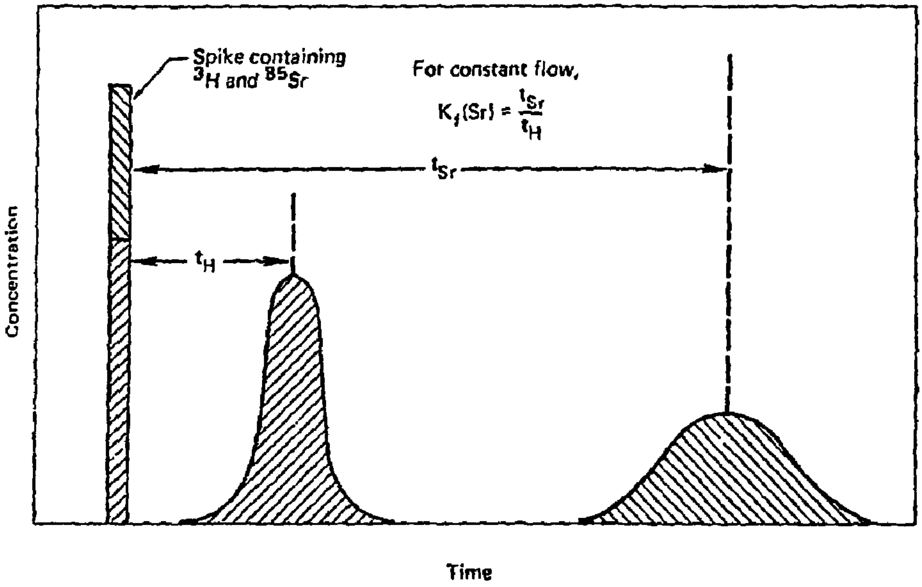


Fig. 10 Measurement of the retardation factor relative to tritium.

TASK 4: LABORATORY SUPPORT STUDIES

Subtask 4.1: Batch K_d Experiments

Limited batch K_d experiments will be performed on both the granite and the fracture fill material. The laboratory technique for batch K_d's was developed as part of the WRIT program and is described in Relyea et al., 1980. These data will help to predict the amount of tracer sorption expected during the field tracer test. This prediction is needed to plan the timing of the experiment. Tracers with high K_d's cannot be expected to exit the fracture within a reasonable time interval. Tracers with low K_d's are expected to be eluted from the fracture in a sequence based on their sorptive character. As this is a test of sorption measuring techniques scaled up from the laboratory to the field, batch K_d measurements will be compared both to the field observations and to the laboratory core sorption studies. To make this comparison, K_d will be calculated on the basis of surface area rather than mass. This surface distribution coefficient (K_a) is expressed in cm instead of ml/g. It can be used to calculate a retardation factor using the equation:

$$K_f = 1 + \frac{2K_a}{b}$$

where K_f is the retardation factor and b is the average fracture aperture. The value for b will either be calculated from the hydraulic data obtained in the flow tests, or will be directly measured using the borescope. The retardation factors obtained using laboratory K_a's can be compared to the laboratory and field retardation factors which are directly measured.

Subtask 4.2: Core Sorption Experiments

Core sorption experiments will be conducted using natural intact fractures to assess tracer movement for the subsequent field study. These measurements will be used in conjunction with the batch K_d measurements for planning the field tests. However, the core sorption studies more nearly simulate the actual field conditions. Consequently, they should provide the best prediction of tracer migration for the field study. Figure 11 is a schematic drawing of the core sorption apparatus developed at LLNL. The core is pressurized externally to lithostatic pressure and then tracer-doped groundwater is pumped through the core.

The core sorption study is a logical step in determining the scaling factors of laboratory to field studies. Data from the core sorption work can be compared both to the batch data and to the field data. Identical water, tracers, and fracture materials will be used for both the core sorption and field studies.

Subtask 4.3: Petrographic Studies

The fracture in the core which has been correlated with the fracture selected for the field migration experiments will be studied to identify the fracture fill material and mineral alteration products. We will use an electron microprobe, scanning electron microscope, x-ray analysis, and thin sections to characterize the fracture materials before contact with the synthetic groundwater and radionuclides. Following the migration experiment, we will analyze fractures obtained from the back-coring operation using the same techniques and determine whether mineral changes have occurred and whether radionuclides are present along the fracture betweeen the inlet and outlet holes. This will only be possible if the amount of radionuclides present are above the detection capabilities of the microprobe. Autoradiography will be used to identify sorption sites in the rock (Smyth, et al., 1980; Beall, et al., 1980).

5.0 PROGRAM INTERFACES

This project will interface closely with ongoing NWTS projects concerned with model development and laboratory data development for radionuclide migration. Of special importance are the three projects in ONWI's Waste Isolation

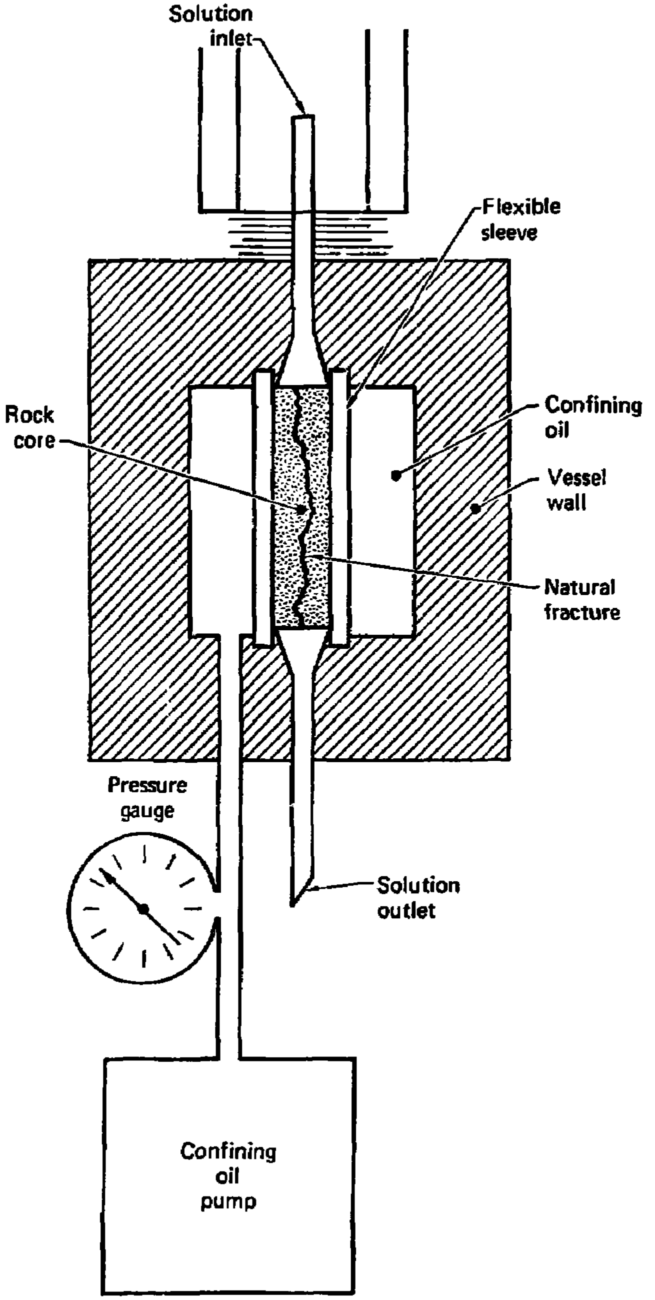


Fig. 11 Schematic drawing of laboratory core sorption apparatus.

Performance Assessment Program (WIPAP). They are: (1) the Systematic Comprehensive Evaluation of Performance and Total Effectiveness of Repositories (SCEPTER); (2) the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS); (3) and Waste-Rock Interaction Technology (WRIT). SCEPTER, being conducted by INTERA, and AEGIS, a PNL project, are both modeling efforts concerned with model development to predict repository performance. The WRIT project is a laboratory project designed to develop laboratory techniques and conduct laboratory experiments. The interaction between these three projects and the field test is shown in Figure 12. The intergration of field, laboratory and model results will be accomplished by the transfer of data in progress reports and topical reports where applicable. Representatives from the three WIPAP projects will be invited to peer review meetings when appropriate. It is hoped that both SCEPTER and AEGIS can participate by providing pre-test predictions prior to the radionuclide migration tests. These pre-test predictions will be compared to the results of our own limited model applications. It is expected that the transfer of information will be two-way. The field tests will provide field measurement techniques, test results, and data interpretation to the WIPAP projects. They in turn will provide laboratory techniques, experimental data, developed models and/or pre-test predictions.

In addition to the WIPAP interaction, this project will cooperate and interact on a regular basis with the field migration study in tuff at NTS being conducted by LASL, SNL, and ANL. The results of the two field studies will complement each other and provide a solid base for future field testing.

The Spent Fuel Test (SFT) now operating in the Climax granite will also interface with this project by providing access to the existing data acquisition system to remotely monitor and control the radionuclide migration experiments and collect and store data.

6.0 SCHEDULE/MAJOR MILESTONES

The program schedule (Fig. 13) lists all project activities with estimated start and finish dates. These dates were derived from the network chart (see Appendix), a planning aid used to show the interrelationship of activities.

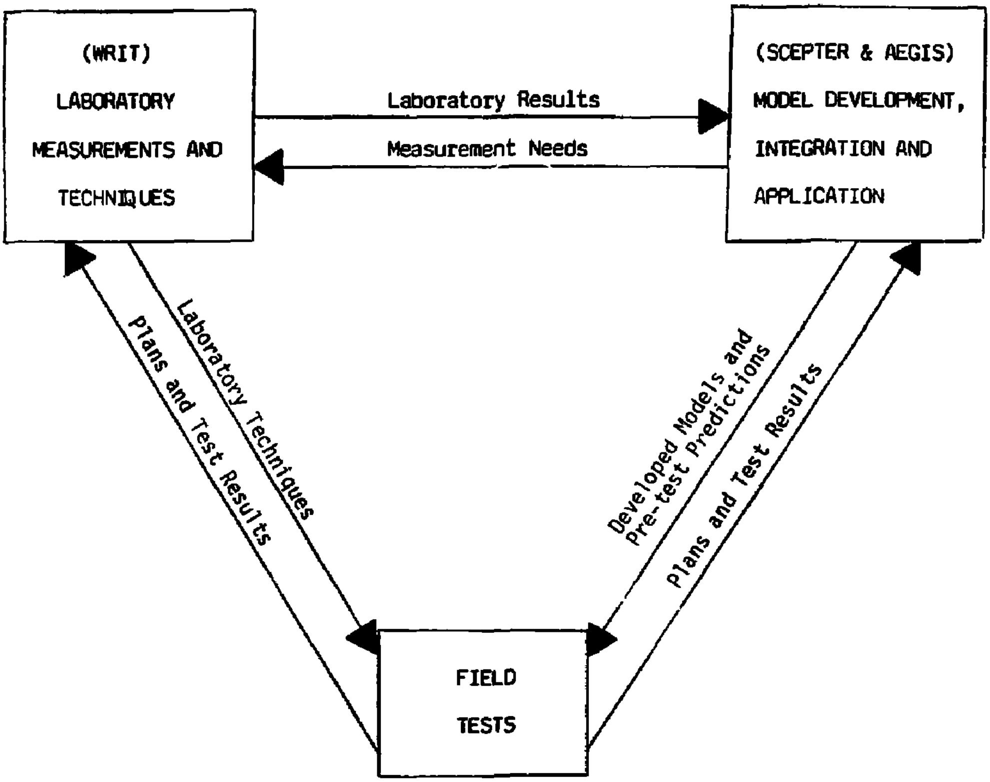


Fig. 12 Flow diagram showing the interaction between ongoing ONWI programs and field migration studies.

FIG. 13 ACTIVITY SCHEDULE

	EST. TIME WEEKS
1. REV/APPR MIGR EXPER FUNDG	25.2
2. AUTHORIZE FUNDS TO NV	4.8
3. NEGOTIATE/PLACE CONTRACT	4.0
4. ESTABLISH STAFF F/PROJECT	4.0
5. AUTH EXPER FUNDS TO LLL	4.0
6. DSN WATR COLLCTN APPARATS	8.0
7. PREP PREL EXPER DESIGN	8.0
8. PREPARE QA PLAN	8.0
9. DESIGN PREL FLOW TST/LIST EQ	8.0
10. PREPARE SITE	4.0
11. COMPL PREL SITE SURVEY	4.0
12. PREP/AUTH F/WATER EQUIP	2.0
13. PREP/AUTH PR F/FLOW TST	3.0
14. SELCT SITE F/PREL FLW TST	4.0
15. ADAPT HYDRO MODS. PRETST	18.0
16. DSN/FAB PLATE FLOW EQUIP	18.0
17. PREP DRILLNG REQST/TRANSF	4.0
18. PROC EQUIP SHIP TO SITE	8.0
19. NEGO DRILL CONTR DRIL HOL	4.0
20. PREPARE PROGRAM PLAN	12.4
21. CONDUCT PEER REVIEW	3.0
22. PREP CORE/SHIP TO LLL	4.0
23. FAB WATER COLLCTNG EQUIP	14.0
24. REVISE PROGRAM PLAN	4.0
25. DSN TRACER INJECTN/SAMPLE	20.0
26. INSTL EQUIP PERF FLOW TST	16.0
27. SHIP TO SITE/CHK-OUT	4.0
28. REV/EVL DTA PERF HYDR TST	8.0
29. PUBLISH PROGRAM PLAN	8.0
30. INSTALL/COLLCT WATER	8.0
31. ANAL/CHARACTERIZE WATER	2.0
32. MAP FRACTURES/SELCT SITES	8.0
33. PREP SYNTHETIC GROUND WTR	2.0
34. SHIP WATER TO SITE	2.0
35. PREP ENGINRNG TST PLAN NV	8.0
36. PERF LAB SORPTION STUDIES	25.0

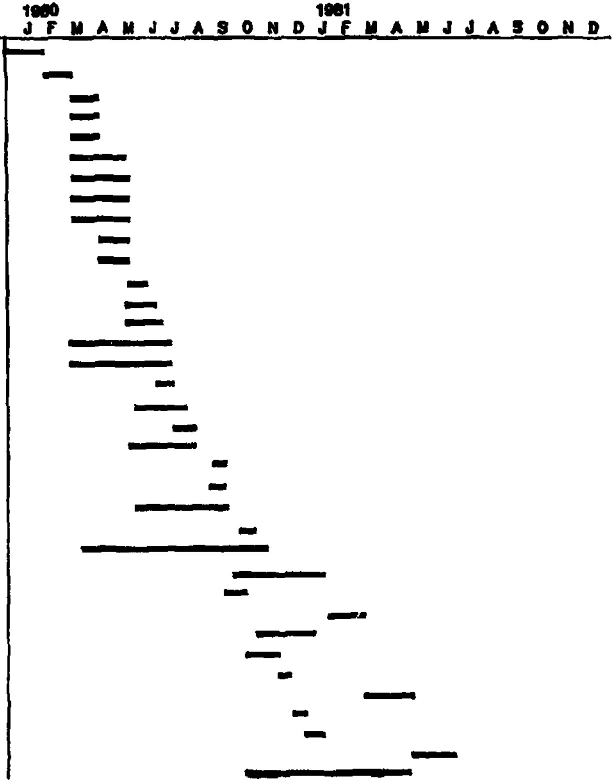
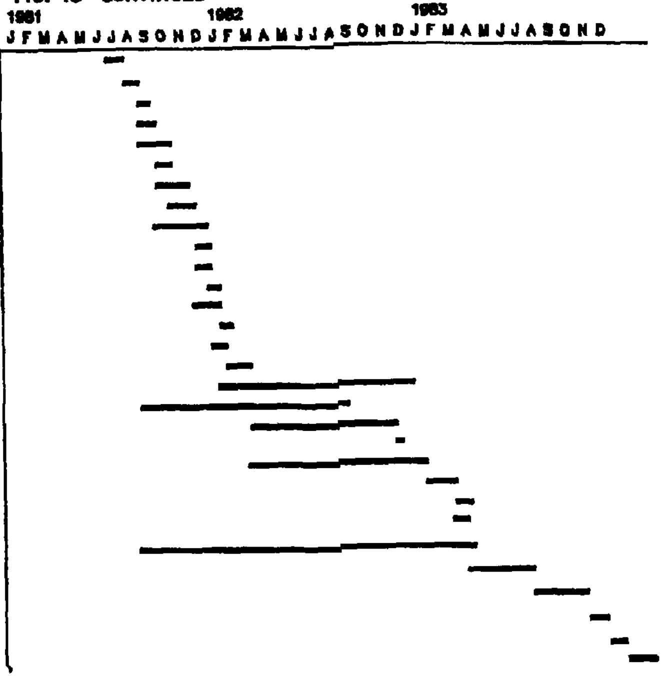


FIG. 13 CONTINUED

	EST. TIME WEEKS
37. PEER REVW OF ENGINRNG PLN	6.0
38. INCORP CHNGS SUGG BY REVW	4.0
39. PREP AUTH PR F/RNM EQUIP	3.0
40. PREP DRILLNG REQ/TRAN MV	4.0
41. PUBLISH ENGNEERNG TST PLAN	8.0
42. NEGOT/PLACE DRLLNG CONTR	4.0
43. PROCURE RNM EQUIPMENT	8.0
44. DRILL HOLES/INSTALL EQPMT	6.0
45. PROCURE TRACERS	13.0
46. CONDUCT FLOW TESTS	4.0
47. PREP CORE/SHIP TO LLL	4.0
48. PREP SOLUTNS F/TRACR EXPR	3.0
49. PERF EQUIPMNT CHECK-OUT	8.0
50. SHIP TO SITE	2.0
51. EVAL DATA/INCORP CHNGES	4.0
52. INSTL/CHK-OUT RNM EQUIPMT	6.0
53. PERF ADDL LAB SORPTN STDY	50.0
54. COND LAB PARA PLATE FLOW	54.0
55. LEAD TIME	34.0
56. PREP BACK-CORNG CRIT LETR	1.0
57. CONDUCT TRACER EXPERIMENT	44.0
58. PREP F/BACK-CORING OPS	6.0
59. CLEAN-UP SITE	4.0
60. PREP CORE/SHIP TO LLL	4.0
61. PERF TRANSPRT MODLNG STDY	80.0
62. PERF FRCTURE-CORE ANALYS	16.0
63. PREP IN SITU MIGRATN RPT	13.0
64. PEER REVW OF DRFT RPT	6.0
65. REVIEW DRAFT REPORT	4.0
66. PUBLISH FINAL REPORT	8.0



It is important to remember that the dates in the schedule represent best current estimates and will need to be revised as the project evolves. This is especially true for fiscal years 1982 and 1983. We have included a detailed list of activities and time estimates for these years primarily as a guide to future planning.

The program schedule is based on the following assumptions:

1. Flow will be established in the initial hydraulic test.
2. Equipment and supplies will be available without extraordinary delays.
3. Extensive redesign of equipment will not be necessary.
4. Peer reviews of the project will be timely and not require extensive modification.
5. Extensive revision of documents will not be required.
6. Access to the Climax underground workings remains unrestricted.
7. Work stoppages or strikes will have little or no effect on project needs.
8. Equipment which will satisfy the experimental requirements can be engineered and built within the projected schedules.

Failure of these assumptions will mean added cost and time. A more detailed analysis of the impact on the program and an updated version of the activity schedule and network charts will be included in the Engineering Test Plan. Prior to writing the Test Plan, we will have tested assumption number 1 with our initial flow test. Failure to establish flow will require a decision on whether to continue with the project by testing several additional fractures. This would require a significant revision of both the schedule and budget.

We have established major program milestones (Table 3) to measure program progress and indicate program goals. Criteria for milestone completion are provided to give a clear understanding of what constitutes a completed milestone. The date of milestone completion is an estimate based on the activities schedule. Milestones for FY82 and 83 may need to be revised in accordance with changes in the activities as defined in the Engineering Test Plan. The project will be essentially complete in FY 83. We anticipate a short time in FY 84 will be needed for formal publication of the final report.

7.0 BUDGET

The budget showing estimated costs of the program described in this document is broken down by fiscal years in Table 4. A revised budget will be prepared once we have completed the Engineering Test Plan.

Table 4. Estimated Project Budget

FY	Operating Costs ($K)	Equipment Costs ($K)
1980	250	-
1981	760	160
1982*	810	100
1983*	720	30
1984*	300	-
Total	2840	290

* 1981 Dollars

TABLE 3: MILESTONE SCHEDULE FOR RADIONUCLIDE MIGRATION STUDIES - GRANITE

Milestone	Criteria for Milestone Completion	Estimated Date
FY 1980		
1. Draft Program Plan completed.	The draft Program Plan will be sent for review to peer review group, ONWI and NVO.	8/1/80
FY 1981		
1. Program Plan distributed.	The Program Plan is revised to reflect the recommendations of the reviewers and will be distributed to ONWI and NVO.	12/1/80
2. Initial flow test completed.	A technical letter report describing the flow characteristics of the fractures and an evaluation of the feasibility of the tracer experiments will be sent to ONWI and NVO.	1/14/81
3. Draft Engineering Test Plan issued.	The draft Engineering Test Plan will be sent for review to the peer review group, ONWI and NVO.	6/18/81
FY 1982		
1. Engineering Test Plan published.	The revised Engineering Test plan will be published as a LLNL document and distributed to ONWI and NVO.	10/26/81
2. Site suitability for tracer experiment verified.	A technical letter report describing the results of the flow tests to evaluate the suitability of the site for the radionuclide migration experiment will be sent to ONWI and NVO.	1/13/82
3. Radionuclide migration experiment initiated.	The installation of the tracer injection-collection equipment followed by an equipment check-out will be documented in the project records and verified by the Project Leader. ONWI and NVO will be notified.	3/24/82

TABLE 3: PROGRAM MILESTONES (CONTINUED)

Milestone	*Criteria for Milestone Completion*	Estimated Date
FY 1983		
1. Radionuclide migration experiment completed.	This milestone will be reached when the field radionuclide migration experiments are completed as described in the engineering test plan. A technical letter report briefly describing the results of the experiments will be sent to ONWI and NVO.	1/19/83
2. Migration studies completed	The petrographic and sorption studies on the core material will be completed with sufficient detail to allow for a comparison with and interpretation of the field data. A preliminary report will be included in the quarterly report.	7/22/83
FY 1984		
1. Draft final report submitted	A draft final report covering all aspects of the project will be distributed for peer review by ONWI and NVO	10/22/83
2. Final report published.	A revised final report will be published as an LLNL document and provided to ONWI and NVO for distribution.	3/7/84

8.0 TECHNICAL CONTROL

Technical control of the project belongs primarily to the Project Leader who has the overall responsibility for defining tasks, assigning task leaders, approving task activities at critical stages and maintaining the Quality Assurance (QA) Plan. A QA Plan for this project has been reviewed and released as a separate document. The QA Plan defines responsibilities for each of the quality control elements of the project and specifically states the requirements for corrective action, QA records, QA audits and procurement procedures.

LLNL operates under a matrix system in which personnel belong to a functional organization and, at the same time, are assigned to projects. The technical quality is the responsibility of line management. Reports are approved and signed off by both line and project management. The LLNL Associate Director approves all projects and budgets. There are no separate internal reporting requirements, however the LLNL Technical Project Officer reviews all progress reports and topical reports sent to ONWI and NVO.

9.0 PROGRAM CONTROL

Program control will be established and maintained by mutual agreement between LLNL, NVO and ONWI. The LLNL principal investigator (project leader) is responsible to the LLNL Technical Project Officer (TPO) for technical leadership. Management decisions regarding budgets, lines of communication and reporting requirements will be approved by the TPO (and where necessary, by higher LLNL management), followed by negotiations with NVO and ONWI. Subsequent changes in cost, schedule or scope of a technical milestone will be negotiated with NVO with approval by ONWI. Program reporting requirements including report scheduling currently established for this project are outlined in Table 6. The required weekly, monthly and quarterly reports are sufficient to document technical progress of the project. The cost analysis provided in the monthly report will provide information needed for financial planning and accountability.

Table 6 : Deliverable Data and Reporting Requirements*

Title	Frequency	When to be Submitted
Activity Report	Weekly	Friday
Progress Status Report including milestone status and cost report	Monthly	Within 10 calendar days
Quarterly Progress Report	Quarterly	Within 15 calendar days
Milestone Completion Reports	As Needed	N.A.
Topical Reports	As Needed	N.A.
Engineering Test Plan	Once	Draft 6/81
QA Plan	Once	9/80

*The distribution list and number of copies required will be in accordance with current ONWI and NVO needs, and LLNL policy.

ACKNOWLEDGMENTS

The authors are grateful to all the reviewers of a draft version of this Program Plan for their helpful suggestions and comments. We especially wish to thank Dr. Jesse Cleveland, Dr. Paul Fenske, Dr. Gerry Grisak, Dr. Liang-Chi Hsu, Dr. John Osmond, Dr. Peter Sargent, Dr. David Snow, and Dr. Paul Witherspoon for their participation in the formal peer review of our program held several months ago. We hope that we have made the most out of their suggestions, however, as authors of this document, we take complete responsibility for the final results.

REFERENCES

C. Ammann, Case History Analyses of Characteristics of Reservoir Rocks from Drill-Stress tests; Jour. Pet. Tech., V. 12, No. 5, 1960.

G. Beall, G. O'Kelley, and B. Allard, An Autoradiographic Study of Actinide Sorption on Climax Stock Granite; Oak Ridge National Laboratory, ORNL-5617, 1980.

E. Bondietti and C. Francis, Geologic Migration Potentials of Technetium-99 and Neptunium-237, Science; V. 203, 1337, 1979.

I. Borg et al., Information Pertinent to the Migration of Radionuclides in Ground Water at the Nevada Test Site; UCRL-52078, Part 1, May, 1976.

J. Cobbs, Design and Development of Horizontal Borehole Packers for Use in Coal Beds; Open File Report No.: BuMines-OFR-6-72, Bureau of Mines, Feb., 1972.

J. Dennis and J. Lucas, Adsorption of Caesium Ions by Some Materials Used in the Manufacture of PVC-Based Surface Coatings; Journal of Materials Science, V. 13, p. 119-127, 1978.

J. Dolan, C. Einarsen and G. Hill, Special Applications of Drill-Stem Test Pressure Data; Am. Inst. Mining Metall. Pet. Eng. Trans., V. 210, p. 318-324, 1957.

F. Ichikawa, Studies of the Behavior of Carrier-free Radioisotopes; Radiochimica Acta Band 22 Heft 3, p. 97-100, 1975.

F. Ichikawa and T. Sato; Studies of the Behavior of Carrier-Free Radioisotopes, Radiochimica Acta Band 16 Heft 2 p. 78-80, 1971.

G. Morgan E., Galbraith and F. Gilereas, The Adsorption of Various Radioisotopes Upon Selected Materials; in Surface Contamination, Proceedings of a Symposium held at Gatlinburg, Tennessee, June 1964.

Nuclear Regulatory Commission, Waste Conference Rulemaking, Statement of Position of the U.S. Department of Energy, DOE/NE-0007, April 15, 1980.

Office of Nuclear Waste Management, Department of Energy and U.S. Geological Survey, Earth Science Technical Plan for Disposal of Radioactive Waste in a Mined Repository, DOE/TIC-11033 (draft), April 1980.

L. Ramspott et al., Technical Concept for a Test of Geologic Storage of Spent Reactor Fuel in the Climax Granite, Nevada Test Site, UCRL-52796, June 1979.

L. Ramspott and N. W. Howard, Average Properties of Nuclear Test Areas and Media at the USERDA Nevada Test Site; Lawrence Livermore National Laboratory, Rept. UCRL-51948, 1975.

Relyea, J., et al, Methods for Determining Radionuclide Ratardation Factors: Status Report; Pacific Northwest Laboratories, PNL-3349, 1980.

E. Shuter an R. R. Pemberton, Inflatable Straddle packers and Associate Equipment for Hydraulic Fracturing and Hydrologic Testing, U.S. Geological Survey, Water-Resources Investigations, p. 78-55, 1978.

A. Skul'skii and A. Lyubimov, Comparative Investigation of the Adsorption of Yttrium-90 and Yttrium-91 from Sea Water on Teflon; Radiokhimiya, V. 13, No. 2, p. 276-278, 1971.

A Skul'skii and A. Lyubimov, The Adsorption of Yttrium-91 and Cesium-137 from Sea Water and Aqueous Solutions of Various Ages on Glass and Teflon; Radiokhimiya V. 13, p. 272-275, 1971.

J. Smyth, J. Thompson and K. Wolfsberg, Microautoradiographic studies of the sorption of U and Am on natural rock samples; Radioactive Waste Management, V. 1, p. 13-24, 1980.

G. Walker, Ground Water in the Climax Stock, Nevada Test Site, Nye County, Nevada; U.S.G.S., Report TEI-813, 1962.

APPENDIX

The network charts included in the Appendix are work-flow diagrams which include an identification of the activities, the sequence in which they take place, the assignment of responsibilities and time estimates. It is important to emphasize that the network charts are to be used as a plan, in every sense of the word. Because of the uncertainty of research projects, the plan must have flexibility and be easily changed. The times given are not commitments, but current estimates of the time required for an activity provided the work goes smoothly with only minor delays. As more information becomes available, these time estimates will need to be revised. For more information on the approach and proper use of network charts, read Archibald and Villoria, 1968. For a brief, but informative discussion of the philosophy and realistic use of network charts, I suggest Becktell, 1980.

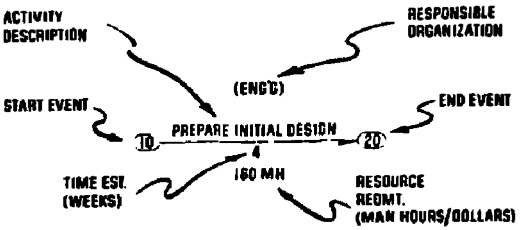
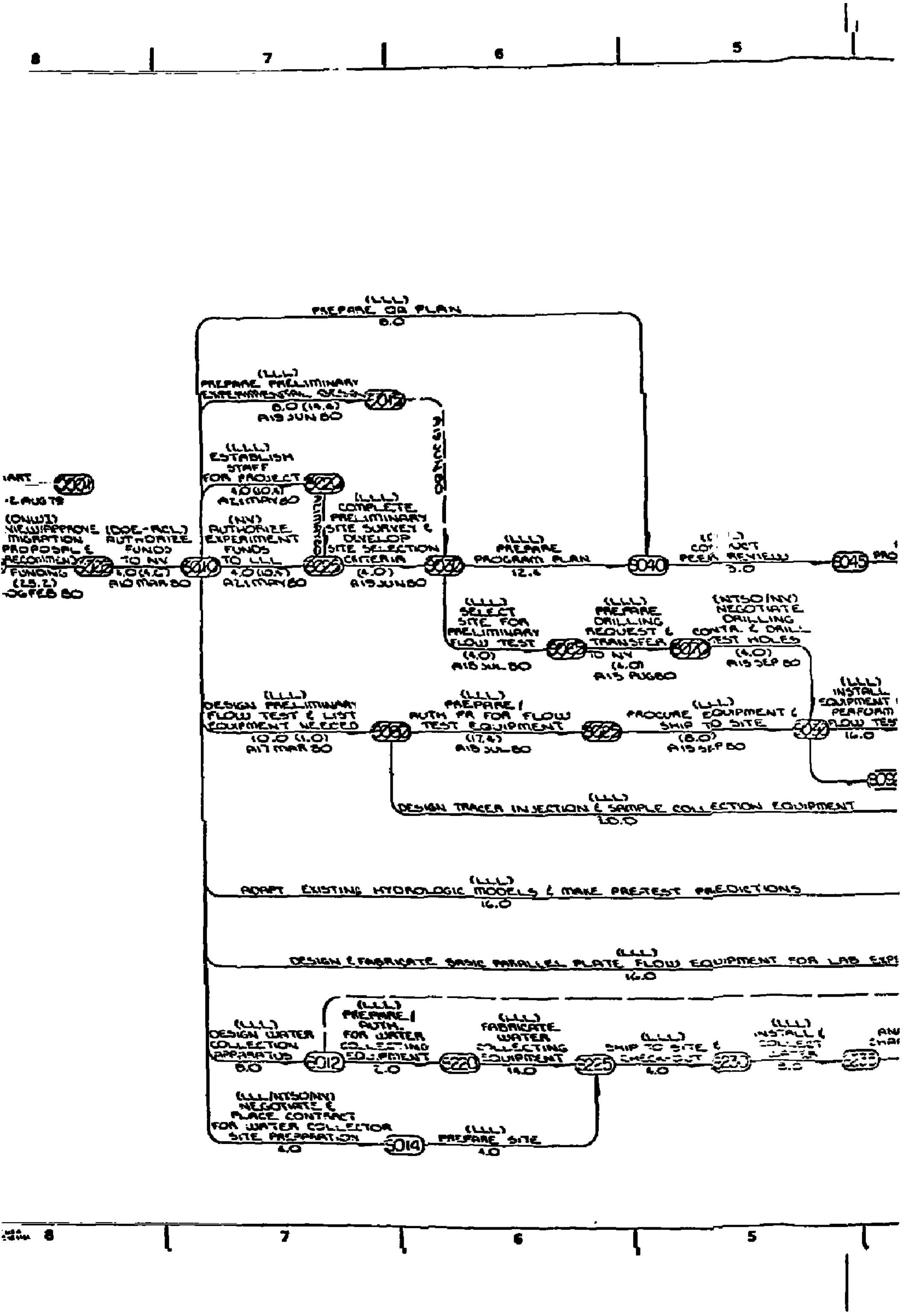


Fig. I: This example identifies the various elements in the network charts. The event numbers are used to identify activities for computer generated schedules and to show their interrelationship (e.g., activity 10-20 comes before activity 20-30). Figure is from Becktell, 1980.

REFERENCES

Archibald, R., and R. Villoria, Network-Based Management Systems (PERT/CPM) (New York: John Wiley and Sons, 1968).

Becktell, M., A Realistic Approach to the Planning of High Technology, High Risk Projects, Sandia National Laboratories, SAND79-1483, 1980


8
7
6
5
(LLL)
PREPARE QA PLAN
8.0
(LLL)
PREPARE PRELIMINARY
EXPERIMENTAL DESIGN
8.0 (14.4)
A15 JUN 80
(LLL)
ESTABLISH
STAFF
FOR PROJECT
4.0 (0.4)
A21 MAY 80
ART
-2 AUG 79
(ONWI)
REVIEW/APPROVE
MIGRATION
PROPOSAL &
RECOMMEND
FUNDING
(25.2)
-06 FEB 80
(DOE-RCL)
AUTHORIZE
FUNDS
TO NV
4.0 (4.6)
A10 MAR 80
5010
(NV)
AUTHORIZE
EXPERIMENT
FUNDS
TO LLL
4.0 (10.4)
A21 MAY 80
(LLL)
COMPLETE
PRELIMINARY
SITE SURVEY &
DEVELOP
SITE SELECTION
CRITERIA
(4.0)
A15 JUN 80
(LLL)
PREPARE
PROGRAM PLAN
12.4
5040
CONDUCT
PEER REVIEW
3.0
5045
(LLL)
SELECT
SITE FOR
PRELIMINARY
FLOW TEST
(4.0)
A15 JUL 80
(LLL)
PREPARE
DRILLING
REQUEST &
TRANSFER
TO NV
(4.0)
A15 AUG 80
(NTSO/NV)
NEGOTIATE
DRILLING
CONTR. & DRILL
TEST HOLES
(4.0)
A15 SEP 80
(LLL)
INSTALL
EQUIPMENT
PERFORM
FLOW TEST
16.0
(LLL)
DESIGN PRELIMINARY
FLOW TEST & LIST
EQUIPMENT NEEDED
10.0 (1.0)
A17 MAR 80
(LLL)
PREPARE/
AUTH PR FOR FLOW
TEST EQUIPMENT
(17.4)
A15 JUL 80
(LLL)
PROCURE EQUIPMENT &
SHIP TO SITE
(8.0)
A15 SEP 80
(LLL)
DESIGN TRACER INJECTION & SAMPLE COLLECTION EQUIPMENT
10.0
(LLL)
ADAPT EXISTING HYDROLOGIC MODELS & MAKE PRETEST PREDICTIONS
16.0
(LLL)
DESIGN & FABRICATE BASIC PARALLEL PLATE FLOW EQUIPMENT FOR LAB EXP
16.0
(LLL)
DESIGN WATER
COLLECTION
APPARATUS
8.0
2012
(LLL)
PREPARE/
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FOR WATER
COLLECTING
EQUIPMENT
2.0
5220
(LLL)
FABRICATE
WATER
COLLECTING
EQUIPMENT
14.0
5225
(LLL)
SHIP TO SITE &
CHECK-OUT
4.0
(LLL)
INSTALL &
COLLECT
WATER
3.0
(LLL/NTSO/NV)
NEGOTIATE &
PLACE CONTRACT
FOR WATER COLLECTOR
SITE PREPARATION
4.0
5014
(LLL)
PREPARE SITE
4.0

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	2		REVISED UPDATED	GA	3-21-80		
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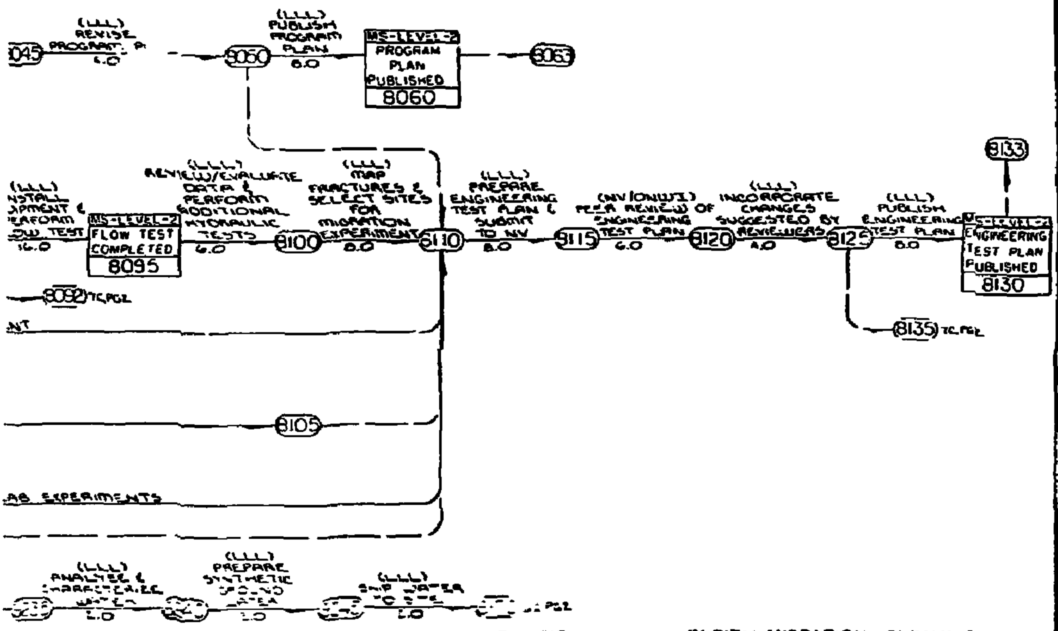

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[illegible]	NELSON
[illegible]	LINCOLN
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SHEET INDEX

PART CLASSIFICATION

Sandia

DWG CLASSIFICATION LEVEL

UNCLASSIFIED

TITLE

GRANITE

NTS MGRANT

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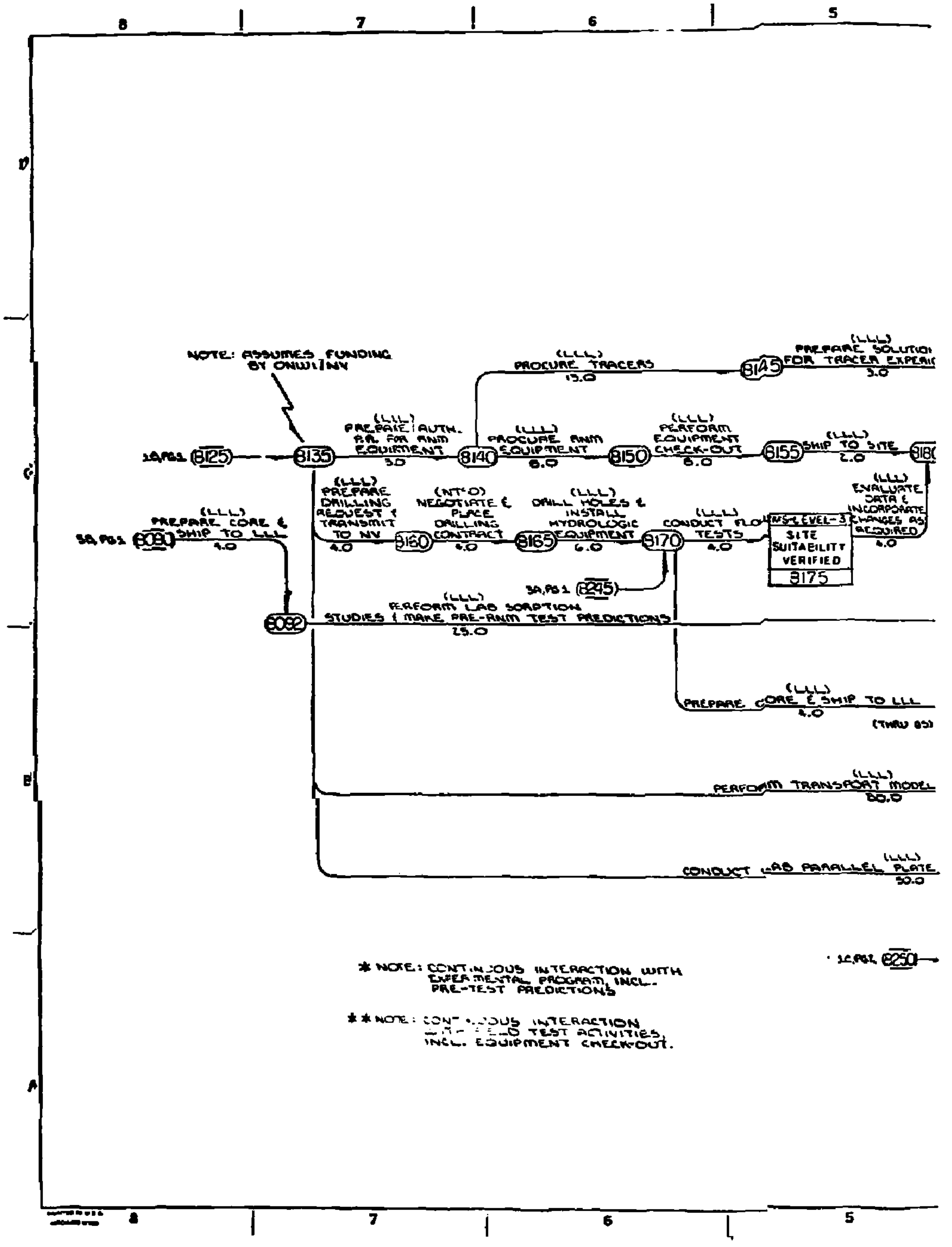
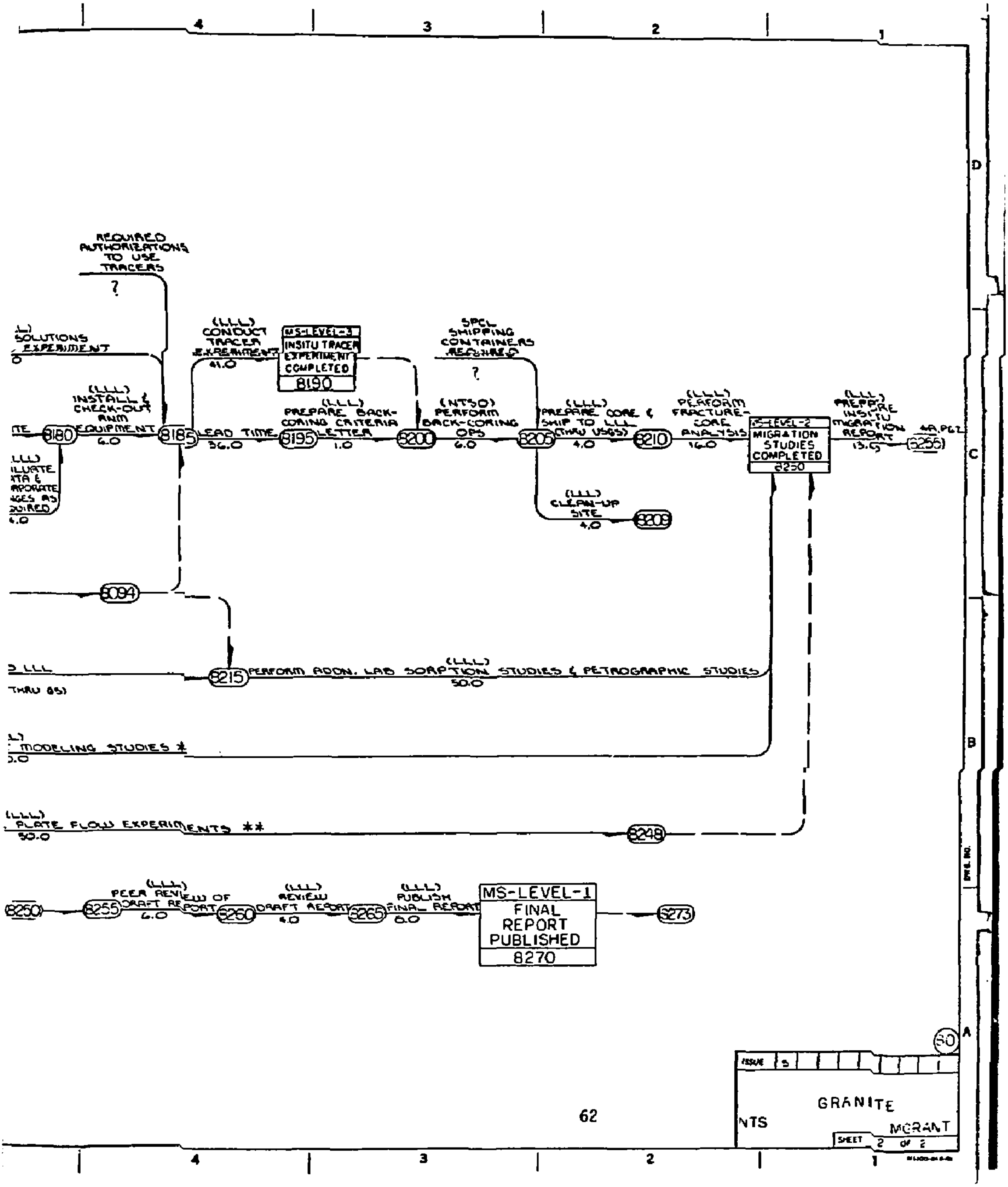
SHEET 1 OF 2



* NOTE: CONTINUOUS INTERACTION WITH EXPERIMENTAL PROGRAM, INCL. PRE-TEST PREDICTIONS

** NOTE: CONTINUOUS INTERACTION WITH FIELD TEST ACTIVITIES, INCL. EQUIPMENT CHECKOUT.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SOLUTIONS EXPERIMENT
(LLL) CONDUCT TRACER EXPERIMENT 41.0
MS-LEVEL-3 INSITU TRACER EXPERIMENT COMPLETED 8190
SPCL SHIPPING CONTAINERS REQUIRED
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(LLL) INSTALL & CHECK-OUT RNM EQUIPMENT 6.0
8180
8185
LEAD TIME 36.0
8195
(LLL) PREPARE BACK-CORING CRITERIA LETTER 1.0
8200
(NTSO) PERFORM BACK-CORING OPS 6.0
8205
(LLL) PREPARE CORE & SHIP TO LLL (THRU USGS) 4.0
8210
(LLL) PERFORM FRACTURE-CORE ANALYSIS 16.0
MS-LEVEL-2 MIGRATION STUDIES COMPLETED 8250
(LLL) PREPARE INSITU MIGRATION REPORT 13.5
4A,PG.2
8255
(LLL) CLEAN-UP SITE 4.0
8209
(LLL) EVALUATE DATA & INCORPORATE CHANGES AS REQUIRED 4.0
8094
LLL (THRU 85)
8215
(LLL) PERFORM ADDN. LAB SORPTION STUDIES & PETROGRAPHIC STUDIES 50.0
(LLL) MODELING STUDIES * 0.0
(LLL) PLATE FLOW EXPERIMENTS ** 50.0
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8250
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