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Permeability Testing of Fractures in Cl'max Stock Granite, NTS

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Permeability Testing of Fractures in the Climax Stock Granite at the Nevada Test Site*

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ABSTRACT

Permeability tests conducted in the Climax stock granitic rock mass indicate that the bulk rock permeability can be highly variable. If moderately to highly fractured zones are encountered, the permeability values may lie in the range of 10^{-4} to 10^{-1} darcies. If, on the other hand, only intact rock or healed fractures are encountered, the permeability is found to be less than 10^{-9} darcies. In order to assess the thermomechanical effect on fracture permeability, discrete fractures will be packed off and tested periodically throughout the thermal cycle caused by the emplacement of spent nuclear fuel in the Climax stock.

INTRODUCTION

The Climax stock is an intrusive granitic mass in which nuclear weapons effects tests have been conducted at the Nevada Test Site (NTS). NTS is located about 100 km northwest of Las Vegas, Nevada (see Figure 1). As can be seen in Figure 2, the Climax stock is exposed at the ground surface over an area of about four square kilometers at the north end of NTS. Two major shafts have been excavated for nuclear tests in the Climax stock. Their locations are indicated on Figure 3 as Tiny Tot and Pile Driver. The Pile Driver shaft leads to tunnel complexes on two levels - the Hard Hat level about 250 meters below ground surface and the Pile Driver level about 420 meters below ground surface. The layout of these two tunnel complexes is shown in Figure 4.

The existing underground facilities have provided ready access to the Climax granite at a considerable depth - an ideal in situ test facility. A generic test of geologic storage of spent reactor fuel known as the Spent Fuel Test - Climax (Ramspott, et al., 1979) is being conducted in newly mined drifts adjacent to the existing drifts at the 420 meter level of the Pile Driver shaft. The recently initiated Tracer Migration Test (Isherwood, et al., 1980) is being conducted in an existing drift from the Pile Driver event.

In connection with the two in situ tests mentioned above, some permeability tests have been conducted and more are planned. Furthermore, permeability tests have been conducted to assess the fracture damage done by the nuclear explosions in the Climax granite, and the U.S.G.S. has conducted permeability tests in boreholes drilled for the initial exploration of the Climax stock intrusive mass. Permeability tests on core from the initial exploratory boring have also been made.

This report describes the character of the Climax granite and past permeability measurements, and it presents plans for future tests in conjunction with the Spent Fuel Test (SFT) and the Tracer Migration Test. Also, the possibility for future work involving the assessment of fracture damage around mined openings, fracture damage due to a thermal cycle, and general fracture flow hydrology is suggested.

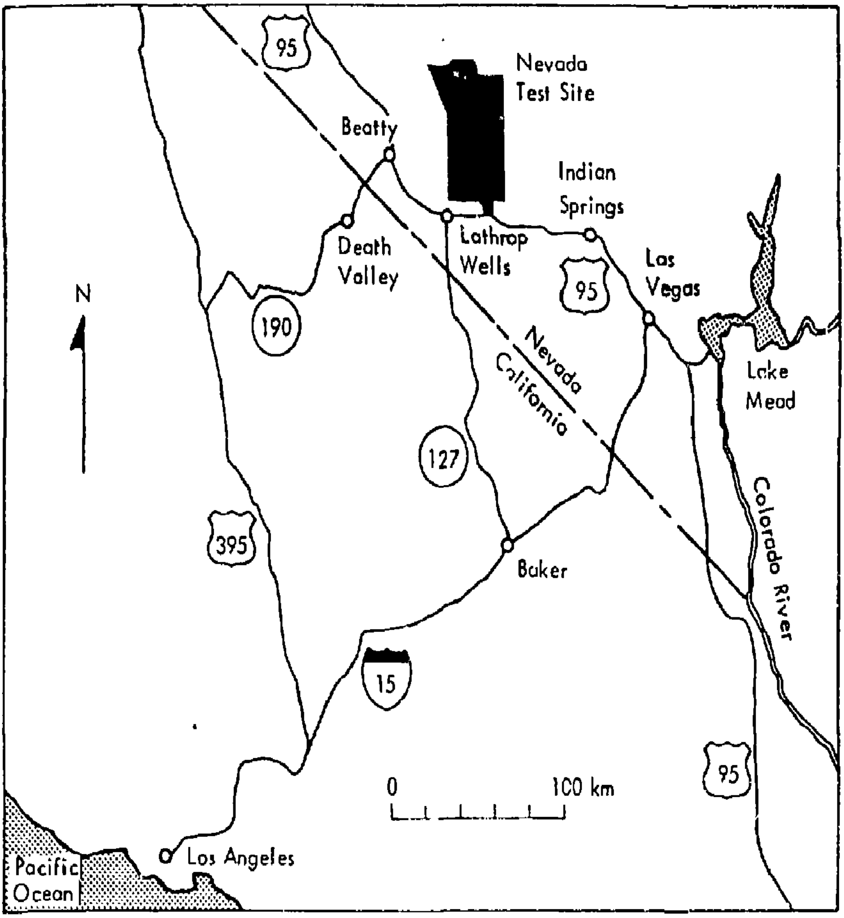

Figure 1 - Location of Nevada Test Site
(Borg, et al., 1976)

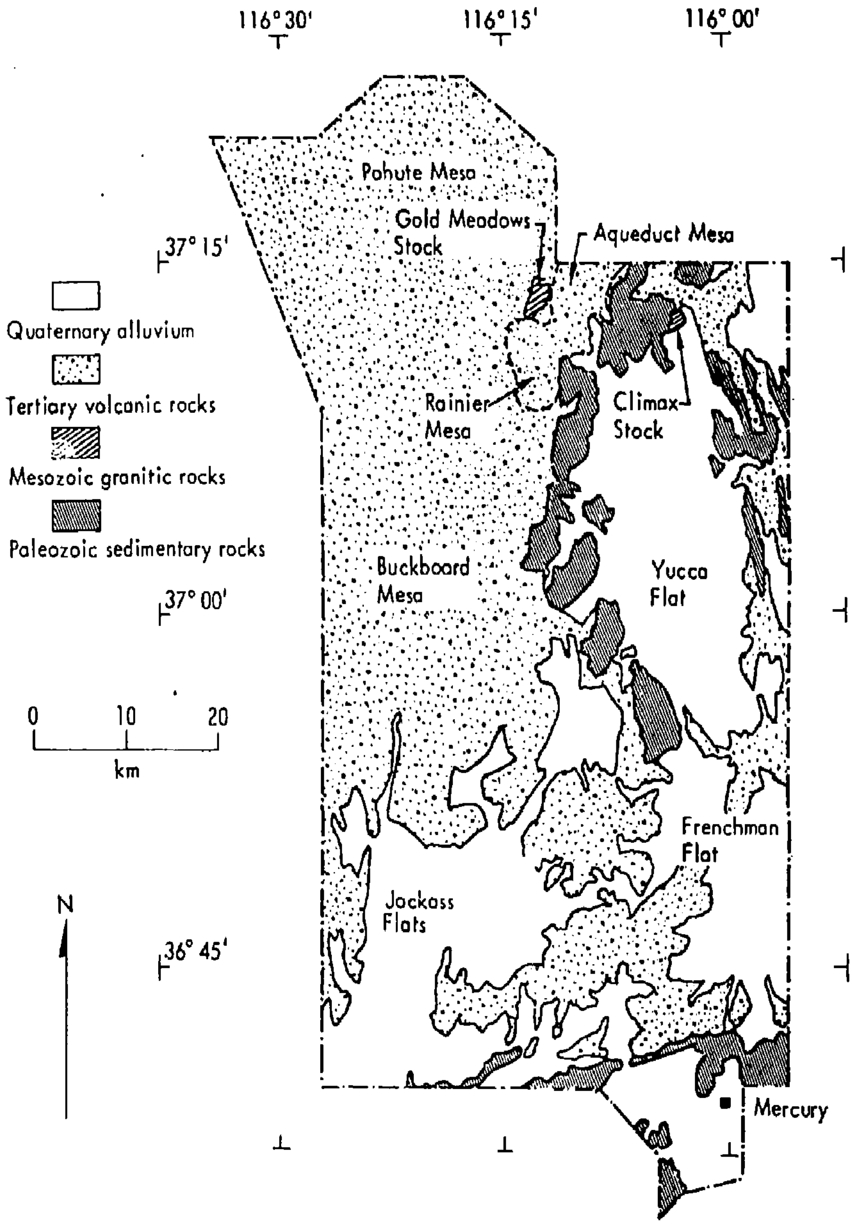

Figure 2 - Rock Types at Nevada Test Site
(Ramspott and Howard, 1975)

EXPLANATION

Qal — ALLUVIUM (QUATERNARY)

Tv — VOLCANIC TUFF, UNDIFFERENTIATED (TERTIARY)

Kqm — QUARTZ MONZONITE, CLIMAX STOCK (CRETACEOUS)

Kgd — GRANODIORITE, CLIMAX STOCK (CRETACEOUS)

Pz — LIMESTONE, DOLOMITE, SHALE, AND QUARTZITE, UNDIVIDED (PALEOZOIC)

CONTACT--Dashed where approximately located

FAULT--Dashed where approximately located. Dotted where concealed. Bar and ball on downthrown side

SHAFT

UE15d O TD 6,000 (1,829 m) — DRILL HOLE--Showing total depth in feet, meters in parenthesis

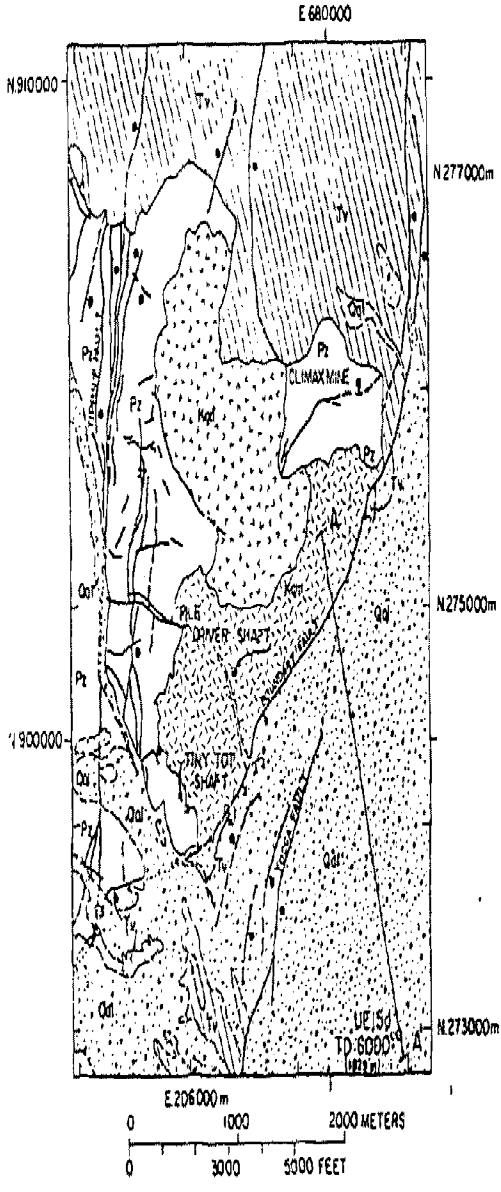

Figure 3 - The Climax Stock with Locations of Pile Driver and Tiny Tot Shafts. (Modified from Barnes, et al., 1963)

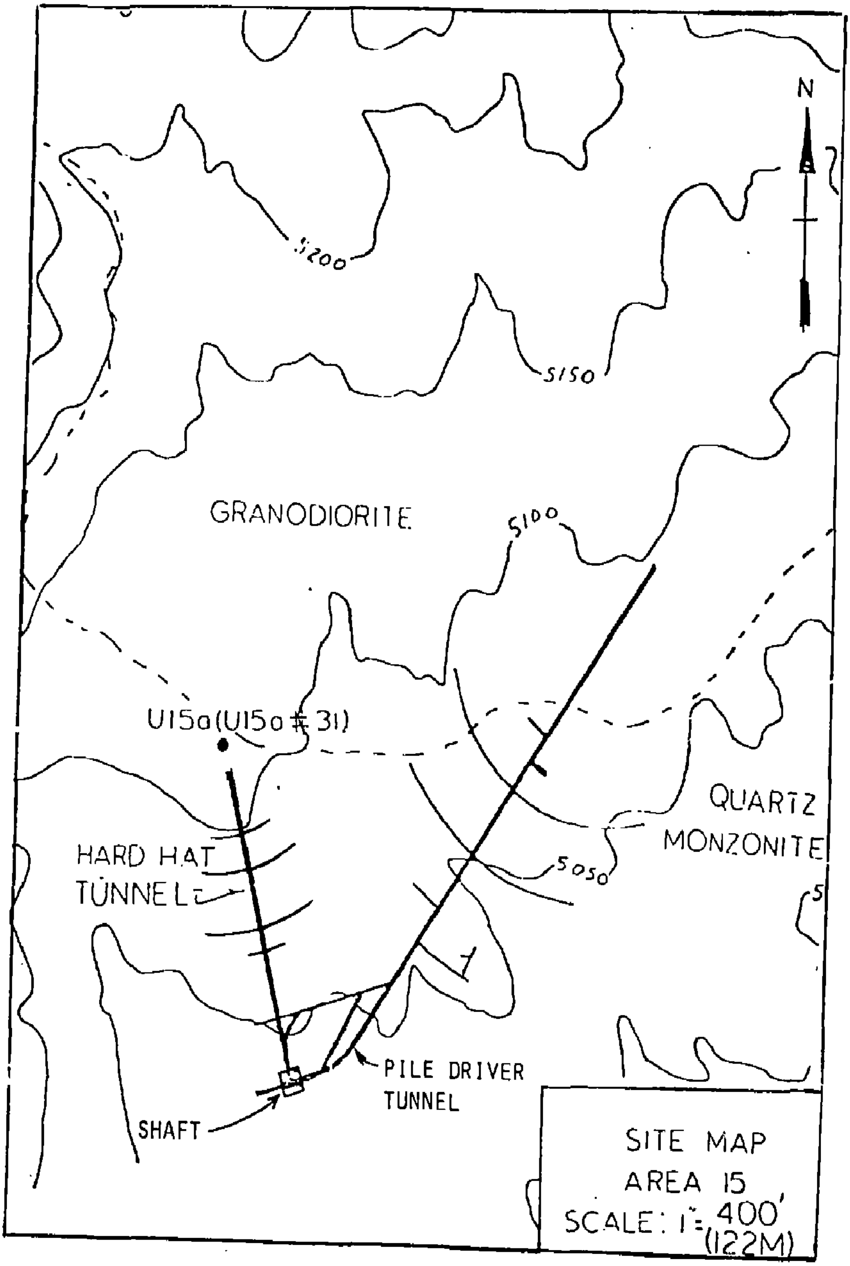

FIGURE 4 - PLAN OF UNDERGROUND TUNNELS

CHARACTER OF THE ROCK

The Climax stock is a composite granitic rock composed of quartz monzonite and granodiorite; specific compositions are discussed by Maldonado (1977). The location of the surface outcrops of these components is shown in Figure 3. Maldonado reports the average porosity of these rocks to be 0.6 percent and bulk density to average about 2.68 g/cm^3.

There are three predominant sets of fractures in the Climax stock (Wilder and Patrick, 1980), two (nearly orthogonal) of high angle (70°-90° dip) and one of low angle (less than 45° dip). The low angle fractures tend to be healed by quartz, pyrite and secondary feldspar. The high angle fractures are more open, although many are filled with calcite and clay minerals (Walker, 1962). The extensive high angle fractures occur either as discrete fractures or in shear zones. The shear zones are composed of a series of several (typically 5 or more) closely spaced (typically 5 cm or less) fractures and commonly have extensive zones of crushed rock. Maldonado (1977) reports detailed information on the chemical composition, physical properties, and the structure of faults and joints of the Climax granite.

PREVIOUS STUDIES

The first tests of the permeability of the Climax stock were conducted in the late 1950's in connection with exploration to determine suitability of this rock for nuclear tests. The earliest permeability measurements were conducted on one core sample from a borehole and one outcrop sample. Izett (1960) reported the permeability to be 10^{-7} darcies for the outcrop sample and 10^{-16} darcies for the borehole core. The extremely small value for the borehole core is much lower than reported values for hard rock from either laboratory or field testing (Brace, 1980). However, recent tests at Lawrence Livermore National Laboratory (Trimmer, et al., 1980) have shown permeability values as low as 10^{-12} darcies.

Borehole testing was conducted in the period 1959-1961 by the U.S.G.S. for the Atomic Energy Commission for the purpose of estimating the quantity of ground water in the stock (Walker, 1962). Eleven test holes were drilled and investigated and it was concluded that ground water is present but only locally in isolated pockets where the rock is highly fractured. None of the test holes penetrated to the depth of the regional water table and hence the locally occurring ground water is considered perched. In some of the boreholes there was loss of fluid circulation during drilling while in others 100% return circulation was reported. Borehole depths ranged from 215 meters to 610 meters. Although bailing tests and/or injection tests were conducted in most of the test holes, permeability was only qualitatively assessed in all but two of the test holes. In these two, values of the transmissibility were reported to be $9.5 \times 10^{-7} m^2/sec$ and $7 \times 10^{-5} m^2/sec$. Price (1959) concluded, from borehole logs, that the permeable zone which yielded the lower figure was 12 meters in thickness at a depth of 98 to 110 meters. Hence the permeability of this zone can be calculated to be about 2.5×10^{-3} darcies. The larger value of transmissibility was obtained from a 276 meter deep hole that had a static water level at a depth of 130 meters (Walker, 1962). If it is assumed that the entire depth of saturation (146 m) contributes to the flow, the permeability is about 1.5×10^{-2} darcies. These two values of permeability fall within the general range of values reported by McMullen and Pasternak (1970) in their study of the extent of rock fracture caused by the Pile Driver event (about 10^{-3} to 10^{-1} darcies). Brace (1979) suggests that the McMullen and Pasternak permeabilities were probably enhanced by damage due to the nuclear explosion. This is certainly plausible since these measurements were made within 200 feet of the Pile Driver cavity. It is interesting to note, however, that the U.S.G.S. measurements were made in areas at a much greater distance from any such explosion and hence the permeability values may be considered more indicative of that of the natural rock mass (albeit in highly fractured zones). Boardman and Skrove (1966) conducted tests after the Hard Hat event to establish the nature and magnitude of the permeability in the annular fractured zone around a contained nuclear explosion. Their tests indicate that permeability increases about 2 to 3 orders of magnitude within a radial distance of about 200 feet from the shot point. The bulk rock permeability was found to vary from 10^{-4} to 10^{-2} darcies. These values were assumed to be indicative of pre-shot permeability. Within the 200 feet radial distance from the shot point, permeability values as high as several darcies were found.

In situ permeability has been measured in connection with heater tests prior to the emplacement of spent fuel assemblies at the 420 meter level in the Climax stock (Ballou, 1979). The location of the heater test is shown in Figure 6 along with the layout of the Spent Fuel Test Facility. During the cool-down period after a borehole heater test, five boreholes in the proximity of the heater hole were instrumented for permeability measurements. These holes were 48 mm and 76 mm in diameter and ranged in depth from 9 m to 12 m below the drift floor. The instrumentation, shown schematically in Figure 5, consisted of inflatable rubber borehole packers with pressure-tight feedthrough connections to permit thermocouples and power leads to penetrate the region below the packer. A manifold with precision pressure transducers and solenoid valves enabled the pressurization of boreholes individually with air and to monitor and record the pressure response with time. The permeability testing was conducted over a period of 83 days. A total of six repressurization test cycles were made. The time required for significant pressure decay for a given test cycle was of the order of several days. The measured permeabilities are very low - all less than 10^{-9} darcies. Because of these extremely low values of permeability, typical of laboratory test values for intact granite core (Trimmer et al., 1980), it is thought that the boreholes tested only intercepted solid rock or very well healed fractures.

Extensive laboratory tests of permeability of two granite samples and one gabbro sample has been conducted by Trimmer et al. (1980). Using 15 cm diameter core samples, permeabilities were measured as a function of confining pressure. After testing for the permeabilities of intact rock core, throughgoing fractures were introduced in the rock cores. Tests of these fractured samples yielded values of permeability that were 6 to 10 orders of magnitude larger than the intact rock values. This may give an indication of values to be expected in situ for non-healed fractures.

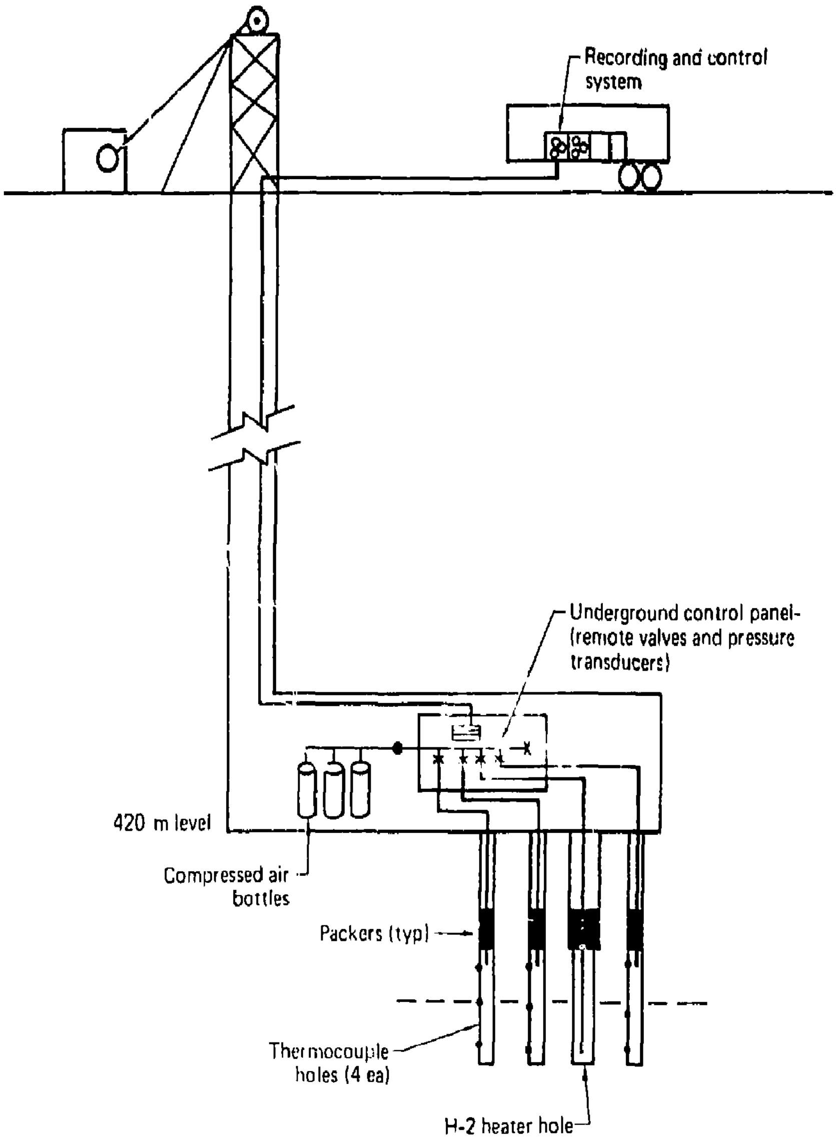

Figure 5 - Schematic of Measurement System
for Permeability Test (Ramspott, 1979)

PROPOSED TESTS

Permeability testing of discrete fractures in the Climax stock granite is proposed in connection with the Spent Fuel Test and the Radionuclide Tracer Migration Test. The Tracer Migration Test will be conducted in the old Pile Driver drift at the location indicated on Figure 6. Nearly vertical discrete fractures which can be traced from one side of the drift to the other have been mapped. Boreholes have been drilled from the drift wall to intercept a fracture in two locations (an inlet hole and an outlet hole) at a distance of three to four meters away from the drift wall into the rock mass. The inlet and outlet boreholes are separated by a vertical distance of about 2 meters. After locating the desired fracture in the two boreholes, straddle packers will be inserted to isolate the discrete fracture. Water will be pumped into the fracture to determine the permeability. The method used for permeability determination will depend upon how readily the fracture accepts water. If the fracture is very tight, a pulse test will be used; if more permeable, possibly a constant flow/variable head test will be conducted. Ultimately a steady state flow will be established between the inlet and outlet holes and this will allow another method of permeability determination.

In connection with the Spent Fuel Test, plans are being formulated to measure permeability and its variation over time as the rock heats up and then cools down. The Spent Fuel Test Facility (see Figure 6) is heavily instrumented to measure the thermomechanical response of the rock and therefore these permeability measurements will provide data for permeability as a function of thermomechanical stress. Several 15 cm diameter boreholes 5 to 8 meters deep, located about midway along the south heater drift (see Figure 6) could be used for permeability testing. In two of these holes preliminary inspection to locate fractures has been conducted. The location of these boreholes is shown relative to the canister drift and south heater drift on Figure 7. Also shown are predicted rock temperature contours at 4.2 years after spent fuel emplacement. It can be seen that the rock adjacent to the vertical hole will experience a maximum temperature of about 70°C and that adjacent to the horizontal hole about 38°C. It is planned to use

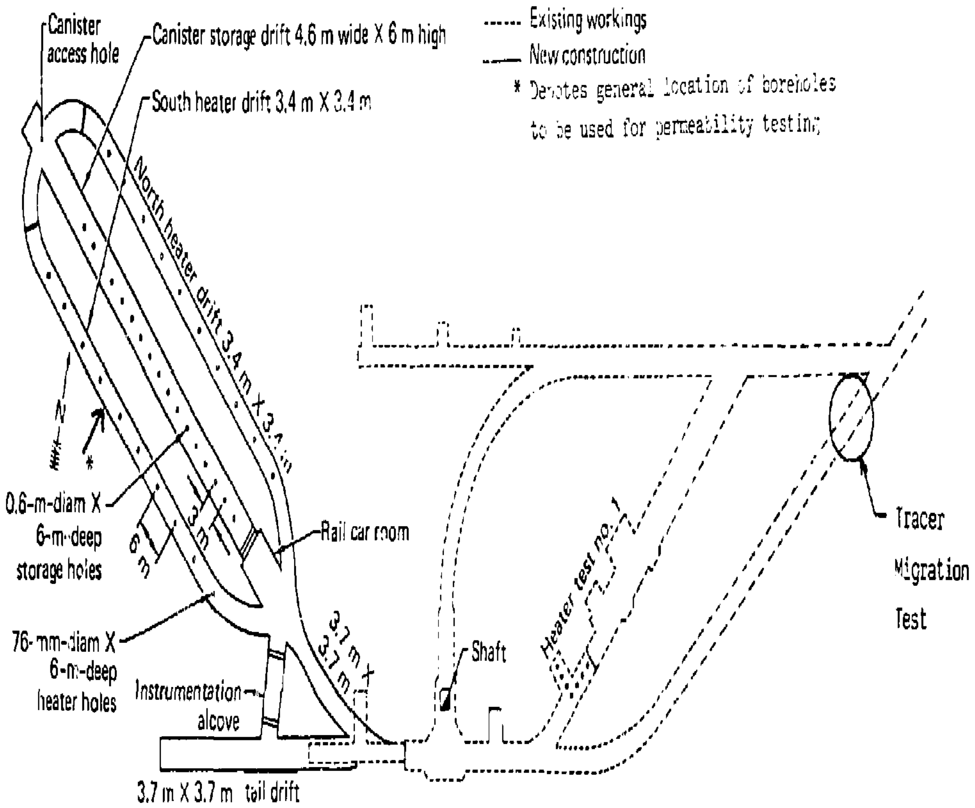

FIG. 6 Layout of the spent-fuel-storage-test facility and adjacent work...
(Modified from Ramspott, et al., 1979)

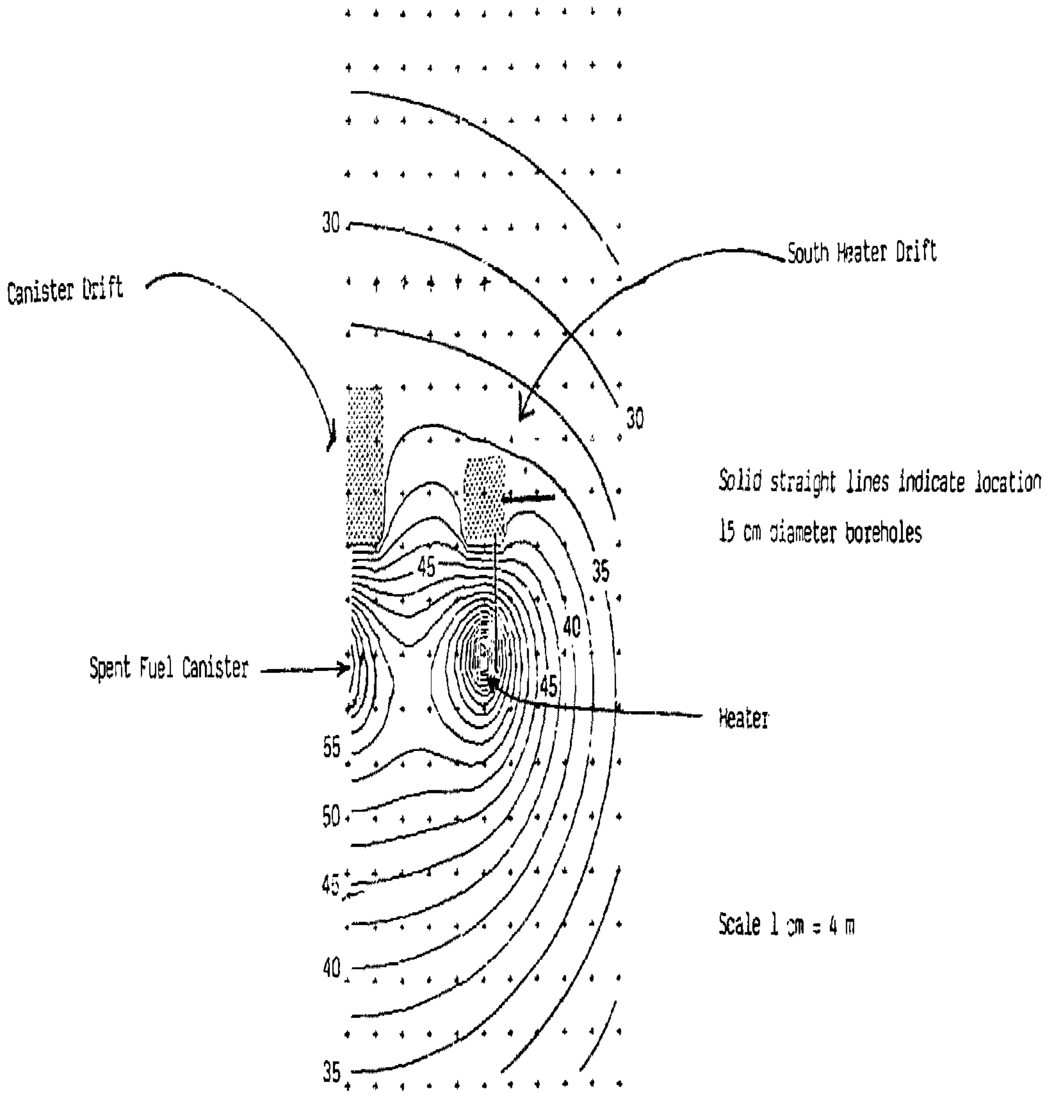

Figure 7 - Borehole locations and calculated isotherms at 4.2 years after insertion of spent fuel (after Ramspott et al., 1979)

compression packers to isolate discrete fractures at several locations in each borehole. The packers would be emplaced semi-permanently such that the same fractures can be easily tested periodically over the duration of the spent fuel test, including the cool down period after the fuel has been removed. Since the working level is above the regional water table, the fractures are, for the most part, unsaturated and hence air injection tests are planned.

Work has just been completed which deepened one of the original exploratory boreholes for the Spent Fuel Test. The layout of these exploratory boreholes is shown on Figure 8. Test hole UG-2, inclined at 60^0 below horizontal, has been increased in length from 125 m to 184 m. This hole has been deepened in an attempt to locate the regional water table. No test measurements have been made yet, however, plans for fracture characterization and hydraulic testing are being finalized.

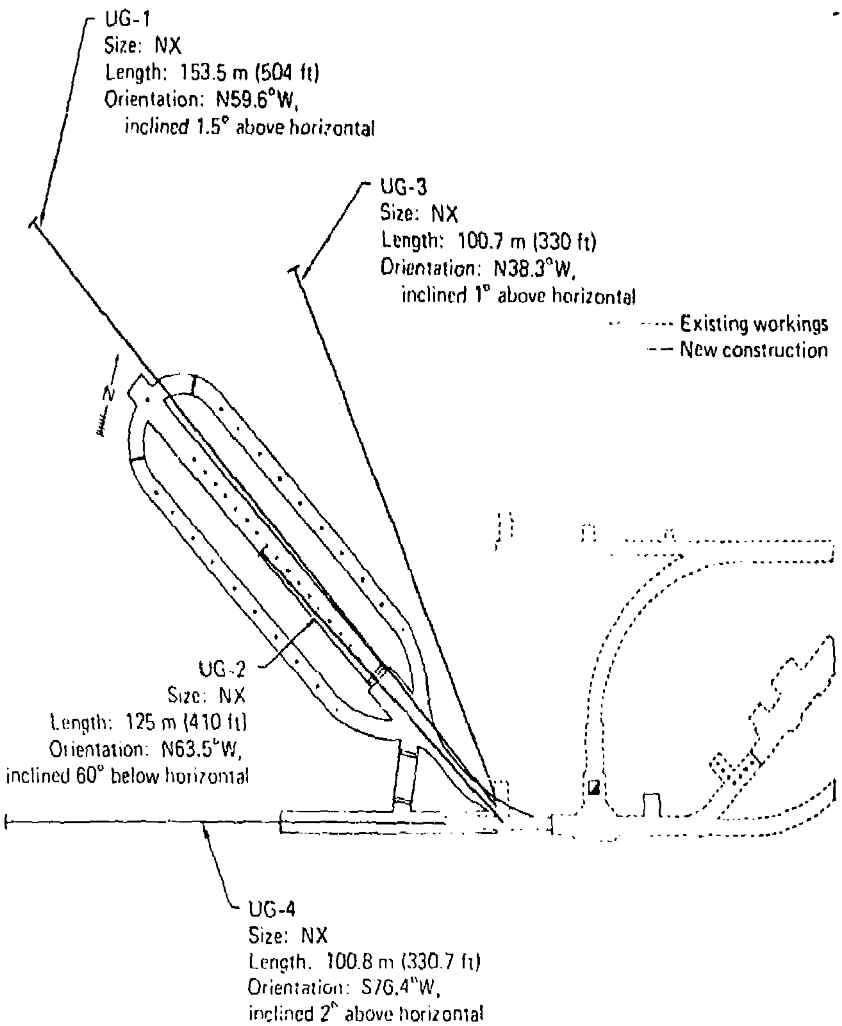

FIG.8 Exploratory core boring layout.

(Ramspott et al., 1979)

SUGGESTED FUTURE WORK

The existence of Pile Driver shaft and associated tunnel complex offers a unique opportunity for conducting hydrologic tests related to repository sealing in a granite medium. The fact that deep underground mined openings as well as boreholes exist in the Climax stock granite make this site very attractive for development into a hard rock test facility.

Some preliminary plans have been made to use the existing facilities for tests regarding the following items:

1. Assessment of fracture damage around mined openings and development of methods for assessment.

2. Permeability testing throughout a thermal cycle to assess any fracture damage caused by the thermal cycle.

3. Borehole drilling from the present working level of the Spent Fuel Test to define the regional water table within the Climax granite and to perform hydrologic testing in a saturated environment.

REFERENCES

Ballou, L., Field Permeability Measurements, in Waste Isolation Projects: FY 1978, UCRL-50050-78, Lawrence Livermore National Laboratory (Edited by L. D. Ramspott) Jan. 12, 1979.

Barnes, H., Houser, F. N., and Poole, F. G., "Geologic Map of the Oak Spring Quadrangle, Nye Co., Nevada," U.S.G.S. Quad. Map GQ-214, 1963.

Boardman, C. R., and J. Skrove, "Distribution in Fracture Permeability of a Granitic Rock Mass Following a Contained Nuclear Explosion", UCRL-14292, Rev. II, Lawrence Livermore National Laboratory, February 25, 1966.

Borg, I. Y., Stone, R., Levy, H. B., and Ramspott, L. D., "Information Pertinent to the Migration of Radionuclides in Ground Water at the Nevada Test Site," UCRL-52078 Part 1, Lawrence Livermore National Laboratory, May 25, 1976.

Brace, W. F., "Permeability of Crystalline and Argillaceous Rocks," Int. J. Rock Mech. Min. Sci. (In Press) 1980.

Isherwood, D. J., Raber, E., and Coles, D. G., "Program Plan: Field Radionuclide Migration Studies in Climax Granite," (Draft), Lawrence Livermore National Laboratory, Aug. 1, 1980.

Izett, G. A., "Granite" Exploration Hole, Area 15, Nevada Test Site, Nye County, Nevada - Interim Report, Part C, Physical Properties: U.S.G.S. TEM-836-C, 1960.

Maldonado, F., "Summary of the Geology and Physical Properties of the Climax Stock, Nevada Test Site," U.S.G.S. Open-File Report 77-356, 1977.

McMullen, E. T., and Pasternak, A. D., "Field Measurements of Fracture Permeability in Granodiorite," UCID-15653, Lawrence Livermore National Laboratory, May 11, 1970.

Price, C. E., "Granite" Exploration Hole, Area 15, Nevada Test Site, Nye County, Nevada - Interim Report, Part B, Hydrologic Data, U.S.G.S. TEM-836-B, 1959.

Ramspott, L. D., Ballou, L. B., Carlson, R. C., Montan, D. N., Butkovich, T. R., Duncan, J. E., Patrick, W. C., Wilder, D. G., Brough, W. G., and Mayr, M. C., "Techanical Concept for a Test of Geologic Storage of Spent Reactor Fuel in the Climax Granite, Nevada Test Site," UCRL-52796, Lawrence Livermore National Laboratory, June 15, 1979.

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

Trimmer, D., Bonner, B., Heard, H. C., and Duba, A., "Effect of Pressure and Stress on Water Transport in Intact and Fractured Gabbro and Granite," UCRL-83932, Lawrence Livermore National Laboratory, Feb. 1, 1980.

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

Wilder, D. G. and Patrick, W. C., "Preliminary Geotechnical Data Report for Test Storage of Spent Reactor Fuel in Climax Granite, Nevada Test Site," UCRL 85096, November, 1980. Lawrence Livermore National Laboratory, Presented at AEG Meeting, Dallas, TX., Oct., 1980.