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Vol. II

HEATER TEST PLANNING FOR THE NEAR SURFACE TEST FACILITY
AT THE HANFORD RECEPTION

VOLUME II
APPENDIX

BY

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104

VOLUME 11
TABLE OF CONTENTS

	<i>Page</i>
1. Theoretical Support for Radioactive Waste Storage Projects: Development of Data Analysis Methods and Numerical Models -- <i>C. F. Tsang and T. Chan</i>	1-1
2. Inactivity Temperature Profiling as a means of Permeability Characterization -- <i>P. Nelson</i>	2-1
3. Geophysical Holes at NSTF, Hanford -- <i>P. Nelson, T. Ioe and H. Pratt</i>	3-1
4. Proposed Geophysical and Hydrological Measurements at NSTF, <i>Hanford</i> -- <i>P. Nelson and T. Ioe</i>	4-1
5. Suggestions for Characterization of the Discontinuity System at NSTF, Hanford -- <i>R. Thorpe</i>	5-1
6. Monitoring Rock Property Changes Caused by Radioactive Waste Storage Using the Electrical Resistivity Method -- <i>H. F. Morrison</i>	6-1
7. Microseismic Detection System for Heated Rock -- <i>M. S. King</i>	7-1
8. Pasco Basin Groundwater Contamination Study -- <i>D. Girvin</i>	8-1
9. Letter to Mark Board on Gable Mountain Faulting -- <i>H. Wollenberg</i>	9-1
10. Report on Hydrofracturing Tests for In Situ Stress Measurement, Near Surface Test Facility, Hole DC-11, Hanford Reservation -- <i>B. C. Haimson</i>	10-1
11. Borehole Instrumentation Layout for Hanford Near Surface Test Facility -- <i>Terra Tek</i>	11-1

FORWARD

This report has two parts. Volume I contains the text of the report, and Volume II contains the Appendix. Volume I has been published under separate cover.

SECTION 1

MEMORANDUM

TO: Paul Witherspoon, Neville Cook, and Charles Brown
FROM: Chin Fu Tsang and Tin Lam
SUBJECT: Theoretical Support for Radioactive Waste Storage Projects;
Development of Data Analysis Methods and Numerical Models.

PURPOSE

There are currently field experiments being carried out at Stripa, Sweden, and new field experiments are being planned for Hanford. To our understanding (which may be incomplete), the purpose of these field tests are: (a) obtain data for the particular site (b) develop new instrumentation and techniques (c) gain experience and define problems one may encounter in actual field conditions and (d) obtain well defined data to confront numerical or analytical results. Thus the purpose of theoretical support is three-fold:

- 1) To develop analytical methods for the field data that will be coming in, e.g. multiple packer injection tests; pumping out tests; tracer, temperature and deformation measurements.
- 2) To apply existing analytic and numerical models to calculate what one may expect to happen in the field tests. This may help in the design of the experiments and to verify these mathematical models.
- 3) To develop an appropriate numerical model to study the radioactive waste storage system. The model will be validated against field data. This is a very important (long term) goal because a validated model can be used to calculate expected behaviors of a rock system for other sites (given their geological conditions) and to predict results for longer periods of time than any field tests can be expected to provide.

GOALS

The following goals are suggested:

- 1) Development of well test analysis methods for a rock system with deformable tight fractures.
- 2) Application and modification of existing numerical and analytic models:
 - (a) Heat and/or fluid transfer calculations
 - (b) Stress calculations given temperature distributions

- (c) Coupled fluid and stress calculations
- 3) Development of numerical model for coupled fluid, stress and thermal calculations:
- (a) Bob Taylor's "representative elementary volume" approach for regions away from the bore hole.
- (b) Deterministic approach for region near to the bore hole.
- 4) Miscellaneous (but important) studies; for example, two phase flow in fractures.

EFFORTS

The following list indicates the ~~expected~~ efforts that may be expected. The burden may be supported by both Swedish and Hanford projects, since results obtained will eventually be used by both.

SUBJECT	PERSONNEL
Well Test Methods (TRUST & Semi-analytic methods)	$\frac{1}{2}p/JW/CFT$
Heat and Fluid Transfer (CCC & analytic methods)	$p/TC/CFT$
Thermal Stress Calculations (FEM)	p/TC
Fluid-Stress Calculations	MA/TC
Coupled Fluid-Stress-Thermal Numerical Model	$TC/MA/CFT$
Taylor's Approach	$\frac{1}{2}p/RT$
Misc: Steam Production etc.	CFT/TC

TC = Tin Chan; JW = Joe Wang; RT = Bob Taylor; CFT = Chin Fu Tsang;
MA = Mohammed A; p = a programmer or student.

Summary: TC (1.0), MA (1.0), CFT ($\sim .3$), p (3.0), RT (0.1?), JW (1.0)

SECTION 2

September 28, 1977

MEMORANDUM

TO: Paul A. Witherspoon

FROM: Phil H. Nelson

SUBJECT: Injectivity - Temperature Profiling as a Means of
Permeability Characterization

INTRODUCTION

Temperature profiling promises to be a useful, inexpensive means of detailing the permeability character of rock penetrated by a borehole. This memorandum reviews the "state-of-the-art" as it pertains to the applications of injectivity-temperature logs in low permeability rock. The use of this technique is predicated on the need to characterize the permeability of an entire rock sequence as opposed to a limited vertical interval. I propose that an in-house effort be undertaken at LBL: (1) through the use of computer models to study the temperature distribution caused by fluid injection and (2) to apply the technique in the Swedish and Hanford projects for the disposal of radioactive wastes (see recommendations).

APPLICATIONS IN PETROLEUM ENGINEERING

Temperature logs in combination with other "production" logs are used fairly routinely to delineate injection or production zones in petroleum reservoirs. The method is quite straightforward operationally: a fluid, usually water is injected into the well for some period of time. A temperature log is obtained during the final stages of injection and the flow is terminated. Subsequently a sequence of temperature logs are obtained at appropriate time intervals, typically over a period of several days. Figure 1 sketches some typical field data taken from Figure 1 of Smith and Steffensen (1970). As time progresses the temperature of the well-bore fluid gradually increases from the initial cool temperature to the warmer geothermal temperature of the rock. A zone where the fluid entered the rock during injection warms more slowly, producing a distinct signature on the suite of temperature logs. In this way the permeable zones can be located. Note that the magnitude of the anomaly is on the order of 5°F.

Generally this method is used in a qualitative fashion, simply to locate the injection zones. However, a few authors have examined the problem in some detail. Ramey (1967) develops the solution for the temperature dependence on depth and time for a fluid flowing in a cased well, assuming no fluid loss into the formation. Witterholt and Lixier (1972) discuss Ramey's solution in combination with one-dimensional considerations of the fluid flow in the rock mass. The most comprehensive modeling of the entire problem is discussed by Smith and Steffensen (1970) and Steffensen and Smith (1973). They employ the finite-difference technique on a two-dimensional grid, incorporating the thermal effects of tubing and casing as well as the flow in the zone of fluid loss. Their computed examples are quite convincing, but their results apply to the long injection times (1/2 year or more) typical of waterflood operations in petroleum reservoirs.

Fig 1 Typical field-measured absolute
temperature surveys during injection (0.0)
and at 0.5, ... 48 hrs after 'shut-in'.
from Smith + Steffensen, 1970

Memo: Paul A. Witherspoon
September 28, 1977
Page Two

HEAT FLOW STUDIES

Two characteristic parameters in the petroleum engineers use of temperature logs are the long injection times and the measurement of anomalies of several degrees and more. Temperature measurements are also used in heat-flow studies where the requirements are quite different: no fluid motion can occur in the wellbore and temperatures are measured to an accuracy of about 0.05°C . Absolute values are not as important as the resolution in measuring the thermal gradient, however, and Roy, et al. (1963) state that the mean gradient can be determined to within a few percent for intervals as small as 10 meters. This implies a resolution of roughly $\pm 0.006^{\circ}\text{C}$, using equilibrium measurements with the thermistor probe stationary in the wellbore. Incidentally, the gradients tabulated by Roy, et al. (1963) and by Sass, et al. (1971) show geothermal gradients can be as low as $7^{\circ}\text{C}/\text{km}$ and as high as $86^{\circ}\text{C}/\text{km}$ with typical values of $30^{\circ}\text{C}/\text{km}$ (1.65°F per 100 feet).

HYDROLOGICAL INFILTRATION RATES

Stallman (1965) presents a brief theoretical treatment on the estimation of groundwater infiltration rates using temperature measurements. Here a fluid of periodically varying initial temperature (diurnal or annual variations) percolates downward through the soil, altering the temperature regime which would exist if thermal conduction were acting alone. Stallman uses the amplitude and time lag information to estimate the infiltration rate. Using the diurnal information, he notes a sensitivity to flow velocity of about 2 cm/day but with large errors when the velocity is low. Unfortunately no field data are presented.

Sorey (1971) presents very convincing and encouraging data from three field sites where vertical flow occurs upwards from confined aquifers. The curvature of temperature data in the confining beds is used to detect vertical flow rates of one foot per year. The temperature deflections were only a few tenths of one degree Centigrade. A steady-state analysis was applied. Sorey reports minimal problems with convective overturn in the borehole. His work is encouraging both from the standpoint of the small temperature perturbations which could be detected and utilized, and from the analysis of steady-state flow regimes.

CONTINUOUS TEMPERATURE LOGS

Costain (1970) and Conaway (1977) deal with the problem of using continuous temperature logs rather than relying on the slower stationary measurements. They design inverse operators to deconvolve the response characteristic of the probe from the continuous data. The deconvolved logs can be used for stratigraphic correlation using the thermal conductivity. Our interest is obtaining higher quality data for injection logging and the deconvolution technique may well offer significant time savings and improved vertical resolution.

Memo: Paul A. Witherspoon
September 28, 1977
Page Three

CONVECTIVE OVERTURN

Convective overturn in the borehole will occur if the geothermal gradient is too high. Although the critical thermal gradient has been established theoretically, experimental confirmation is lacking and the size of the convective cells and the resulting temperature disturbances need further substantiation. Diment (1967) displays temperature excursions of 0.02°C at 100 meters depth in a 25 cm diameter steel casing which was plugged to prevent entrance of ground water. Samuels (1968) shows much larger perturbations in smaller diameter boreholes. The data of both Diment and Samuels show that the temperature perturbations increase with increasing thermal gradient. Hence, convective overturn should not be a problem in the early stages of thermal recovery of an injection experiment but could introduce a noise level which increases with time as the well recovers to the geothermal conditions.

NUMERICAL MODELING EXAMPLE

Figure 2 shows computed results from a finite-difference computer model (Kennecott Copper Corp, unpublished). The model is similar to the approach of Smith and Steffensen, but modified to handle the short injection and measurement times. In this case 70°F water is injected for a 12 hour period, then flow is discontinued and the temperature distributions as a function of radial and vertical distances are printed out for specified time increments. Figure 2 shows the temperature in the wellbore 2 and 24 hours after injection has stopped. The temperature anomaly at the 10-foot interval of fluid loss from the borehole is both time and volume dependent. The 0.1 gallon per minute (6.31 cc/sec) loss rate is discernible at 2 hours but not at 24 hours, at least not on the scale plotted. Obviously a fair amount of modeling is required to design and interpret useful field experiments.

RECOMMENDATIONS

Numerical modeling results similar to those of Figure 2 are required to estimate the sensitivity requirements and noise limitations of temperature surveying, to see if quantitative estimates of flow are at all possible from temperature data, and to establish the interdependence of experimental parameters, such as flow rate and injection duration, or such as flow rate and the thickness of the injection zone. We will need to estimate the limitations of the method in terms of the duration of injection, duration of measurement period, and fluid-rock temperature contrast. Other obvious parameters include the borehole diameter, thermal conductivity contrasts, borehole flow rate, and injection pressure (due to Joule-Thomson heating).

The development of an accurate model is a non-trivial task. For example, because of the relatively short times involved, care must be exercised in introducing the cooler fluid front into the well bore (in the numerical sense). Because the radial influence changes markedly with the injection rate and duration, the grid geometry may have to change from one model suite to the next. At least several man-months are required for the modeling, depending upon the suitability of existing LBL computer programs (for example, Lippmann, et al., 1977).

FIG. 2 Temperature profiles for water exhalation of 0.1 and 1.0 gpm into a 10-ft interval, at shut-in times of 2 and 24 hours.

Geothermal (rock) temperature = $100^{\circ}\text{F} + 0.005 \times \text{depth (ft)}$

Injection temp of water = 120°F

Injection duration 12 hrs

Water diffusivity $0.0055 \text{ ft}^2/\text{hr}$, Rock diffusivity $0.085 \text{ ft}^2/\text{hr}$

Injection radius if 1% porosity 0.1 gpm: 3.2 ft 1.0 gpm: 10.1 ft

Revised: Paul A. Witherspoon
September 28, 1988
Page Four

Experimentally, the requirements are:

1. *adequate water supply for injection*
2. *high permeability reservoir*. This may be the fracture zone of a well at which the permeability is too great to inject the fluid into the reservoir surface without a wellbore, or the fracture zone may be too small to inject the fluid into the reservoir. If the latter is the case, the wellbore must be impaled through the fracture zone, and the fluid must be injected into the fluid zone before it reaches the point of fracture.
3. *adequate permeability*
4. *refracting equipment*
5. *temperature logging and data recording equipment.*

Execution of the injectivity profiling method and analysis of the data must be coordinated with other efforts. Other techniques exist for permeability profiling, specifically spinner logs and radioactive tracer tests. Pressure tests provide the most reliable means of obtaining permeability estimates. Injectivity-temperature logs, to be as early as possible, and should be applied fairly early in the test sequence.

PHH:pab

cc: B. Steward
P. Kurfurst
C. Brown
C. Tsang
T. Narasimhan
T. Chan
M. Lippmann
N. Cook

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Geological Society of America
Library, June 1977

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SECTION 3

ITEMS TO BE DONE

I. Holes for air

A. Holes for air permeability

1. Holes for air permeability on the heater

a. Holes for air permeability on the heater

1. Vertical holes for section, 10 holes, 10 cm deep, 1.5 cm dia.

A. Eliminate the 0.5 m part of the hole

B. Add 1 pair of holes at each heater, 10 cm deep, 1.5 cm dia.

C. Add 1 pair of holes at each heater, 10 cm deep, 1.5 cm dia.

C. Add 1 pair of holes at each heater, 10 cm deep, 1.5 cm dia.

II. Horizontal Holes for air permeability on the heater

One horizontal hole at each heater, 10 cm deep,

10 cm diameter, located on 5 KW heater, line of holes to be within 1.0 m of heater to be about 0.5 m from the heater. Expected requirements for part the heater.

III. Holes for continuous monitoring of air

No specs at this time. H. Pratt will discuss the requirements with

L. Lingle and W. Bastrulid and specify the holes. A. L. Lingle will specify 3 holes in the time-scale space and 3 in the full-scale space.

IV. Holes for resistivity monitor

11 holes, 0.5 m deep, can be percussion drilled, 1.5-2.0 inches diameter, located on 5KW heater, line of holes to be within 1.0 m of borehole. P. Nelson will specify the location of the holes as soon as possible.

V. Holes for acoustic emission

No specs at this time. Expected requirements are 5 holes each 10 m deep, all vertical. P. Nelson will specify the holes.

PN:TD:HP:LE

cc: N. Cook

W. Bastrulid

P.S. Item IV to be 10 colinear holes symmetrically disposed about the 5 KW heater hole with 2 meter separation between holes.

SECTION 4

May 10, 1978

MEMORANDUM

TO: W. S. Stetler

FROM: P. Nelson and T. Lee *P. Nelson T. Lee*

SUBJECT: Proposed Geophysical and Hydrological Measurements at NSTF, Hanford

A plan for a Near Surface Test Facility (NSTF) at Hanford, Washington has been drawn up by Powell-Barnard Operations (Gard and Macon, 1977). The test facility will be constructed in the Perched Tuff at a site on the Hanford Reservation. The purpose of the test facility is to test in situ the characteristics of the basalt (chiefly its thermal and mechanical response) with a view to its suitability as a repository medium. To this end the facility is being designed to thermally load the rock with heaters set in a regular grid, and the thermal and mechanical response of the surrounding rock mass will be sensed with temperature and strain sensors.

The purpose of this note is to enumerate appropriate geophysical and hydrological measurements which can be carried out in conjunction with the construction and operation of the NSTF and which will supplement the thermal and mechanical measurements. Similar measurement sequences have been employed by LL at the Stripa test site in Sweden, although a few of the measurements listed below are new. Some of the methods must be modified because the NSTF is not expected to be water-saturated. Most importantly this requires the use of an air injection system instead of water for permeability tests and precludes the monitoring of water pressure.

Purposes of the geophysical and hydrological measurements are:

- 1) To examine with physical methods the extent and nature of the fractures. These methods will supplement the data supplied by core logging, core photography and television logging. It should be mentioned that the NSTF affords a prime opportunity to examine in detail the inhomogeneities of the basalt on the scale of tens of meters.
- 2) To quantify and measure the spatial variation of porosity and permeability. Emphasis here is on the neutron-thermal neutron tool which responds to water content and the air injection-packer assembly which measures air permeability which in turn can be interpreted in terms of effective fracture aperture.
- 3) To measure other subsidiary physical properties such as the background gamma radiation (spectrally if possible), rock density and acoustic velocity.
- 4) To detect changes in any physical properties occurring during thermal loading which will provide insight into the behavior of the rock mass. This refers to the monitor measurements discussed below.

From: P. Nelson and T. Lee
 May 16, 1978
 Page 2

Many of the measurements will be carried out prior to the emplacement of monitor instrumentation; others will be performed during the heater tests at regular intervals or on a continuous basis in boreholes designated for these purposes. Hence the measurements can be classified as pre-test or monitor measurements. Pre-test measurements are generally designed to assess the physical parameters and their spatial variations. Monitor measurements are designed to assess changes in these parameters during the heater tests with the additional idea in mind that at some future date we will require a reliable method of monitoring reservoir behavior in an operating repository.

A. Pre-test borehole measurements.

- 1) With an air injection-packer system, permeability estimates and its variations will be made. Injection tests will be run at very low pressures to avoid deformation of the rock mass.
- 2) Using the LBL borehole logger, the following geophysical logs will be acquired:
 - a. Neutron-thermal neutron.
 - b. Gamma ray (possibly spectral gamma).
 - c. High resolution gamma-gamma (bulk density).
 - d. Electrical resistivity (if applicable).
 - e. Mechanical caliper (≥ 2 mm sensitivity).
- 3) Using a clamped acoustic tool, P and S-wave velocities will be obtained to detect open cracks.

B. Monitor Measurements.

- 1) Open borehole sequence - air permeability. Three to four pairs of boreholes spaced along parallel radial planes emanating from the main heaters will permit sequential measurements with different borehole tools during the heater operation. Air permeability measurements will be made in these holes, if possible, on selected fractures with the following orientations: a) horizontal, b) sub-vertical striking radially from the heater, and c) sub-vertical striking circumferentially about the heater. This range of orientation will allow evaluation of fracture aperture change due to vertical, radial and circumferential thermally induced loads. For all three types, the measurements will commence before heater turn-on to provide a base level reading.

Figure 1.3 - a and b. cont.

May 14, 1978

Page 4

- 2) Open borehole responses - acoustic velocity and neutron. The acoustic and neutron tools will be run, the first to see if changes in individual fracture can be detected with a small tool bit, the neutron tool to determine the water content in the rock temperature also. These tools will be run in the same holes as the temperature capability. Both of the measurement responses will continue before the heater turns on to provide a baseline reading.
- 3) Acoustic emission. Preliminary observations suggest that the stresses induced in the immediate vicinity of the heaters will be great enough to trigger acoustic emissions due to micro-fracturing in the rock. Both the time dependence and the location of such events will be of interest in interpreting the reaction of the rock mass. To locate events an array (6 or 7) of transducers will be deployed and events triggering the array above a preset threshold will be recorded. This experiment can be interfaced with the computer data acquisition system.
- 4) Acoustic velocity monitor. Small changes in fracture aperture induced by the thermal loading can be expected to produce changes in the acoustic velocity. Permanently installed sensors will monitor these changes across the rock mass surrounding one of the heaters. This experiment will run periodically and automatically and can be interfaced with the computer system.
- 5) Electrical resistivity monitor. As the rock heats, the small amounts of pore water become more conductive electrically, then as heating progresses further water will be driven off thereby reducing the electrical conductivity of the rock in a gradually expanding cylindrical volume. A linear set of permanent electrodes installed in small (0.5) boreholes will periodically "sound" the volume of the rock mass below the floor of the heater room. Very sensitive, low drift, low frequency instrumentation developed for earthquake monitor experiments can be applied to this installation and can be interfaced with the computer system.
- 6) Radio frequency electromagnetic propagation. As mentioned above, the electrical properties of rock first increase, then decrease as heating progresses. Two borehole arrays of transducers can thereby track the changes occurring along the ray-paths linking the transducers, in effect performing an integral measurement of the water properties. It should be

From: P. Nelson and T. Doe
May 16, 1978
Page 4

mentioned that the attraction of the two electrical experiments lies in their promise as a monitor tool for an operating repository, when it will become desirable to have a "volumetric thermometer" with a minimum of boracholens.

Reference: M. P. Board and J. F. Marron, 1977, Near Surface Test Facility (NSTF) Test Plan Rockwell Hanford Operations.

PR/TD/ewc

cc: H. Pratt, TerraTek
N. Cook
M. McEvoy
E. Binnall
C. Wilson
R. Galbraith

SECTION 5

LAWRENCE BERKELEY LABORATORY
Room Trailer Bldg 90 Ex. 5432

May 22, 1978

MEMORANDUM

TO: W. Stromdahl
FROM: P. Thorpe
SUBJECT: Suggestions for Characterization of the Discontinuity System at NSTF, Hanford

In the vicinity of the planned heater tests at the Near Surface Test Facility (NSTF) it is desirable to define and characterize the discontinuities for at least two reasons:

1. Their effects on heat transfer in the rock mass may be significant, from both a conductive and convective standpoint.
2. New fracturing caused by the heating should be interpreted in relation to the existing discontinuities.

Therefore, a thorough characterization of the discontinuities will be supportive of the geophysical and hydrological measurements proposed by P. Nelson and T. Doe in their memorandum of May 16, 1978. It is important that physical measurements be correlated with visual description of the medium so that anomalous behavior can properly be ascribed to discrete features.

Our experience in characterizing local fractures surrounding heater sites at Stripa can provide a basis for such work at Hanford. The process involves the following steps:

1. Scale and remove loose rock and dust from the floor and walls of the site. Since the NSTF is apparently a nonsaturated environment, I suggest that air be used.
2. Establish a local grid system by painting coordinate points on the floor. At Stripa a 1 x 1 meter horizontal system was laid out to an accuracy of about ± 3 cm.
3. Develop a photomosaic of the floor surface. Using a wide-angle, low distortion lens, an area of about 9 m² can be photographed from a height of about 3 to 4 meters. A front loader works well as a platform. I suggest that a person experienced in photogrammetry be consulted; however, the actual photography can be done by LBL photographic services. The main purpose of the photomosaic is for display and delineation of the most prominent features.
4. Prepare a detailed map of the discontinuities in the floor. If distor-

tion of the photomosaic is minimal, an overlay may work well as a base map. At Stripa, the photomosaics were too distorted for this purpose, so the mapping was done independently. I suggest that a scale of 20:1 be used. Mapping is greatly facilitated by placing a decimeter-graduate frame of one meter on a side over the section being mapped. To provide adequate detail, features of about 0.5 meter length or greater should be mapped. Fractures are delineated by their lines of outcrop in the floor. Discontinuities should be described in terms of their filling mineralogy, thickness, aperture, and dip angle. A parallax-viewing inclinometer works very well for measuring orientations.

5. From the detailed map, delineate major features. The main criteria for this selection is a discontinuity's length, thickness or aperture, and continuity. Examination of the walls and roof of the drift are very helpful for this purpose.
6. Extrapolate the major floor features to the subsurface and correlate them with the borehole information, including Tv logs, core log, and core inspection. To facilitate the correlation, I suggest that prominent features which appear sealed in the core be logged right along with the open fractures. The extrapolation of a fracture can be accomplished by two methods:
 - a. Extension from mapped orientations in either graphical cross-sections or a physical 3-D model of the subsurface.
 - b. Numerical extension by the equation of a plane.
7. Delineate major features which do not outcrop in the floor. This must be done by cross-correlation of borehole data.
8. Confirm subsurface continuity of major features by some type of qualitative borehole test. It was not possible to accomplish this at Stripa, but I believe it is necessary due to the large amount of ambiguity in the cross-hole correlation process. I envision a simple test whereby a fracture is isolated in one hole, then pressurized with air. Pressure increases at extrapolated positions in adjacent holes would confirm the fracture's continuity.
9. Code the discontinuities in the manner being used at Stripa; that is, each surface is approximated by a series of planar triangles whose vertices are coded in 3-dimensional coordinates. These coordinates are principally known borehole locations, except for extrapolated points where some features are truncated by others.

Memo: W. Stromdahl
 May 22, 1973
 Page Three

Approximate time and cost estimates for an area of about 100 m² are as follows:

	<u>Time</u>	<u>Cost</u>
1. Initial cleaning	1-2 Days	
2. Layout grid system	½-1 Day	
3. Photography (LBL)	2-3 Days	
4. Photomosaic construction (LBL)		~\$500-\$800
5. Floor Mapping*	2-3 Weeks	
6. Characterization of 3-D system*	4-6 Weeks	
7. Borehole confirmation testing*	1-2 Weeks	
8. Fabrication of test apparatus, using equipment on hand at LBL		~\$500

*Depending on complexity of system and accessibility.

In conclusion, I emphasize the need for scheduling the mapping in relation to any drilling, since it is necessary that the floor be kept reasonably clean until the mapping is finished. If this presents problems (which I foresee), the photomosaic will be very valuable for postmapping interpretation. Also, adequate fluorescent lighting should be provided in the drift.

If I can be of further assistance, don't hesitate to contact me.

RT:pb

cc: T. Doe
 M. Hood
 P. Nelson

SECTION 6

6-1

Proposal from

The Regents of the University of California
c/o Campus Research Office
M-H Wheeler Hall
University of California
Berkeley, California 94720

to

Lawrence Berkeley Laboratory

on

MONITORING ROCK PROPERTY CHANGES
CAUSED BY RADIOACTIVE WASTE STORAGE
USING THE ELECTRICAL RESISTIVITY METHOD

UCB-Eng-4700

Principal Investigator: H. F. Morrison

Amount: \$ 33,370

Duration: Sixteen Months
(June 1, 1978 - September 30, 1979)

College of Engineering
Office of Research Services
May 1978

PROPOSAL FOR:
Monitoring Rock Property Changes Caused by
Radioactive Waste Storage Using the Electrical Resistivity Method

H.F. Morrison

Changes in rock properties adjacent to buried radioactive waste containers can be measured by a variety of point measuring probes (temperature, pressure, etc.). But it is also important to determine larger-scale or volume-averaged effects, in case alteration, fracturing, or diffusion of heat are anisotropic phenomena that are inadequately sampled with the discrete probes. Further, it would be desirable to monitor the changes without having to disturb the integrity of the surrounding host rock by drilling holes deep enough to reach the affected region.

The major effect that is to be addressed in this study is the change in electrical resistivity caused by the heating and possible changes in porosity (microfracturing) brought about by the heating. Initially the rock resistivity will be governed by the porosity, and the conductivity of the pore fluid. As the rock is heated the conductivity of the pore fluid increases and the rock resistivity drops. Further heating may cause microfracturing as the rock matrix expands and inhomogeneous stresses develop around the container cavity. Both these effects can be expected to reduce the rock resistivity. At still higher temperatures a steam phase could develop. This will cause a drop

in apparent resistivity but not as dramatic a one as might be expected. Brace has shown that enough residual surface water is retained in the pores to keep the resistivity low even when the bulk of the pore water is converted to steam.

Over a long period of time chemical alteration may occur tending to seal the pores in the surrounding rock (or alternatively causing them to increase in size) and this would have strong effects on the electrical resistivity.

It is not clear a priori what the sequence for resistivity variations would be. However, monitoring the resistivity changes, coupled with the other point measurements, would be essential for unraveling the processes in the first, test, burial.

An intrinsic appeal of the resistivity method is the fact that it will monitor changes in relatively large volumes of rock and the measurement procedure is simple and inexpensive. A disadvantage is that the interpretation of results is not unique and it is sometimes difficult to determine exactly the location and size of the volume of rock undergoing changes. The questions will be discussed below.

A common resistivity measuring technique is the dipole-dipole method. Current is injected between two electrodes separated by 'a' and at some integer multiple, na , away from the current electrodes the voltage is measured between two more electrodes separated by a distance 'a'. An apparent resistivity is obtained from the product of a geometric factor and the ratio V/I . For data display purposes the value of apparent resistivity obtained for a particular transmitter-receiver pair is plotted at the intersection of two lines descending from the midpoint of each dipole at a 45° angle from the horizontal. The dipole-dipole

array and plotting scheme is illustrated at the bottom of Figure 1.

The resulting data points fill a grid which, when contoured, results in a pseudo-section. If the ground were uniform all the apparent resistivities would be the same and equal to the resistivity of the ground. An inhomogeneity will lead to departures from the background value and a pattern will appear in the contours of the pseudo-section. This pattern must be interpreted by comparing the results to numerically generated pseudo sections from known models.

We have shown in previous studies (Beyer, 1977) that the dipole-dipole technique is superior to other arrays (Schlumberger or Wenner) in resolving discrete two or three dimensional inhomogeneities. The other arrays on the other hand may be superior for resolving horizontal layers.

Before describing a resistivity survey for monitoring rock resistivity near buried conductors an important difference between traditional resistivity surveys and the proposed time monitoring experiment must be emphasized. Exploration surveys are rarely made with accuracies in excess of 5%. More accuracy is unusable since near surface variations have effects greater than 5% even for large arrays. Consequently model studies showing, for example, the detectability of a buried sphere usually conclude that the sphere is undetectable when the perturbation it produces in the pseudo section is less than 5%. These criteria do not apply in a time monitoring experiment. We have achieved accuracies of one part in 10^4 (.01%) in a resistivity variometer designed to monitor earth strain in earthquake regions and this is over electrode spacings of several hundred meters. This was accomplished at 0.1 Hz using a digital synchronous detection scheme. At the higher frequencies that could be used in this study an analog variometer similar to that used by Yamazaki (1967) and by Fitterman and Madden (1977) would probably be used. It can be assumed that this accuracy can be obtained in the proposed experiment.

As an illustration of the effectiveness of the resistivity technique in monitoring small changes in resistivity in a discrete volume within a uniform rock mass, we have considered the spherical model in Figures 1 and 2. We have considered the electrical array to be on the surface of a uniform half space. In reality the electrodes would be in a tunnel within the half space. This configuration can also be modeled but not as simply as this preliminary model. The results would not be changed enough to alter the conclusions of this analysis.

The background or host rock resistivity has been chosen to be 3000 ohm meters. A spherical volume with a radius of two meters has been selected to represent a volume that might, over time, be expected to undergo changes in resistivity. The depth to the center of this sphere is 4 meters in Figure 1 and 6 meters in Figure 2. The electrode spacing has been chosen to be 2 meters.

The resistivity changes considered are decreases of 3% and 10% in the spherical rocks with respect to the host rock (3000 ohm meters). The changes in apparent resistivity in percent are plotted in the pseudo sections.

The characteristic patterns for buried three dimensional bodies are observed in the pseudo sections--a broad arcuate low draped over the sphere and a relative high beneath it.

The important feature to note for the proposed study is that the maximum changes in apparent resistivity are approximately an order of magnitude less than the intrinsic change within the sphere for the 4 m burial depth and about an order and a half (40 times) less for the 6 meter depth of burial.

With a measuring accuracy of 10% we can thus conclude that changes of as little as 1% in the resistivity of a spherical volume 4 meters deep could easily be monitored. From the problem posed directly we can also infer from the results at 6 meter depth that a one meter diameter sphere at a 3 meter depth undergoing changes in resistivity of 3% would also be easily detectable.

Proposed Study

It is thus proposed that a resistivity measuring program be initiated to monitor rock resistivity changes at the underground storage test facility at Hanford.

The proposed experiment would use electrodes imbedded in shallow holes in the floor of the storage gallery. The spacing would be 2 meters since the preliminary spherical model analysis has shown that this would be adequate for detecting resistivity changes to a depth of 6 meters.

Measurement would be made at regular intervals to obtain time sequenced pseudo sections showing the progressive change in resistivity of the subsurface. The measurements would be made and the data reduced by the on site computer.

The design of the measuring apparatus will require some preliminary study--principally to determine the contact resistance since the current source has to be designed to match this impedance. The overall project will then require the following phases:

May 1, 1978-October 1, 1978--

- 1) Tests of current electrodes in large rock blocks (in the laboratory and at Richmond Field Station.) Selection of electrodes (lead in pressure contact, painted on amalgam, or conductive epoxy). Selection of appropriate power supply for the observed contact resistance.
- 2) Design of measuring system; selection of operating frequency, detection circuit and method of selecting appropriate electrode pairs for automated generation of the pseudo section.

3. Preliminary measurement of bulk apparent resistivity, in-situ, at the Hanford test site.
4. Further modeling with inhomogeneous lateral models and with electrodes within, rather than on, the half-space.

Oct. 1, 1978--Sept. 30, 1979

1. Fabrication of measurement system--testing in Berkeley.
2. Preparation of electrode site, measuring cables, etc. at Hanford.
3. Installation and begin monitoring.

All of the work in the period ending September 30, 1979 can be carried out in the Engineering Geoscience Laboratory. Fabrication and installation of the system in '78-'79 will require technical support from LBL.

REFERENCES

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- Fitterman, David V. and Theodor P. Madden, 1977, Resistivity observations during creep events at Meisdy Ranch, California, *Journal of Geophysical Research*, 82 n. 33, pp. 5491-5498.
- Yamazaki, Y., 1967, Electrical conductivity of strained rocks (3) A resistivity variometer, *Bulletin, Earthquake Research Institute, Tokyo University*, 45, pp. 849-860, 1977.

RESISTIVITY CHANGE $\Delta\rho = 90 \Omega\text{-m}$ (3%)

RESISTIVITY CHANGE $\Delta\rho = 300 \Omega\text{-m}$ (10%)

6-10

RESISTIVITY CHANGE $\Delta\rho = 90 \Omega\cdot m$ (3%)

RESISTIVITY CHANGE $\Delta\rho = 300 \Omega\cdot m$ (10%)

$$\rho_h = 3000 \Omega\cdot m$$

6 m.

FIGURE 2

6-11
BUDGET

A. <u>Personnel</u> ^(a)	<u>6/1/78 - 9/30/78</u>	<u>10/1/78 - 9/30/79</u>
1 Research Assistant @ \$244/mo. (Mr. Juan Parra) 100% summer (3 months ea. summer) 50% academic year (1 month) 50% academic year (9 months)	\$ 2,973 ++ 472 **	\$ 3,123 ++ 4,460 **
1 Principal Elect. Technician @ \$1,724/mo. (Mr. Lamb) 50% each month	3,577 *	10,997 *
Research Services Office Assistance ^(b)	<u>302 *</u>	<u>799 *</u>
<u>Total Personnel</u>	7,324	19,379
B. <u>Employee Benefits</u>		
22% of salaries marked *	853	2,595
2.77% of salaries marked ++	82	87
1% of salaries marked **	<u>5</u>	<u>45</u>
<u>Total Employee Benefits</u>	940	2,727
C. <u>Supplies and Expense</u>		
Miscellaneous components (electrodes, electronic components, etc.)	500	1,000
Rock preparation (hole drilling)	500	00
Miscellaneous (xeroxing, telephone, mail, etc.)	<u>500</u>	<u>500</u>
<u>Total Supplies and Expense</u>	1,500	1,500
<u>Total Estimated Cost for Each Period</u>	<u>\$9,764</u>	<u>\$23,606</u>
<u>Total Estimated Cost for 16 Months</u>	<u>\$33,370</u>	

(a) Current salary rates are shown; extensions include 5% projected salary increases effective July 1, 1978 and July 1, 1979.

(b) Includes direct payroll preparation, budget control, preliminary processing of material requisitions, expediting, property accountability, etc.

UNIVERSITY OF SASKATCHEWAN

DEPARTMENT OF PHYSICS AND ASTRONOMY

SASKATOON, CANADA

S1N 0A0

17 August, 1971

Dr. Philip Nelson
 Waste Storage Group - Bldg. 2
 Lawrence Berkeley Laboratory
 University of California
 Berkeley, CA 94720

Dear Phil,

I am enclosing my final report entitled "Microscopic Detection System for Heated Pore".

You probably have already received my last letter, with my Check for Consulting Services, and be therefore aware of movements the next few weeks. Please call me after 1 September in Saskatoon if you have any queries.

I look forward to seeing you in California at the end of October.

Yours sincerely,

M. S. King,
 Professor.

Enclosure.
 Registered Mail.

SECTION 7

MICROSEISMIC DETECTION SYSTEM
FOR HEATED ROCK

by

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August 1976

CONTENTS

	Page
1. INTRODUCTION	7-3
1.1 Terms of reference	7-3
1.2 Design parameters	7-3
1.3 Recommendations	7-4
1.4 Estimated cost	7-8
2. DESIGN	7-10
2.1 Physical properties of basalt	7-10
2.2 Microseismic event detector	7-11
2.3 Signal conditioning system	7-14
2.4 Acoustic impulse source	7-15
2.5 Layout of detectors and impulse source	7-16
2.6 Software	7-17
2.7 Tape recorder	7-18
3. COST ANALYSIS	7-19
3.1 12-channel system	7-19
3.2 8-channel system	7-20
4. SOURCES OF EQUIPMENT	7-21
4.1 Microseismic detectors	7-21
4.2 Signal conditioning systems	7-21
4.3 Acoustic impulse source	7-22
4.4 Tape recorder	7-22
5. REFERENCES	7-23
6. APPENDIX	7-24
6.1 Manufacturers' leaflets	7-26

Microseismic Detection System
for Heated Rock

by

M. S. King

1. INTRODUCTION

1.1 Terms of Reference

The terms of reference for the study comprise a recommendation for a microseismic event detection system to be used for the following purposes:

- i. To locate the foci of microseismic events caused by thermal decrepitation of basalt in the vicinity of a heater embedded in the rock;
- ii. To study the pattern of generation of microseismic events as the rock is heated and the foci of events migrate from the vicinity of the heater;
- iii. To determine the acoustic propagation characteristics of basalt as it is subject to thermal stresses.

1.2 Design Parameters

In arriving at a recommendation, the following basic design parameters and assumptions were considered:

- i. Accuracy of location of foci of microseismic events: ± 1 cm;
- ii. Velocity of compressional waves in basalt: ranges from 6000 to 5000 m/sec; attenuation of compressional waves in basalt: Q ranges from 200 to 10;

- iii. Foci of microseismic events are located within 2 m of heater;
- iv. Maximum rate of generation of microseismic events: 5/sec;
- v. Amplitudes of microseismic events such that accelerations are greater than 10^{-2} m/sec²;
- vi. Energy content of microseismic events is contained in frequency band 100 Hz to 50 kHz;
- vii. Maximum temperature encountered by microseismic equipment is less than 75°C;
- viii. System should be compatible with a Modcom 14 computer for calculating the coordinates of foci of microseismic events.

1.3 Recommendations

It is recommended that a system with the following characteristics be employed:

- i. Twelve microseismic event detectors are located in four 3/4 in diameter boreholes, as indicated in Figure 1 at positions A1 to A12. A minimum of eight detectors may be employed at positions A1, A3, A4, A6, A7, A9, A10 and A12 in Figure 1, but problems associated with blind spots could arise with this configuration in locating foci of events originating close to the heater.
- ii. A schematic design for the microseismic detectors is provided in Figure 2. This shows a design suitable for a detector located at the bottom of each borehole; it requires modification for those detectors located further up the borehole. Rigid plastic tubing is specified for the extension pieces to couple

SCHEMATIC LAYOUT OF ACCELEROMETERS AND
ACOUSTIC IMPULSE SOURCE IN
RELATION TO HEATER

FIGURE 2

MICROSEISMIC DETECTOR FOR USE
IN 38mm DIA. BOREHOLES

- detectors within a borehole. This material will effectively isolate the detectors acoustically. The assembly described will permit any accelerometer to be placed within ± 0.5 mm of the desired position. The accelerometer and preamplifier recommended for each microseismic detector are: Columbia Research Laboratories model 5002 accelerometer; Ithaco model 144F preamplifier. Best-quality 3-conductor (individually shielded) cable should be used throughout for the microseismic event detectors.
- iii. The signal conditioning system must be capable of resolving time differences for the arrivals of microseismic events to ± 2 microsecond. This corresponds to a spatial resolution of ± 1 cm. The equipment must be compatible with a RS232 link to the Modcomp IV computer. The RS232 link is capable of handling the expected maximum rate of emission of microseismic events for the 12 channels recommended. Provision of extra buffer storage will depend upon the time to gain access to the Modcomp IV. A signal conditioning system satisfying these requirements is the Dunegan-Endevco DART.
 - iv. Suitable microseismic source location computer programmes are given in detail by Blake et al (1974) in USEM Bulletin 665. Operational programmes have also been described by Mowrey (1977) of the Penn State Rock Mechanics Laboratory.
 - v. An acoustic impulse source is recommended, to provide velocity control in the location of foci of microseismic events and to study the acoustic propagation characteristics of the rock as it is heated. A suitable site for the impulse source is indicated in Figure 1, in a 38 mm diameter borehole. A schematic design of an acoustic impulse

source suitable for this application is given in Table 2.

- vi. An instrumentation tape recorder will be required to provide an intermittent record of microphones signals detected by selected accelerometers and of the change in wave form of the signal from the acoustic impulse source as the over detector. These records will later be harmonically analyzed in the laboratory to determine the wave propagation characteristics of the case. It is recommended that a four channel instrument operation in the direct record mode be employed for this purpose. A suitable instrument is the Hewlett-Packard model 2964A tape recorder, with four channels of direct record/reproduce electronics. A four-channel preamplifier of 20 db gain will be required for use with the tape recorder. It is recommended that four Ithaco model 14-6 preamplifiers be used.

1.4 Estimated Cost

The total cost of the system recommended is \$47400.00 for 12 channels. This cost is reduced to \$40000.00 for an 8-channel system. A cost breakdown is presented in Section 3.

FIGURE 3 ACOUSTIC IMPULSE SOURCE FOR 38mm DIA. BOREHOLES

2. MICHIGAN

2.1 Physical Properties of Basalt

Table I
Acoustic Velocities in Basalt

Location (and notes)	Compressional, kr/sec	Shear, kr/sec
Germany (laboratory)*	6.4	3.2
Germany (field)*	5.6	
Germany (field, 710 m depth)*	5.06	2.72
Colorado (lab, 200 bars)*	5.41	3.21
Guadalupe Moho (lab, 0 bars, 2.82 gm/cm ³)*	5.55	2.53

Table II
Internal Friction in Basalt

Location (and notes)	Frequency, kHz	Q
USSR (20°C)*	3-4	400
USSR (100°C)*	3-4	480
Michigan*	10	100,210
Michigan (2.85 gm/cm ³)*	9	160
USSR (2.86 gm/cm ³)*	1000	580

* Clark (1966)

** Somerton et al (1963)

The acoustic velocities and internal friction measurements made in the laboratory, presented in Tables I and II, were made on intact specimens of basalt and therefore represent upper bounds for the values of these parameters.

The field values expected will probably lie in the ranges:

Compressional wave velocity, 6000m/sec to 5000 m/sec;

Internal friction, Q=200 to Q=10.

Attenuation impedances for basalt will then be within the range 14.3×10^6 and $17.1 \times 10^6 \text{ km}^{-2} \text{ sec}^{-1}$ (compared with $46 \times 10^6 \text{ km}^{-2} \text{ sec}^{-1}$ for stainless steel and $18 \times 10^6 \text{ km}^{-2} \text{ sec}^{-1}$ for aluminum).

2.2 Microseismic Event Detector

A microseismic event is reduced in amplitude as it travels from the focus. The causes for this are:

i. Geometric spreading, for which the amplitude varies inversely as the distance travelled: $A \propto \frac{1}{r}$;

ii. Attenuation due to internal friction: $A = A_0 e^{-\frac{x}{VQ}}$

where A_0 = reference amplitude,

x = distance travelled, m.

f = frequency, Hz,

V = velocity, m/sec,

$1/Q$ = specific dissipation constant.

To obtain a feel for the quantities involved, consider the distance travelled, x , required for the amplitude of the microseismic event to be reduced by 50 percent (equivalent to a 6 db reduction in amplitude).

$$x = 1103 \frac{Q}{f} \text{ m for a compressional wave velocity of } 5000 \text{ m/sec.}$$

Table III

Distance in cm for 6 db Reduction in Amplitude

f, kHz	5	10	20	50	100
100	2.2	3.1	4.6	9.2	9.1
50	4.4	2.2	3.1	9.4	9.2
20	11.0	5.5	2.8	3.1	9.6
10	22.1	11.1	5.5	2.2	3.1
5	44.1	22.1	11.0	4.4	2.2
2	110	55.2	22.6	11.0	5.5
1	221	110	55.2	22.1	11.0

The resonant frequency of the accelerometer must be 50 kHz or greater. During the initial stages of the experiment, when the Q value of the rock is high, a considerable amount of high frequency microseismic energy will be detected at the accelerometer. As the Q value decreases, however, a study of Table III shows that the frequency content sharply decreases. The effect of operating the accelerometer near its resonant frequency is to amplify the high frequency signals detected. For an accelerometer of 50 kHz resonant frequency, the range of linear response is to 20 kHz ($\sim 10\%$). This represents then the frequency range to which the microseismic signals should be harmonically analysed.

A satisfactory and inexpensive accelerometer of small size, suitable for incorporating in the detector shown in Figure 2, is the Columbia Research Laboratories model 5002. This accelerometer has a resonant frequency of 50 kHz and a sensitivity of $1.5 \text{ mv/m.sec}^{-2}$. A suitable preamplifier is the Ithaco model 144F of 40 db gain, with a noise level of less than 8 microvolts referred to input. Thus the threshold

output of the accelerometer and preamplifier combination represents an acceleration of $1 \times 10^{-7} \text{ g}$ rms. At the output from the preamplifier the signal is represented by rms value. The maximum output level of the preamplifier is 6 v peak-to-peak when the regulated power is 12 v d.c. The maximum rise to 11 v peak-to-peak at 16 v d.c.

The microseismic event detector illustrated in Figure 2 has plastic wrist-bore connectors for the rigid plastic extension tubes. The sensing head is made of aluminum, to provide a low acoustic impedance matched with the basalt. The force on the spring-loaded reaction piston is approximately 30-40 N. The design must be modified for those microseismic detectors located midway down and at the top of the borehole, to permit passage of electrical leads and to provide connecting tubes for precise alignment in the borehole (to within $\pm 0.5 \text{ mm}$). The connecting tubes must be constructed of rigid plastic of low acoustic velocity and low Q to provide acoustic isolation between the accelerometers.

It is recommended that the preamplifiers be provided with a regulated power supply of 14 v d.c. It should be emphasized at this point that only the best-quality cable be used to provide power to the preamplifiers and to transmit the microseismic signals to the signal conditioning system. The 3-conductor cable must have the individual conductors shielded with aluminum foil. In this way, the system noise level can be substantially reduced.

* See section 4 for availability.

2.3 Signal Conditioning System

Assuming the compressional wave velocity is about 5000 m/sec, location of the focus of a microseismic event to 1 cm requires a resolution in time of ± 2 microseconds. Hardy and Langston (1977) indicate that if f is the fundamental frequency component of the event, arrival time differences can be expected to be resolved to an accuracy of $\pm 1/8f$ seconds. For the maximum frequency of 50 kHz proposed for the detectors, we can expect them to determine time differences to within approximately 2.5 microseconds. This is satisfactory. Clearly, the resolution of time differences will deteriorate as the fundamental frequency component of the microseismic events drops, as would be expected when the rock mass quality degrades upon heating.

The data encoded by the system must be in a form suitable for handling with a RS232 link to the Modcomp IV computer. The link capacity will in fact limit the maximum rate at which data can be transmitted. The size of the buffer chosen will depend upon two factors: the time required to gain access to the main computer and the length of time over which bursts of microseismic events occurs.

A system which fulfils the requirements noted above is the Dunegan-Endevco DART. The microprocessor of the system has been designed to be compatible with a RS232 link. Data is encoded in ASCII characters of even parity, with between 32 and 44 ASCII characters required per microseismic event per detector. It is FORTRAN compatible and is in fixed-width fields. Time is handled by a real-time clock for reference, and a 16-bit counter is employed for determining time differences to the required accuracy. It should be noted that either the first-arrival threshold or maximum peak can serve as the reference. For

As further data on the 10^4 and 10^5 series are added to the data sets, the above described 10^4 and 10^5 estimates of β will converge to the true β value. The 10^4 and 10^5 estimates of β are also unbiased, but the variance of the estimates of β for 10^4 and 10^5 estimates increase as the number of the estimates increases. The 10^4 and 10^5 estimates of β are each additional 100,000.

The schematic drawing of a suitable acoustic impulse source for use in a 1.9 mm diameter borehole is given in Figure 3. The active element consists of a stack of piezoelectric discs, polarized across the thickness, sandwiched between a stainless steel shoe and a stainless steel backing. The stainless steel shoe has a built-up stellite surface which is forced in contact with the borehole wall. Dimensions in the direction of the axis of the stack have been calculated from Langevin's theory (see Hueter and Bolt, 1955, p. 137-146) for broad-band operation with a central frequency of 33 kHz. The dimensions are: stainless steel shoe, 3.80 cm; stack of transducers (PZT5)*, $4 \times 2.00 = 8.00$ cm; backing, 5.40 cm.

* See section 4 for availability.

The stack of piezoelectric transducers is attached to the discs having their directions of polarization as indicated in Figure 1. The voltage pulse is applied to the copper foil connected between heater discs marked +. This copper foil is connected between the heater discs marked - is grounded.

The pulse transformer consists essentially of a 1000 turn primary, a capacitor and an electronic switch. The piezoelectric transducers are driven by a trigger pulse from a 2500 cps. to the heater copper foil from the pulsing unit at the surface. The latter is powered by the 115 volt, regulated power supply employed for the heater drive.

The impulse source is placed in position in the 10 cm diameter borehole with aluminum channel sections of 1/8 in. similar to that employed with the microseismic event detectors. A confining pressure of approximately 4 MPa is sufficient to seat the drill-actuated piston in contact with the borehole wall. The reaction is achieved by a nylon or delrin head to minimize transmission of energy to the rock through the piston.

2.5 Layout of Detectors and Impulse Source

A schematic layout of the microseismic event detectors and acoustic impulse source is shown in Figure 1. Boreholes I, II, III and IV are shown located 20 cm from the walls of the heater drift. This distance was chosen to be similar to that shown in the original drawings for extensometer borehole E9. If it proves impossible to drill boreholes this close to the wall, the 4 m dimension (from the heater axis) can be reduced to 3.5 m. This will provide approximately 50 cm clearance.

the velocity of the compressional wave in the material is assumed to be the same in all directions. The least squares solution for a constant velocity medium (d) should be used. The arrangement of micro-seismic event detectors shown in Figure 1 ensures that at least six accelerometers will sense any event, even though the remaining accelerometers are masked by the heater.

More sophisticated programmes are reported by Mowrey (1977). These are described fully in the reference. Mowrey's programme IBMSL permits the employment of isotropic or anisotropic velocities, the

and follows:

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9. The least squares solution for a constant velocity medium (d) should be used. The arrangement of micro-seismic event detectors shown in Figure 1 ensures that at least six accelerometers will sense any event, even though the remaining accelerometers are masked by the heater.

10. The least squares solution for a constant velocity medium (d) should be used. The arrangement of micro-seismic event detectors shown in Figure 1 ensures that at least six accelerometers will sense any event, even though the remaining accelerometers are masked by the heater.

If it is assumed that the compressional wave velocity in brass is the same in all directions, the least squares solution for a constant velocity medium (d) should be used. The arrangement of micro-seismic event detectors shown in Figure 1 ensures that at least six accelerometers will sense any event, even though the remaining accelerometers are masked by the heater.

More sophisticated programmes are reported by Mowrey (1977). These are described fully in the reference. Mowrey's programme IBMSL permits the employment of isotropic or anisotropic velocities, the

in operation of boundary conditions to prevent inclusion of those source locations lying outside selected boundaries, the skipping of detectors provided at least 5 remain, the employment of an inclusive source of energy whose location is accurately known to provide velocity control. Program 18M1 (developed at Penn State Rock Mechanics Laboratory, appears to be an attractive alternative to Black's least squares solution.

2. Tape Recorder

The tape recorder should have four channels, at least and a capacity of one hour's recording per tape, a bandwidth of 100 Hz to 30 kHz and a sensitivity of 20 mV at minimum requirements, when used with preamplifiers of 20 db gain. A suitable, well-proven 4-channel instrumentation tape recorder possessing the necessary characteristics is the Hewlett-Packard model 3964A used in the direct record/reproduce mode. Operating at 7.5 ips (19.05 cm/sec) with a 2500 ft (750 m) tape there are 61 minutes recording time per tape. The bandwidth at this speed is 50 Hz - 32 kHz, with a signal/noise ratio of 30 db.

The least expensive, satisfactory method for amplifying the signals from the microseismic event detector is to use a 4-channel amplifier made up from four Ithaco model 143F preamplifiers of 20 db gain. The threshold acceleration of the microseismic event detector is $5 \times 10^{-3} \text{ m/sec}^3$. This results in a noise level of 0.8 mV at the output of the detector preamplifier. The resulting noise at the tape recorder input after 20 db further amplification is then 8 mV. When the tape recorder input sensitivity is set at 1 v, the threshold level is 13 mV. Thus the two noise levels are approximately of the same magnitude. The dynamic range that can be recorded will then represent accelerations of $8 \times 10^{-3} \text{ m/sec}^2$ to 0.6 m/sec^2 measured at the accelerometer.

3.2 8-Channel System

Microseismic event detectors

Columbia Research Lab accelerometer, model 5002, 8 @ \$139.50	\$ 1,116.00
Ithaco preamplifier, model 144F 8 @ \$305.00	2,440.00
Probes & extension tubes: Material & construction	1,600.00
Power supply, 14 v.d.c. (for all electronics except recorder)	400.00
Cable (3-conductor, individually shielded)	120.00

Signal conditioning system

Dunegan-E leeco DAEI (8-channel)	25,000.00
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Acoustic impulse source

Impulse source, including pulsing unit & hydraulics: materials & construction	1,500.00
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Tape recorder and amplifier

Hewlett-Packard tape recorder, model 3964A, main frame	5,300.00
Hewlett-Packard direct record/reproduce modules, model 3964A002 4 @ \$330.00	1,320.00
Ithaco preamplifier, model 143F 4 @ \$305.00	1,220.00
	<hr/>
	\$ 40,016.00
	<hr/>

(Add \$500.00 - \$2000.00 for extra buffer storage)

4.1.1.1. Amplifiers

4.1.1.1.1. Piezoelectric Detectors

4.1.1.1.1.1. Accelerometers

Columbia Research Laboratories
 7410 Elyrd & Fillmore Lane
 Berkeley, CA 94698
 (415) 841-9466

Dunegan-Endevco
 Rancho Viejo Road
 San Juan Capistrano
 CA 92675
 (714) 831-9131

Level & Flair Instruments Inc.
 5111 West 164 Street
 Cleveland, Ohio 44142
 (216) 267-4400

4.1.1.2. Pre-amplifiers

Ithaco Inc.
 735 West Clinton Street
 Ithaca, N.Y. 14850
 (607) 272-7669

4.1.1. Plastic wishbone connectors

J. B. Sebrell Co.
 301 South San Pedro Street
 Los Angeles, CA 90013
 (213) 625-2648

4.2. Signal Conditioning Systems

Dunegan-Endevco (Jim Borst)
 Rancho Viejo Road
 San Juan Capistrano, CA 92675
 (714) 831-9131

Acoustic Emission Technology Corp.
 1828A Tribute Road
 Sacramento, CA
 (916) 927-3861

Nortec Inc.
 3001 George Washington Way
 Richland, Washington 99352
 (509) 943-9141

Trodyne Corp.
 39 Industrial Avenue
 Teterboro, N.J. 07608
 (201) 288-4400

4.3 Acoustic Impulse Source

4.3.1 Piezo-electric transducers

P71-5 material, made to order:

Specialty Engineering Associates (Nate Brown)
830 Charcot Avenue
San Jose, CA 95131
(408) 946-0171

(This firm will quote on small orders competitively)

Gulton Industries Inc. (G-1512 material)
P. O. Box 4359
Fullerton, CA 92634
(714) 871-2150

Vernitron Piezoelectric Division (P77-5 material)
232 Forbes Road
Bedford, Ohio 44146
(216) 232-8600

4.4 Tape Recorder

Hewlett-Packard Inc.
1430 East Orangethorpe Avenue
Fullerton, CA 92631
(714) 870-1000

6. J. J. HARRIS, 1977, *ibid.*
7. J. J. HARRIS, R. J. LILLY & M. J. J. ALI, 1974, "Microseismic techniques for monitoring the evolution of rock structures," *USP* Bulletin 665.
8. J. J. HARRIS, R. J. LILLY, 1966, Handbook of physical constants, revised edition, Geological Society of America Memoir 97.
9. R. J. HARRIS & E. W. LEIGHTON (Eds.), 1977, Proceedings First Conference on Acoustic Emission/Microseismic Activity in Geologic Structures & Materials, p. 462.
10. J. J. HARRIS & R. H. BOLT, 1971, *ibid.*, New York: J. Wiley, p. 137-146.
11. J. J. MURPHY, 1977, Computer processing and analysis of microseismic data, in Proceedings First Conference on Acoustic Emission/Microseismic Activity in Geologic Structures & Materials, R. J. Harris & E. W. Leighton (Eds.), p. 427-444.
12. R. J. SCHMIDT, S. H. KARP & M. S. FERG, 1963, Physical properties of Mohole test site basalt, *Journal of Geophysical Research*, v. 68, p. 449-455.

columbia miniature accelerometers models 200-1 & 200-3

5001

5002

5003

STANDARD AND HIGH TEMPERATURE RANGES
WIDE SELECTION OF OPTIONAL CHARACTERISTICS

GENERAL PURPOSE — HIGH SENSITIVITY

MODEL 200-1 Miniature Accelerometer has a well balanced combination of characteristics with a sensitivity of 50 mv/g, frequency response flat up to 5 kc, a high crystal capacitance of 550 pf, and a weight of only 16 grams. This unit is ideal for general purpose test work and airborne applications where the impositions upon the transducer may vary considerably.

HIGH FREQUENCY STANDARD & SHOCK APPLICATIONS

MODEL 200-3 Miniature Accelerometer has exceptionally high frequency response up to 10 kc, a high crystal capacitance of 550 pf and a weight of 10 gr. Its excellent characteristics for all applications requiring high frequency response and low mass make this unit ideal for shock measurements and unsurpassed as a laboratory standard for high frequency calibration of other accelerometers.

SIDE OUTPUTS •
DETACHABLE STUDS •

The design of the 200 Series Accelerometers designates the achievement of miniature size and weight without any loss of the characteristics and features necessary for truly general purpose transducers. Not only is outstanding quality and reliability maintained, but an unusually wide gamut of characteristics can be selected to meet optimum test requirements of sensitivity, weight, frequency response and crystal capacitance from the one physical configuration.

These units are very ruggedly built for long life and continued use. The output connector is conveniently positioned on the side and the #8-22 stud is detachable allowing either direct mounting or mounting by adhesive techniques. The special case design affords complete mechanical isolation so that the unit is totally insensitive to mounting torque, body strains, cable vibration and whip, pressure variations and most heat transients.

This miniature series is made even more flexible and broad in scope with the many additional features available on special order. These include

- (1) Intermediate values of sensitivity, frequency response and weight combinations.
- (2) Precise sensitivities within $\pm 1\%$ and/or matched sensitivities between units of $\pm 1\%$.
- (3) Cross axis sensitivity as low as 1%.
- (4) Hermetically sealed connectors.
- (5) High temperature units for operation to +500°F.

7-13 SPECIFICATIONS

	General Purpose High Sensitivity	Shock Work High Frequency Standard
MODELS	200-T Series	200-3-15 & C-1
NOMINAL SENSITIVITY: ¹	100 mV/g	100 mV/g
CHARGE SENSITIVITY:	40 pC/g	100 pC/g
FREQUENCY RESPONSE:	5 cps to 100 cps	5 cps to 100 cps
RESONANT FREQUENCY:	100 cps	100 cps
MAXIMUM ACCELERATION:	100 g	100 g
MINIMUM ACCELERATION	0.001 g	0.001 g
MAXIMUM CROSS AXIS SENSITIVITY:	0.1%	0.1%
AMPLITUDE LINEARITY:	±1%	±1%
NOMINAL CAPACITY:	100 pF	100 pF
OUTPUT RESISTANCE:	100 ohms	100 ohms
TEMPERATURE RANGE:	-55°C to +125°C	-55°C to +125°C
MOUNTING TORQUE SENSITIVITY:	0.1%	0.1%
ACOUSTIC NOISE SENSITIVITY:	100 mV/g	100 mV/g
HUMIDITY	95% RH	95% RH
ALTITUDE:	Unlimited	Unlimited
SALT SPRAY:	100 hrs	100 hrs
MATERIAL:	Aluminum	Aluminum
WEIGHT:	10 grams	10 grams
DIMENSIONS:	1.2 x 1.2 x 1.2 in.	1.2 x 1.2 x 1.2 in.
MOUNTING:	8-32 data table stud	8-32 data table stud
GROUNDING:	Electrically grounded to case	Electrically grounded to case
CABLE:	Model LN-10 supplied. Approx. 10 ft, 300 mfd cap.	Model LN-10 supplied. Approx. 10 ft, 300 mfd cap.
OUTPUT CONNECTOR:	Coaxial, 8-14-32 thread mates with cable assembly supplied	Coaxial, 8-14-32 thread mates with cable assembly supplied
OUTPUT POSITION:	Side	Side
CALIBRATION:	Individual measurements of capacitance, resistance, natural frequency, and calibration of sensitivity, transverse response, and frequency response are supplied on a calibration card with each transducer. The frequency range of calibration is from 20 cps to the rated upper limit.	Individual measurements of capacitance, resistance, natural frequency, and calibration of sensitivity, transverse response, and frequency response are supplied on a calibration card with each transducer. The frequency range of calibration is from 20 cps to the rated upper limit.
RECALIBRATION CHARGE:	\$75.00 per axis at room temperature.	\$75.00 per axis at room temperature.
RELIABILITY:	All Columbia transducers and instruments are manufactured, inspected and tested in accordance with the most exacting government-improved quality control requirements. All components, subassemblies and completed transducers are subjected to careful in-process and assembly inspections and 100% final inspection and testing. Each unit is temperature cycled while in process of assembly to attain maximum stability of operation. A certificate showing traceability of calibration to NBS is furnished.	All Columbia transducers and instruments are manufactured, inspected and tested in accordance with the most exacting government-improved quality control requirements. All components, subassemblies and completed transducers are subjected to careful in-process and assembly inspections and 100% final inspection and testing. Each unit is temperature cycled while in process of assembly to attain maximum stability of operation. A certificate showing traceability of calibration to NBS is furnished.
PRICES:	1 - 5 Units \$155.00 ea. 6 - 10 Units 139.50 ea. 11 - 50 Units 131.00 ea.	1 - 5 Units \$155.00 ea. 6 - 10 Units 139.50 ea. 11 - 50 Units 131.00 ea.

NOTE:

¹Sensitivity range ±2% from nominal. For vibration measurements using RMS-mv pk-mv multiply by 0.707.

SPECIFICATIONS AND PRICES ARE SUBJECT TO CHANGE WITHOUT NOTICE

still apply
August 1976

columbia ultra high sensitivity & performance accelerometers models 302-2 & 302-5

• UNEXCELLED CASE ISOLATION

AIRBORNE APPLICATIONS ELECTRICAL ISOLATION

The Model 302-2 Accelerometer has a very wide frequency range, a combination of characteristics with a sensitivity of 100 mV/g, frequency response flat up to 30,000 cps, a natural frequency of 100,000 cps, and a weight of less than 20 grams. The base is electrically isolated from the case to minimize ground loop problems. The unit is ideal for general vibration test work and airborne applications where the impedance upon the transducer may be as high as possible.

GENERAL VIBRATION MEASUREMENTS

The Model 302-5 Accelerometer has the best signal-to-noise ratio of characteristics of this series with a sensitivity of 200 mV/g, frequency response flat up to 3,000 cps, a natural frequency of 40,000 cps, and a weight of less than 20 grams. The unit is unsuited for general purpose test work, airborne applications, and in all cases where the transducer may be exposed to rough handling and other adverse conditions encountered in general use.

GENERAL VIBRATION MEASUREMENTS

The Models 302-2 to 302-5 accelerometers are highly recommended for reliable measurement of the wide range of vibration work encountered in missile studies and industry today. These units combine accuracy and very high sensitivity with ruggedness, small size and relatively light weight. The special case design represents a breakthrough in accelerometry affording maximum case isolation. The unique construction provides minimum spurious response from mounting torques (no variation from hand tight to overtorque of 3 times), acoustic noise (in fields up to 155 db), in low and high temperatures (from -100 F to +300°F), and other non-vibrational environments of altitude and humidity.

In missile studies the extremely high sensitivity gives very good signal to noise ratio requiring the use of little or no amplification, even in very low level acceleration

measurements. When used as a system with the Columbia line of amplifiers, the accelerometer amplifier combination can be operated with extension cables (Model CFP-LN-N where N = length of cable) up to 100 ft. or more between them - - - with only negligible loss in sensitivity.

Mounting is simple by means of a detachable #10-32 stud and the output connector is conveniently located on the side. Numerous optional features are available on special order. These include:

- (1) Intermediate values of sensitivity, frequency response and weight combinations.
- (2) Precise sensitivities within $\pm 1\%$ and or matched sensitivities between units of $\pm 1\%$.
- (3) Cross axis sensitivity as low as 1%.

WATER-RESISTANT THERMISTOR ELEMENTS

DESCRIPTION OF MODEL

WATER-RESISTANT THERMISTOR
ELEMENTS

WATER-RESISTANT THERMISTOR
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WATER-RESISTANT THERMISTOR
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WATER-RESISTANT THERMISTOR
ELEMENTS

REFLECTION CHARTS

REFLECTIVITY

REFLECT

NOTES

1. The results are given in terms of resistance and temperature. 2. Results with Coefficient of Resistance (TCR) values of 4000 series. 3. Results are given in terms of resistance and temperature.

columbia ultra high performance accelerometers models 302-6 to 302-9

SIDE OUTPUT •
DETACHABLE STUD •

GENERAL PURPOSE — HIGH SENSITIVITY

MODEL 302-6 Accelerometer with the highest sensitivity available. It has a sensitivity of 100 mv/g, frequency response up to 50,000 cps, and a weight of 25 grams. It is rugged, shock resistant, and suitable for test work in low g-level applications where it is desired to obtain the maximum sensitivity in a rugged accelerometer.

GENERAL PURPOSE — HIGH CAPACITANCE

MODEL 302-7 Accelerometer provides a wide effort output. It has a sensitivity of 40 mv/g, frequency response up to 20,000 cps, and a weight of only 23 grams. This unit is especially suited for shock and vibration tests requiring a wide frequency range and, at the same time, requires a particularly small sized accelerometer.

SHOCK TEST — HIGH FREQUENCY RESPONSE

MODEL 302-9 Accelerometer has an unusually high frequency response up to 10 kc, sensitivity of 15 mv/g, and crystal capacitance of 100 pf, and a light weight of 23 grams. These unusual characteristics are ideal for high g-level shock measurements of short duration requiring high frequency response in a rugged and serviceable transducer.

GENERAL SHOCK AND VIBRATION STUDIES

The 302 Series Accelerometers are highly recommended for reliable measurement of the wide range of shock and vibration work encountered in missile work, flight tests, space studies and the ever growing number of tests occurring in the environmental laboratory today. These units combine accuracy and very high sensitivity (up to 100 mv/g) with ruggedness, small size and light weight (as low as 23 grams). Their special case design represents a breakthrough in accelerometry. The new housing constructions afford maximum case isolation, thereby providing minimum spurious response from mounting forces (no variation from hand tight to overtorque of two times), acoustic noise (in fields up to 155 db), in low and high temperatures (from -100°F to 350°F), and other non-vibrational environments of altitude and humidity.

The output connector is conveniently positioned on the side and the #10-32 stud is detachable allowing either direct mounting or mounting by adhesive techniques. This series is made even more flexible and broad in scope with the numerous additional features available on special order. These include:

- (1) Intermediate values of sensitivity, frequency response and weight combinations.
- (2) Precise sensitivities within $\pm 1\%$ and/or matched sensitivities between units of $\pm 1\%$.
- (3) Cross axis sensitivity as low as 1%.

11

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17

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11 Transverse resonance frequency at 11 kHz (typical) only, and the useful frequency range further.

Specifications

1-12
 Model d. 1/2

Accelerometer Dimensions

Figure 1-1

Figure 1-2

Figure 1-3

Figure 1-4

Figure 1-5

Figure 1-6

Figure 1-7

Figure 1-8

Figure 1-9

Figure 1-10

Figure 1-11

Figure 1-12

Figure 1-13

Figure 1-14

Figure 1-15

Figure 1-16

Figure 1-17

Figure 1-18

Figure 1-19

Figure 1-20

Figure 1-21

Figure 1-22

Figure 1-23

Figure 1-24

Figure 1-25

Figure 1-26

Figure 1-27

Figure 1-28

Figure 1-29

Figure 1-30

Figure 1-31

Figure 1-32

Figure 1-33

Figure 1-34

Figure 1-35

Figure 1-36

Figure 1-37

Figure 1-38

 

All dimensions in mm

MODELS 2213E
2233E

HIGH SENSITIVITY ACCELEROMETERS

These accelerometers are designed for use in a wide range of applications where high sensitivity and low noise are required. They are available in two models, 2213E and 2233E, which differ in their frequency response and output range.

The 2213E model is designed for use in applications where a wide frequency response is required, from 0.1 Hz to 10,000 Hz. The 2233E model is designed for use in applications where a narrow frequency response is required, from 0.1 Hz to 1,000 Hz.

Both models are available in two output ranges, 0.1 mV/g and 1.0 mV/g. The 0.1 mV/g range is suitable for use in applications where high sensitivity is required, while the 1.0 mV/g range is suitable for use in applications where a lower sensitivity is required.

Specifications for Models 2213E and 2233E Accelerometers

DYNAMIC

Frequency Response	0.1 Hz to 10,000 Hz (2213E) 0.1 Hz to 1,000 Hz (2233E)
Output Range	0.1 mV/g (2213E) 1.0 mV/g (2233E)
Input Impedance	> 100 MΩ
Power Consumption	< 100 mW
Operating Temperature	-40°C to +125°C
Storage Temperature	-55°C to +150°C
Shock Resistance	10,000 g (2213E) 5,000 g (2233E)
Vibration Resistance	10 g (2213E) 5 g (2233E)
Calibration	Factory calibrated to ±1% at 1 Hz

NOTES

1. All specifications are for the nominal operating conditions.
2. The frequency response is defined as the range of frequencies over which the output is within ±1% of the nominal value.
3. The output range is defined as the range of input accelerations over which the output is within ±1% of the nominal value.
4. The input impedance is defined as the impedance seen by the source.
5. The power consumption is defined as the power dissipated in the device.
6. The operating temperature range is defined as the range of temperatures over which the device can operate without degradation of performance.
7. The storage temperature range is defined as the range of temperatures over which the device can be stored without degradation of performance.
8. The shock resistance is defined as the peak acceleration to which the device can be subjected without permanent damage.
9. The vibration resistance is defined as the root mean square (RMS) acceleration to which the device can be subjected without permanent damage.
10. The calibration is defined as the ratio of the output to the input at 1 Hz.

TYPICAL TEMPERATURE RESPONSE

The solid curve shows the nominal change temperature response. The nominal voltage temperature response is illustrated by the dashed curves with external capacitances as indicated.

TYPICAL FREQUENCY RESPONSE

The solid line shows the charge frequency response. The broken lines show the voltage frequency response with the loads shown. Estimated calibration errors:
5 to 1000 Hz: $\pm 1.5\%$
1000 to 10,000 Hz: $\pm 2.5\%$

MODEL 2217E

High Temperature
Accelerometer
With Charge Amplifier

LOW G LEVEL ACCELEROMETER

The high sensitivity, wide frequency response, low level Model 2217E accelerometer is suitable for use in applications requiring high precision measurements of low level acceleration. The high precision, wide frequency response is maintained throughout the operating range without the need for leveling.

The accelerometer is available in two versions: one with a built-in charge amplifier and one with a separate charge amplifier. The response is linear to 100 g and the frequency response is maintained to 100 kHz.

The Model 2217E is available in two versions: one with a built-in charge amplifier and one with a separate charge amplifier.

Specifications for Model 2217E Accelerometer

(The Model 2217E is available in two versions)

DYNAMIC

CHARGE SENSITIVITY	100 mV/g
VOLTAGE SENSITIVITY	100 mV/g at 100 Hz 200 mV/g at 10 Hz
BUILT-IN RESONANT FREQUENCY	20 kHz
FREQUENCY RESPONSE	10 Hz to 100 kHz 10 Hz to 100 kHz
TRANSVERSE SENSITIVITY	5% max
AMPLITUDE LINEARITY	100 g to 1000 g 100 g to 1000 g
TRANSDUCER CAPACITANCE	100 pF
RESISTANCE	100 MΩ at 100 Hz 100 MΩ at 10 Hz

NOTES

1. The Model 2217E is available in two versions: one with a built-in charge amplifier and one with a separate charge amplifier.
2. The Model 2217E is available in two versions: one with a built-in charge amplifier and one with a separate charge amplifier.
3. The Model 2217E is available in two versions: one with a built-in charge amplifier and one with a separate charge amplifier.

TYPICAL TEMPERATURE RESPONSE

The solid line is the nominal charge temperature response. The broken lines show the nominal voltage temperature response with the indicated external capacitance.

TYPICAL FREQUENCY RESPONSE

The solid line shows the charge frequency response. The broken line shows the voltage frequency response with 100 pF external capacitance and the indicated loads.

7701-50
MODELS 7701-100

Low Frequency
High Sensitivity

ISOSHEAR™
ACCELEROMETERS

The ISOSHEAR Model 7701-50 and 7701-100 accelerometers are high performance piezoelectric devices designed for precise vibration measurement applications. The 7701-50 is designed for use in applications requiring high sensitivity and low noise floor. The 7701-100 is designed for use in applications requiring high sensitivity and low noise floor. Both models are available in a variety of mounting options and are designed for use in a wide range of environments.

The ISOSHEAR Model 7701-50 and 7701-100 accelerometers are designed for use in a wide range of environments. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor.

The ISOSHEAR Model 7701-50 and 7701-100 accelerometers are designed for use in a wide range of environments. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor.

SPECIFICATIONS FOR ISOSHEAR MODEL 7701-50 AND 7701-100 ACCELEROMETERS

DYNAMIC	7701-50	7701-100
SENSITIVE ELEMENT	50 pC/g nominal 45 pC/g minimum	100 pC/g nominal 90 pC/g minimum
FREQUENCY RESPONSE (Hz)	1 Hz to 2000 Hz	1 Hz to 5000 Hz
MECHANICAL RESONANCE FREQUENCY	58,000 Hz nominal	20,000 Hz nominal
TRANSVERSE SENSITIVITY	3% maximum, selected units available at less than 1%	3% maximum, selected units available at less than 1%
TEMPERATURE RESPONSE (°F)	-65 F (-54 C) to +500 F (+260 C)	-65 F (-54 C) to +500 F (+260 C)
AMPLITUDE LINEARITY	Sensitivity increases approximately 1% per 100 g, 0 to 2000 g	Sensitivity increases approximately 1% per 250 g, 0 to 2000 g

ELECTRICAL

TRANSDUCER CAPACITANCE	2800 pF at 1000 Hz at 75 F (24 C) -15% to +60% at -65 F to +500 F	2800 pF at 1000 Hz at 75 F (24 C) -15% to +60% at -65 F to +500 F
TRANSDUCER RESISTANCE AT 75 F (24 C) AT 500 F (260 C)	10 GΩ minimum 50 MΩ minimum	10 GΩ minimum 50 MΩ minimum
GND. WELDING	Signal return is connected to case	Signal return is connected to case

NOTES

1. The ISOSHEAR Model 7701-50 and 7701-100 accelerometers are designed for use in a wide range of environments. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor.
2. The ISOSHEAR Model 7701-50 and 7701-100 accelerometers are designed for use in a wide range of environments. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor.
3. The ISOSHEAR Model 7701-50 and 7701-100 accelerometers are designed for use in a wide range of environments. They are designed for use in applications requiring high sensitivity and low noise floor. They are designed for use in applications requiring high sensitivity and low noise floor.

TYPICAL FREQUENCY RESPONSE

The solid line shows frequency response for the 7701-50 and the broken line shows frequency response for the 7701-100.

TYPICAL TEMPERATURE RESPONSE

The curve shows the flat temperature response of the ISOSHEAR design.

TECHNICAL SPECIFICATIONS

1. Transducer, Model 5210

This transducer has an integral preamplifier providing a high level signal from a low source impedance*. It is designed for intrinsic safety and complies with UL910 Specification 1855.614. The Model 5210 is a rugged device with a hermetically sealed stainless steel case suitable for industrial applications.

Sensitivity	250 mV/g
Frequency Response	10 Hz - 500 Hz, usable to 17 kHz (see enclosed response curve)

$$250 \text{ mV/g}$$

$$25 \text{ mV}/1 \text{ m/s}^2$$

*Capable of driving 300 meters cable at 10 kHz.

$$\begin{aligned}
 & \text{In Columbia 3023 +} \\
 & \text{Itaw 144F} \\
 & (3023) \quad (144F) \\
 & 1.5 \text{ mV} \times 100 / \text{m/s}^2 \\
 & = 150 \text{ mV/m/s}^2 \\
 & \text{or } 1500 \text{ mV/g}
 \end{aligned}$$

Frequency, Hz

W-115 5210

7-37

DATE March 1, 1978

Figure 1. Nominal sensitivity deviation versus frequency and temperature.

ITHACO INC.

735 W. CLINTON ST., 3D-45A, ITHACA, N.Y. 14850 TEL 212 734 4000 FAX 516 215 3177

LOW NOISE, HIGH IMPEDANCE PREAMPLIFIERS - MODELS 143 and 144

E F N I

COMMON SPECIFICATIONS - ALL OPTIONS

Model 143	Model 144
Input Impedance	100,000 ohms
Output Impedance	100 ohms
Gain	100
Bandwidth	10 Hz to 100 kHz
Maximum Input Voltage	100 mV
Maximum Output Voltage	10 V
Power Consumption	100 mW
Operating Temperature	0°C to 50°C
Storage Temperature	-55°C to 100°C
Humidity	5% to 95%
Shock	100 g
Vibration	10 g
Life	10,000 hours
Warranty	1 year

Model 143	Model 144
Input Impedance	100,000 ohms
Output Impedance	100 ohms
Gain	100
Bandwidth	10 Hz to 100 kHz
Maximum Input Voltage	100 mV
Maximum Output Voltage	10 V
Power Consumption	100 mW
Operating Temperature	0°C to 50°C
Storage Temperature	-55°C to 100°C
Humidity	5% to 95%
Shock	100 g
Vibration	10 g
Life	10,000 hours
Warranty	1 year

SPECIFICATIONS FOR OPTIONS E, F, I and N (Apply to Models 143 and 144)

Option	Model 143	Model 144
Input Impedance	100,000 ohms	100,000 ohms
Output Impedance	100 ohms	100 ohms
Gain	100	100
Bandwidth	10 Hz to 100 kHz	10 Hz to 100 kHz
Maximum Input Voltage	100 mV	100 mV
Maximum Output Voltage	10 V	10 V
Power Consumption	100 mW	100 mW
Operating Temperature	0°C to 50°C	0°C to 50°C
Storage Temperature	-55°C to 100°C	-55°C to 100°C
Humidity	5% to 95%	5% to 95%
Shock	100 g	100 g
Vibration	10 g	10 g
Life	10,000 hours	10,000 hours
Warranty	1 year	1 year

AVAILABLE MODIFICATIONS

- Remote low noise of gain
- Controlled low frequency roll-off
- Controlled high frequency roll-off
- Remote low noise of low frequency roll-off
- Low noise roll-off for low frequency roll-off
- High noise roll-off for high frequency roll-off

● Preamplifiers with better noise performance are available on special order.

TERMINALS

APPLICATION NOTES

The power supply section of the ITHACO is designed to provide a constant output voltage of 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz.

The power supply section of the ITHACO is designed to provide a constant output voltage of 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz.

The power supply section of the ITHACO is designed to provide a constant output voltage of 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz.

UNIT PRICES

OPTION E
\$242.00

OPTION F
\$242.00

OPTION G
\$242.00

OPTION H
\$242.00

OPTION I
\$242.00

The ITHACO is a precision instrument designed for use in the laboratory. It is capable of measuring the output voltage of a power supply with an accuracy of 0.1%. The ITHACO is designed to provide a constant output voltage of 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz. The output voltage is regulated by a feedback loop which maintains the output voltage at 100 Hz.

\$305 August, 1978

less 5% for orders > 100

Printed in USA

00000-33 PRINTED

Models 3954A, 3968A, and 1304A

[illegible]

Figure 10. The effect of the initial concentration of the monomer on the polymerization of *l*-lysine. The polymerization was carried out at 30°C for 24 h in the presence of 0.05 M NaOH and 0.05 M NaCl. The initial concentration of the monomer was 0.05 M. The initial concentration of the monomer was 0.05 M. The initial concentration of the monomer was 0.05 M.

The 1997 VFA has been hailed as the first step from an end to the cycle of political violence in Cambodia, but it has been criticized for not addressing the

the 1990s, the number of people in the world who are under 15 years of age is expected to increase from 1.1 billion to 1.5 billion. The number of people aged 65 and over is expected to increase from 250 million to 450 million. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion.

"E-to-E" mode for FM recording;

Simplifies to $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ at $\frac{1}{4}$ of the original value.

Tape Tach servo in the tape transport system is controlled by the controller. The controller has a tape tach servo base assembly from a tape transport system that has a tach servo.

Equalization: a process that allows states to share the burden of costs of large-scale programs of transportation, education, health care, and other public services.

Remote control is the primary feature of the automatic model. The unit provides remote control of fast, FF, and variable speed, still and motion picture, tape speeds and operation modes.

AC/DC calibrator, provides an easy AC/DC voltage source for setting up input and output levels for each of the data channels. Voltage levels and channel functions are selected with pushbutton ease.

Flutter compensation: a variable with the flip of a switch. Flutter modulation introduced during the recording process is eliminated providing an improvement in J-M signal-to-noise ratio by up to 12 dB.

Voice capability: recorded data can be voice annotated on Channel 4 of 3964A or Channel 8 of 3974A with press to talk microphone.

Unipolar operation for FM recording: when a signal has a positive or negative only deviation, the FM input reference level can be offset to plus or minus full deviation to permit full utilization of the channel's dynamic range.

54. 28

3964A and 3968A specifications

* $p < 0.05$ compared to control.

* tape width = 1/2 in.

1901 1902

$$i \left(\frac{\partial}{\partial t} + \frac{1}{2} \frac{\partial^2}{\partial x^2} \right) \psi = - \frac{1}{2} \frac{\partial^2}{\partial x^2} \psi, \quad \psi(0, x) = \delta(x), \quad \psi(t, x) = \frac{1}{\sqrt{2\pi t}} e^{-\frac{x^2}{2t}}.$$

1. The first group of variables is the set of variables that are used to describe the characteristics of the firm. These variables are: size, age, industry, and location. Size is measured by the number of employees, age by the number of years since the firm was founded, industry by the two-digit SIC code, and location by the state and county of the firm's headquarters.

Confidentiality of the data. The data were stored in a secure database and were accessible only to the research team.

There is a large number of people who are interested in the study of the history of the United States, and who are also interested in the study of the history of the world. The study of the history of the United States is a very important part of the study of the history of the world, and it is a very interesting and useful study. The study of the history of the United States is a very important part of the study of the history of the world, and it is a very interesting and useful study.

[illegible]

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202	202	203	203	204	204
205	205	206	206	207	207
208	208	209			

Tape motion controls for all reverse record functions are

Start and stop times (typical)

1941-1945	1946	1947	1948	1949	1950
1951-1955	1956	1957	1958	1959	1960
1961-1965	1966	1967	1968	1969	1970

Rewind time (typical): 1800 foot (549 m) reel in 100 seconds
1000 foot (305 m) reel in 45 seconds

Braking: Full safety, no hand or differential brakes

End-of-tape sensing: tape drive stops automatically at the end of tape

Reel revolution counter: 4 digit revolution counter with push button reset

[illegible]

 
70		John Doe	100.00	
71				100.00
72		John Doe	100.00	
73				100.00
74		John Doe	100.00	
75				100.00
76		John Doe	100.00	
77				100.00
78		John Doe	100.00	
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83				100.00
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87				100.00
88		John Doe	100.00	
89				100.00
90		John Doe	100.00	
91				100.00
92		John Doe		

 $kg(g, b)$

 

13064A Tape Decipherer (Specify Opt 001 or 002)¹

PASCO BASIN GROUNDWATER CONTAMINATION STUDY

Introduction

A major barrier to the study of the geochemistry of transition elements in marine and estuarine waters has been the problem of sample contamination (Patterson, 1974). Although researchers have long been aware of this problem, it has taken many years to develop the necessary sampling techniques to the point where representative trace element samples can now be obtained.

Contamination problems will similarly restrict the success of ground water trace element geochemical studies until sources of contamination are identified and corrective measures are taken. The experience and techniques gained from marine and estuarine trace element investigations can be extended to the study of trace elements in ground waters. However, the Sources of contamination in down-hole ground water sampling are distinct from these encountered in open ocean sampling and are more difficult to control. Drilling muds, detergents, additives, pipe, and grouting material used during the drilling and casing of wells are major potential sources of contamination. If these materials contain significant quantities of leachable trace elements, the well waters may become seriously contaminated. Ground water samples may become additionally contaminated during the sampling or "swabbing" process since this method requires the introduction of packers, grease, and metal tubing into the wells.

An awareness of these and other potential contamination problems must be maintained during the development of the Pasco Basin Hydrology Study so that the expenditure of analytical and interpretative effort on hopelessly contaminated samples can be minimized and so that any necessary alternative materials and methods may be selected early in the study.

Objectives

The objectives of this study are to identify potential sources of ground water trace element contamination associated with the materials and equipment used for well drilling and down-hole water sampling and to subsequently estimate the rates of desorption or absorption of trace elements from specific contamination sources.

No previous estimates of the potential contamination of ground water samples have been made. Consequently, the information to be obtained in this contamination study is necessary in order to determine if alternate materials and sampling methods will be required in the preparation and operation of wells whose primary purpose is for the investigation of ground water trace element geochemistry.

Scope

This study will consist of a series of interrelated laboratory experiments in which test materials are placed in one liter, acid cleaned, common polyethylene bottles filled with artificial ground water of known major and trace elemental composition. Artificial ground water rather than actual ground water from the Pasco Basin will be used in these experiments since the extent of trace element contamination in ground water samples is unknown. Trace element concentrations in artificial ground water will be sufficiently low so that contamination from test materials can be quantitatively measured. Experiments will be conducted in the dark at 60°C, the approximate temperature of well waters at a depth of 1300 m. Constant temperature and continuous agitation, if required, will be maintained by use of a shaking, constant temperature, water bath.

Water samples (5-10 ml) will be withdrawn from the experimental containers at time doubling intervals in order to define rates of desorption or absorption of dissolved trace elements. These samples will be immediately filtered through preleached membrane filters (0.2 μ m pore size or smaller), acidified with re-distilled nitric acid to pH 1, and stored in acid cleaned, polyethylene containers. Analyses for aluminum (Al), calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), lead (Pb), and zinc (Zn) will be performed by flameless atomic absorption spectroscopy (AAS) using direct injection. Analysis for silicone (Si) will be performed by DC plasma emission spectroscopy. Approximate detection limits for these analytical techniques are shown in Table 1.

Representative samples of drilling muds, detergents, additives, and greases will be obtained from the drillers at the Pasco Basin site and will be stored under appropriate conditions to maintain the integrity of the samples. Samples of well casing, packers and sample tubing will also be obtained. The size of all samples will be sufficient to allow for additional unforeseen analyses.

The major and trace elemental composition of representative subsamples of each of the test materials will be determined using multielement analytical methodologies; such as emission spectroscopy, x-ray fluorescence spectrometry and neutron activation analysis. The trace elemental composition of each test material will in part determine which elements are to be subsequently examined in individual contamination experiments.

Water samples from at least one well and possibly a spring at the Pasco Basin site will be obtained and characterized prior to the desorption experiments. Parameters to be determined include pH, Eh, conductivity, alkalinity, total dissolved solids, and major and trace element content. These measurements will be made in conjunction with the water sampling program.

Water to be used in all contamination experiments will be made up in the laboratory to match the elemental composition and pH of the Pasco Basin well water. It is anticipated that the major constituent of this water will be NaHCO_3 at a concentration of approximately 100-200 mg/L. Prior to use, the trace element composition of the laboratory prepared water will be determined by emission spectroscopy and AAS.

Individual experiments are described below as tasks 1 through 5. Tasks 1-4 are not intended to exactly duplicate field conditions but rather are designed to provide information on the major potential sources of contamination. Experimental conditions for tasks 1-4 are summarized in Table 2 along with a tentative list of the elements to be measured. Task 5 is designed to evaluate neutral pH adsorption and pH 1 desorption of dissolved trace metals by common polyethylene containers.

Task 1. Drilling Mud

Prior to the drilling mud experiment, bulk sediment characteristics will be determined. These characteristics include but are not limited to particle size distribution by pipette analysis and inorganic and organic carbon content by carbon analyzer.

The drilling mud experiment will be carried out under oxidizing and reducing conditions to determine if oxidation - reduction potential affects the release of trace elements from the sediment. To produce the different conditions, half of the samples will be sparged with air or oxygen and half will be sparged with argon or nitrogen as required. The oxidation - reduction potential of the samples will be monitored by periodic Eh measurements. Periodic pH measurements will also be made.

Two sediment concentrations will be used in order to evaluate the relative importance of desorption and adsorption mechanisms. It is anticipated that these concentrations will be 20 and 100 g/L. Samples will be continuously agitated throughout the experiment to prevent caking of the sediment on the bottom of the containers.

Three replicate samples will be made for each experimental condition. Ten samples for dissolved trace elements will be taken on a periodic basis. Exact sampling times will be determined by preliminary experiments; however, samples will be taken within the first hour to document any initial desorption. The total length of the experiment is not expected to exceed 14 days. Samples will be analyzed for Al, Ca, Cu, Fe, Mg, Pb and Zn.

Task 2. Drilling Detergent and Additives

Since the detergent and additives are either soluble or miscible in water, the purpose of this experiment is to determine if the use of these materials results in the precipitation of trace elements from the water.

Laboratory prepared water will be spiked with the elements of interest which include Ca, Cu, Fe, Mg, Pb, and Zn. Spiked concentrations should be approximately equivalent to concentrations determined for wells or springs in Tacco Basin. Due to the possible contamination of ground water samples, a range of concentrations may be required.

Detergent and additives will be investigated in separate experiments. Four different dilutions of detergent or additives will be used in conjunction with a blank to which only trace element spikes have been added. The dilutions are anticipated to be 10^{-2} , 10^{-3} , 10^{-4} , and 10^{-5} . All sample containers will be maintained at oxidizing conditions without agitation.

Three replicate samples will be made for each experimental reaction. Five samples for dissolved trace elements will be taken on a periodic basis at times determined from preliminary experiments. Measurements of pH will also be made at these times. Trace element analyses will be performed by flameless AAS; however, samples may have to be pretreated in order to remove potential interferences.

Task 3. Swabbing Material and Grease

Experiments with grease and grease will be conducted separately. Two different oil to grease ratios will be used for each material. It is anticipated that these ratios will be 1:1 and 25% oil²/g for the grease and 1:1 and 25 g/L for the grease. All sample containers will be maintained at oxidizing conditions with a nitrogen atmosphere.

Three replicate samples will be made for each experimental reaction. Five samples for dissolved trace elements will be taken on a periodic basis. Since the swabbing materials will only be in place during sampling, the emphasis of these experiments is on short term desorption. At least two samples will be taken during the first hour and the total length of each experiment will probably not exceed 24 hr. Measurements of pH will be made at each sampling interval. Samples for the determination of dissolved organic carbon will also be obtained during the grease experiment. Since the grease may introduce interferences in AAS analyses, these samples may have to be pretreated.

Task 4. Well Casing and Sample Tubing

Sections of pipe and tubing, approximately 15 cm in length, will be placed in one liter containers with laboratory prepared water. The experiments will be carried out under both oxidizing and reducing conditions. Oxidation - reduction potential will be controlled by sparging with appropriate gases and will

to monitor every variable is impractical. Periodic pH measurements will also be made. All sample containers will be continuously agitated.

Three replicate samples will be made for each experimental condition. Since the samples must only be in place during sampling, the emphasis of this experiment is on short term desorption. Two of the five samples to be taken will be obtained during the first hour and the total length of the experiment will probably not exceed 14 days. Desorption from the casing will be followed over a longer time period not to exceed 14 days. Few samples will be taken at time duration intervals to be determined from preliminary experiments.

All samples will be analyzed for Cu, Fe, Mg, Pb, and Zn. Casing samples will also be analyzed for Al, Ca, and Si.

Task 5: Container Effects

This task consists of two parts. First, the magnitude and rate of absorption of dissolved trace elements onto common polyethylene (CPE) container walls will be determined. This determination is necessary since tasks 1-4 will be carried out at neutral or slightly basic pH, and trace elements desorbed from the experimental materials may be partially lost to the container walls. If this occurs, desorption rates will have to be corrected.

Container effects will be determined by adding trace element spikes to acid cleaned, one liter, CPE bottles (see below) containing artificial ground water. At least five replicates and two spike concentrations of each of the eight elements of interest will be used. All bottles will be maintained at 60°C. Approximately ten samples will be withdrawn from each bottle on a periodic basis in order to define any loss curves. The duration of the experiment will not exceed 14 days, the maximum length of tasks 1-4.

Work Schedule

Field work will be completed in 1977. Preparation of experimental apparatus and equipment will continue through July 1977. Laboratory work will be completed by the end of the year. The experimental apparatus will be completed by the end of the year. A preliminary report will be submitted by the end of the year. The results of the experiments will be published in the literature. The results of the experiments will be published in the literature. The results of the experiments will be published in the literature.

Budget

The estimated expenditures are presented in Table 4.

Literature Cited

Wright, J.B. and P. M. Lindstrom 1977.

Selection and cleaning of plastic containers for storage of trace element samples. Anal. Chem. 49: 2264-2267

Patterson, C.C. 1974.

Lead in seawater, Science 183: 553.

FIGURE 1. Work schedule.

TABLE 1. Detection limits based upon 1% abundance.

Element	Absolute sensitivity (10 ⁻¹¹ g)	Sensitivity with 1% abundance (ppb)
Al	70 - 300	4.0 - 1.6
Ca	15 - 100	0.8 - 1.0
Cu	30 - 80	1.5 - 1.0
Fe	15 - 30	1.0 - 1.5
Mg	0.4 - 0.8	0.02 - 0.1
Pb	10 - 100	0.5 - 1.0
Si*	--	100 - 400
Zn	0.6 - 2.0	0.03 - 0.1

*Analysis by DC emission spectroscopy.

TABLE 2. Experimental parameters for Tasks 1-4.

Parameter	Drilled Material		Sampled Material	
	Task 1	Task 2	Task 3	Task 4
Solids to volume ratio	20, 100 g/L	10, 50 g/L	50, 250 g/L 5, 25 g/L	10 g/L
Water	NaCl ₂	NaHCO ₃	NaHCO ₃	NaHCO ₃
Temperature	60 °C	60 °C	60 °C	60 °C
Illumination	dark	dark	dark	dark
Atmosphere	air / inert	air	air	air / inert
Agitation	constant	none	constant	constant
No. of sample	10	5	5	10
No. of replicates	3	3	3	3
Elements to be analyzed	Al, Ca, Cu, Fe, Mg, Pb, Si, Zn	Cu, Fe, Mn, Pb, Zn	Cu, Fe, Mg, Pb, Zn	Al, Ca, Cu, Fe, Mg, Pb, Si, Zn
Additional measurements	pH, Eh	pH	pH, DOC	pH, Eh

TABLE 3. Methods used for cleaning of GPC sample containers for Fe^{3+} , Fe^{2+} , Cr^{6+} analysis.

101-1

1. Rinse with 95% ethanol.
2. Fill with 1M HCl (AP grade) and allow to stand for three days at room temperature.
3. Empty and rinse with de-ionized water.
4. Fill with 1M HNO_3 (AP grade) and allow to stand for three days at room temperature.
5. Empty and rinse with quartz distilled de-ionized water.
6. Fill with 0.5% HNO_3 (Ultrapure grade) made up in quartz-distilled de-ionized water and allow to stand for at least three days at room temperature.
7. Empty; rinse with quartz-distilled de-ionized water, and dry in dust- and fume-free environment.

TABLE 4. Budget

			\$K
Personnel*	Payroll Acct.	Time	
Don Girvin	(9452)	1.0 mo	2.3
Al Hodgson	(9453)	5.5 mo	10.4
Mechanical Shop	--	--	0.3
		Subtotal for indirect costs benefiting	13.0
Supplies and Expenses			
Misc. supplies (itemized below)			2.15
Publications			0.2
		Total Direct Costs	15.3
Energy & Engineering Overhead (%)			1.4
LBL Overhead	(40.5%) [†]		16.6
			6.7
		Total Operating Costs	23.4
Equipment (itemized below)			1.5(3.0)
		TOTAL REQUEST	25.0(26.5)

Supplies:

Polyethylene bottles	\$ 100
Electrodes - 4 pH	300
Electrodes - 4 Eh	400
Carbon tubes for flameless AAs	500
AAS hollow cathode lamps	300
Filter assemblies (47 mm)	50
Filter membranes	250
High purity acids and reagents	250
	\$2150

Equipment:

Temperature controlled water bath & shaker assembly (max T = 80°C ± 1°C; size sufficient for two simultaneous experiments)	\$1500
Digital pH - aux. electrode meter, temp. compensated	(\$1500) [‡]

*Ratio based on Payroll Group Averages in accordance with costing practice for all DOE projects.

[†]Estimate of 40.5% is used; prevailing rate would be used for actual billing.

[‡]Must be purchased if not available within Group.

11/1/21

4-2-2011

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[illegible]

2000

It was a pleasure to meet you and your colleagues at Highland last week, and to "hot up to speak" on the program at Highland. As we discussed in Highland, in our place concentration this summer, following are some of the research topics/studies associated with the near surface to 100 ft depth.

1. Introduction

Examination of the set of drawings for the NSTF and comparison with published geologic data indicated that a fault mapped by Newcombe, et al. (1973) in the NW 1/4 of Sec. 13 and the SW 1/4 of Sec. 14, T. 13 N., R. 26 E., may project into the NSTF area. This was mapped as a normal fault, with the west side down. Discussion with Wes Meyers and Karl Lecht indicated that the fault, if present, probably does not exist as delineated by Newcombe, et al., but rather may be located farther east. This is substantiated somewhat in a USGS Open File Report by Bingham, et al., (1970), who interpret this feature as an eastward-dipping thrust fault, striking north to SNE (Bingham, et al., pp 52-53, Figures 13 and 14). If this latter interpretation holds, the NSTF would probably be less, if at all, effected by the fault, because it would strike clear of the proposed location of the facility and dip away from the site. With these considerations in mind, I believe it is imperative to, as quickly as possible, accurately locate the fault and resolve the discrepancy between the two USGS interpretations of its character. The result of this study should be well documented (perhaps Fecht's forthcoming report, (1976) would be the appropriate document), to have on record the fact that the presence of the fault was recognized and its location and character discerned. If study of the fault discloses its projection on to the site, consideration should be given immediately to re-location and/or re-orientation of the NSTF.

Mark P. Ford

November 1, 1968

2. Detailed Mapping of the Site

In our discussion we agreed that lithologic mapping of the International site is the next step in our investigation. The geologic setting of the hole is described in detail in the report, mapping of the site is a necessary step in the planning of the project. The mapping of the site should be done in a systematic manner, starting with the surface, then in the subsurface, and finally in the subsurface. The first step in the mapping of the site is to determine the location of the hole. This can be done by using the coordinates of the hole, which are given in the report. The next step is to determine the lithology of the rock. This can be done by using the lithologic column, which is given in the report. The third step is to determine the structure of the rock. This can be done by using the structural map, which is given in the report. The fourth step is to determine the mineralogy of the rock. This can be done by using the mineralogical map, which is given in the report. The fifth step is to determine the petrology of the rock. This can be done by using the petrological map, which is given in the report. The sixth step is to determine the geochronology of the rock. This can be done by using the geochronological map, which is given in the report. The seventh step is to determine the geochemistry of the rock. This can be done by using the geochemical map, which is given in the report. The eighth step is to determine the geophysics of the rock. This can be done by using the geophysical map, which is given in the report. The ninth step is to determine the geobotany of the rock. This can be done by using the geobotanical map, which is given in the report. The tenth step is to determine the geozoology of the rock. This can be done by using the geozoological map, which is given in the report. The eleventh step is to determine the geohydrology of the rock. This can be done by using the geohydrological map, which is given in the report. The twelfth step is to determine the geosociology of the rock. This can be done by using the geosociological map, which is given in the report. The thirteenth step is to determine the geoeconomics of the rock. This can be done by using the geoeconomic map, which is given in the report. The fourteenth step is to determine the geopolitics of the rock. This can be done by using the geopolitical map, which is given in the report. The fifteenth step is to determine the geoculture of the rock. This can be done by using the geocultural map, which is given in the report. The sixteenth step is to determine the georeligion of the rock. This can be done by using the georeligious map, which is given in the report. The seventeenth step is to determine the geolaw of the rock. This can be done by using the geolegal map, which is given in the report. The eighteenth step is to determine the geomedicine of the rock. This can be done by using the geomedical map, which is given in the report. The nineteenth step is to determine the geodentistry of the rock. This can be done by using the geodental map, which is given in the report. The twentieth step is to determine the geoveterinary of the rock. This can be done by using the geoveterinary map, which is given in the report. The twenty-first step is to determine the geopharmacy of the rock. This can be done by using the geopharmaceutical map, which is given in the report. The twenty-second step is to determine the geodietetics of the rock. This can be done by using the geodietetic map, which is given in the report. The twenty-third step is to determine the geosports of the rock. This can be done by using the geosports map, which is given in the report. The twenty-fourth step is to determine the geotourism of the rock. This can be done by using the geotourism map, which is given in the report. The twenty-fifth step is to determine the georecreation of the rock. This can be done by using the georecreation map, which is given in the report. The twenty-sixth step is to determine the geoparks of the rock. This can be done by using the geoparks map, which is given in the report. The twenty-seventh step is to determine the geoworld heritage of the rock. This can be done by using the geoworld heritage map, which is given in the report. The twenty-eighth step is to determine the geobiosphere reserve of the rock. This can be done by using the geobiosphere reserve map, which is given in the report. The twenty-ninth step is to determine the geonational park of the rock. This can be done by using the geonational park map, which is given in the report. The thirtieth step is to determine the geoworld heritage of the rock. This can be done by using the geoworld heritage map, which is given in the report.

The detailed description will be done in a systematic manner, coordinated with lithologic mapping. The description of the site will be identified and to determine the way, to be identified by one or more others. A decision on the degree of lithologic mapping should meet to decide on the degree of lithologic mapping. The detailed description will be done in a systematic manner, coordinated with lithologic mapping.

Following excavation, vertical, horizontal, and lithologic cores and instrumentation holes will be logged, lithologic maps and/or physically, to obtain a three-dimensional picture of the site's geologic setting. Drill cores will be logged in detail and selected samples of rock and fracture-filling material analyzed for their physical properties and chemical characteristics.

I look forward to receiving your response to our discussions and to continuing with the planning and conduct of these studies.

With best regards,

Harold A. Wollenberg
Geologist

HAW:og
Attachment

cc: W. Stromdahl, w/a

REFERENCES

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2. Farnham, J.W., *Photoreception: Molecular Biology and Physiology*, in: *Neurobiology of the Visual System*, J. W. Farnham, Ed., Chapman & Co., New York.
3. Dowling, J.E., *The Structure and Function of the Vertebrate Retina*, 1961, Academic Press. Chapter 10, pp. 147-167, describes the structure and function of the rod and cone photoreceptors.

SECTION 10

BEZALEL C. HAIMSON, PH.D.
ROCK MECHANICS
200 NORTH SPONGER
MADISON, WISCONSIN 53705
(608) 262-2563 OFFICE
(608) 238-7010 HOME

October 7, 1978

Mr. Andrew Dubois
Project Manager
Lawrence Berkeley Laboratory, Bldg 95B
University of California
Berkeley, California 94720

Re: Hydrofracturing Stress
Measurements in
Hole DC - 11,
Hanford Reservation

Dear Mr. Dubois:

I am pleased to submit my report on the hydrofracturing tests which I performed at the Hanford site. If there are any questions, please call.

Very truly yours,

Bezalel C. Haimson

Report on
HYDROFRACTURING TESTS
FOR IN SITU STRESS MEASUREMENT-
NEAR SURFACE TEST FACILITY,
HOLE DC-11, HANFORD RESERVATION

Prepared for
Lawrence Berkeley Laboratory
Berkeley, California

by
Bezalel C. Haimson, Ph.D.
209 N. Spooner
Madison, Wisconsin 53705

September 1978

SUMMARY

We conducted six hydrofracturing tests in hole DC-11, Hanford Reservation, between the depths of 55 ft. and 227 ft. All the pressurization tests were successful. Five out of six fracture impressions taken were traceable.

The results show that all the principal stress magnitudes increase with depth: the vertical stress from 65 psi at 55 ft. depth to 280 psi at 227 ft., the least horizontal stress from 115 psi to 275 psi, and the largest horizontal stress from 2120 psi to 3525 psi. The average direction of the latter stress is N60°W.

The measured stresses appear to be strongly affected by the topographic relief. The direction of the largest horizontal stress is subparallel to the axis of Gable Mountain in general, and to the strike of the slope in the vicinity of DC-11 in particular. The magnitude of the largest horizontal stress is also considerably higher than both the least horizontal stress and the vertical stress, the directions of which are perpendicular to the neighboring free surfaces.

TABLE OF CONTENTS

	<u>PAGE</u>
INTRODUCTION	10-5
LOCATION AND LITHOLOGY	10-5
TESTING PROCEDURE	10-5
RESULTS	10-7
STRESS MAGNITUDES AND DIRECTIONS	10-10
REFERENCE	10-12
TABLES 1-4	10-13 to 10-16
FIGURES 1-3	10-17 to 10-19

INTRODUCTION

The hydrofracturing method was used to estimate the in situ state of stress in the vicinity of the planned Near Surface Test Facility (NSTF), Hanford Reservation. We conducted a total of six tests in a vertical hole (DC-11) in July 1978. The following chapters describe in detail the testing procedures and results obtained.

LOCATION AND LITHOLOGY

DC-11 is a 3 in. diameter vertical core hole situated near the western end of Gable Mountain at N60693, N53026 (Hanford coordinate system). The elevation of the hole collar is approximately 760 ft. above mean sea level. The hole is 400 ft. deep and runs adjacent to the future West Access Tunnel.

Hole DC-11 cuts through a number of basalt flows and interbeds. The important Pomona flow is roughly between the hole depths of 100 and 275 ft. (Rockwell Hanford Operations, NSTF, Drawing No. H-6-807).

TESTING PROCEDURE

Hydrofracturing

The selection of the precise depths for testing was based on the condition of the core and of the hole. The latter was inaccessible to below 250 ft. of depth. Within the accessible portion of the hole the criterion followed was that depths to be hydrofractured should be within core segments that are free from visible discontinuities for at least 2.5 ft. length.

A borehole instrument consisting of two 3 ft. long inflatable packers and a 2.25 ft. straddled interval was lowered to the predetermined depth on high pressure tubing. The latter was used also for pressurizing the straddled interval. The packers were inflated through a separate flexible high pressure line. Each of the two hydraulic lines were fed by separate high-pressure air activated pumps.

The packers were first pressurized and their pressure kept constant throughout the test. The pressure in the straddled interval was then raised until a critical value (P_C) was reached and fracture occurred causing a sudden drop in pressure. Pumping was stopped immediately so as to obtain the shut-in pressure value (P_S) before the fracture extended too far from the borehole. The pressurization cycle was repeated several times (Fig. 1).

Fracture Impression

The inclination and direction of the induced hydrofractures at the borehole wall were obtained using an impression packer and a gyroscopic orienting instrument. The impression packer, consisting of an inflatable rubber element covered with a 3 ft. long sleeve of uncured rubber, was lowered on NW drill rod to precisely the depth of the previously hydrofractured interval. The impression packer was held under pressure for some 45 minutes to enable the soft rubber to penetrate the fracture and set permanently. During this period a gyroscopic orienting tool was lowered by a Sperry Sun, Inc. engineer into the borehole on the inside of the NW drill rod until it engaged a key in a sub located at the top of the impression packer. The key was aligned with a deep cut in the impression sleeve. The gyroscopic instrument produced an accurate

orientation of the key with respect to True North, and hence an orientation of the impression packer was automatically obtained.

Recording

A pressure transducer installed in the hydrofracture pressurization line near the hole collar, and a stroke counter mounted in the hydrofracturing high pressure pump were used to continuously record pressure vs. time and pumped water volume vs. time on a dual channel strip chart recorder.

Laboratory Study

Core segments from the hydrofracturing intervals were taken to the laboratory. Two specimens were prepared from each interval (approximately 2 in. x 4.5 in.) for simulated hydrofracturing testing, in order to determine their hydrofracturing tensile strength. The specimens were cut and surface-ground to yield parallel end planes. They were then weighed and their volume measured so as to determine the rock density. A concentric hole (0.3 in. diameter) was then drilled in each specimen. Finally they were each subjected to a small constant axial load and a continuously increasing internal pressure until hydrofracture occurred. The rate of pressurization was similar to that used in the field and the value of the maximum internal pressure was recorded and yielded the hydrofracturing tensile strength.

RESULTS

A total of six hydrofracturing tests were conducted in hole DC-11. Complete information on test depths, and recorded data is given in Table 1.

Vertical Stress

The vertical stress (σ_v) magnitude could not be obtained directly from

the test results. Therefore, it was calculated using the relationship:

$$\begin{aligned}\sigma_V &= \text{depth (ft)} \times \text{rock density (lbs/ft}^3\text{)} \times 1/144 \text{ (ft}^2\text{/in}^2\text{)} \\ &= \text{depth (ft)} \times 176.5 \text{ (lbs/ft}^3\text{)} \times 1/144 \text{ (ft}^2\text{/in}^2\text{)} \\ &= \text{depth (ft)} \times 1.225 \text{ psi/ft of depth} \quad (1)\end{aligned}$$

The value of 176.5 lbs/ft³ was obtained from laboratory measurements detailed in Table 2. This value is also very close to that obtained by Duvall et al (1978) on core from drill hole DC-10. The calculated vertical stresses are given in Table 4.

Horizontal Stresses

The horizontal principal stresses (σ_{Hmin} and σ_{Hmax}) were calculated based on the relationships (Haimson, 1974):

$$\sigma_{Hmin} = P_S \quad (2)$$

$$\begin{aligned}\sigma_{Hmax} &= T + 3 \sigma_{Hmin} - P_C - P_O \\ &= T + 3 P_S - P_C - P_O \quad (3)\end{aligned}$$

where P_S is the shut-in pressure, P_C is the critical pressure required to induce the hydrofracture, P_O is the pore pressure and T is the hydrofracturing tensile strength. All the above pressures are downhole values. Since they were measured on the surface (P_C^S and P_S^S in Table 1), the magnitude of the head pressure (P_H) should be added to them. Moreover since hole DC-11 was dry the prehydrofracture pore pressure (P_O) was assumed to be zero. Hence equations (2) and (3) can be rewritten in terms of measured quantities as follows:

$$\sigma_{Hmin} = P_S^S + P_H \quad (2a)$$

$$\sigma_{Hmax} = T + 3 P_S^S - P_C^S + 2 P_H \quad (3a)$$

The value of P_C^S was taken as the first peak of the pressure time

curve during hydrofracturing, which signals the point where fracture occurred (Fig. 1).

The shut-in pressure (P_S^S) required to keep the fracture open is typically the plateau reached by the pressure-time curve where pumping is stopped. However, as it often happens in shallow tests, the pressure in our measurements did not settle at a constant value. Rather, after the sharp drop following hydrofracturing a slow but persistent decline was observed. The reason for the slow drop in pressure after shut-in has been established is probably due to some intersection of the induced hydrofracture with an existing joint. Since our tests were conducted in a zone of intense jointing it is conceivable that most hydrofractures intersected other discontinuities. The point where the slope of the pressure-time curve following shut-in was 45° was defined as P_S^S (Fig. 1). This was based on previous experience with such shallow tests. The magnitude of P_S^S for each depth was averaged from values clearly established in the different pressurization cycles conducted.

The hydrofracturing tensile strength (T) is the maximum tensile tangential stress at the borehole wall prior to failure when the horizontal stresses are both zero. This value could only be determined in simulated hydrofracturing tests run in core specimens (see chapter on 'Testing Procedure'). The values obtained for each depth tested were rather consistent (Table 2). They match quite well the Brazilian tensile strength values obtained by Duvall et al (1978) in core from hole DC-10. It should be recalled that the field test hole diameter is about 10 times larger than the diameter of the laboratory specimen. There is no way, however, to evaluate the reduction (if any) in the relatively high T values obtained with the increase in specimen size.

Hydrofracture Orientation

Table 3 gives the test hole and hydrofracture orientation based on the Sperry-Sun gyroscopic tool readings. Hole DC-11 was found vertical within 20' drifting basically to the south. All the hydrofracture impressions (five out of six taken were visible) were approximately vertical and oriented NW to WNW.

STRESS MAGNITUDES AND DIRECTIONS

Table 4 lists the calculated principal stress magnitudes based on equations 1, 2a and 3a. It also lists the direction of σ_{Hmax} which is taken as parallel to the orientation of the vertical hydraulic fractures produced.

The least horizontal compressive stress (σ_{Hmin}) increases with depth from 115 psi at 55 ft. to 275 psi at 227 ft, and is throughout very close to the magnitude of the vertical stress, σ_v (Fig. 2). The maximum horizontal stress (σ_{Hmax}) is extremely high relative to the other stresses and varies from 2120 psi at 55 ft. depth to 3525 psi at 227 ft (Fig. 2). The direction of σ_{Hmax} is rather consistent at $N60^\circ W \pm 15^\circ$ (Fig. 3).

A look at the topographic map of Gable Mountain, particularly where DC-11 is located (see Rockwell Hanford Operations, NSTF, Drawing No. H-6-807), reveals that the hole is in close proximity (1000 ft.) to a steeply dipping southwesterly slope, and to a gently dipping north-northeasterly slope. The axis of Gable Mountain as a whole is oriented in a west-northwesterly direction. Hence the average direction of σ_{Hmax} is in accord with the topographic relief of the area, being approximately parallel

to the axis of the mountain and to the neighboring slopes. Note, however, that an apparent shift in directions appears to occur between the depth range of 55-176 ft. (average direction: $N75^{\circ}W$) and the range of 196-227 ft. (average direction: $N45^{\circ}W$). This apparent shift may be related to a gradual adjustment of σ_{Hmax} direction from that affected by topography near the top of the hole to one aligned with the regional trend in North America (NE) as the hole depth approaches the base of the mountain.

The relatively low σ_{Hmin} values can also be explained based on the test hole proximity to the free surface of the mountain slopes. Since the direction of σ_{Hmin} is perpendicular to that of the slopes and since at the free surface its magnitude is therefore close to zero, no large increases can be expected within 1000 ft. or so into the mountain.

The magnitude of σ_{Hmax} can be expected to be considerably larger than that of σ_{Hmin} . For example in the Southern Appalachians the magnitude of σ_{Hmax} , which is parallel to the mountain range axis, is 2-3000 psi, twice the value of σ_{Hmin} . However, there is no way to predict how much larger should σ_{Hmax} be in a given situation. The magnitudes obtained for σ_{Hmax} in DC-11 are probably the upper limits of the real values, since it is expected that the hydrofracturing tensile strength of the test hole is lower than that obtained in the laboratory tests. Nevertheless the magnitudes of σ_{Hmax} remain considerably larger than either σ_{Hmin} or σ_v even if an extreme assumption is made that the field value of T is, say, one half of the laboratory obtained T .

It is important to realize that the stress regime in the vicinity of DC-11 appears to have little in common with the regional tectonic trend in North America which calls for σ_{Hmax} to be oriented in a NE direction.

Rather, the measured stresses appear to be strongly affected by the local topographic relief. Both the directions of the two horizontal principal stresses and the magnitude of σ_{Hmin} are related to the direction of the mountain axis and the proximity of the slopes.

REFERENCES

Duvall, W. I., Miller, R. J. and F. D. Wang, Preliminary report on physical and thermal properties of basalt, drill hole DC-10, Pomona flow-Gable Mountain, prepared for Rockwell Hanford Operations, 1978.

Haimson, B. C., A simple method for estimating in situ stresses at great depths, in Field Testing and Instrumentation of Rock, ASTM Special Technical Publication 554, p. 156-182, 1974.

TABLE 1
Hydrofracturing Pressures: Hole DC-11

Test No.	Dept. ft.	P_o psi	P_H psi	P_C^s psi	P_S^s psi
1	55	0	25	950	90
6	144	0	60	750	175
2	172.5	0	75	1175	65
3	196	0	85	975	90
5	200	0	85	1625	125
4	227	0	100	750	175

TABLE 2

Laboratory Density and Hydrofracturing
Tensile Strength: Hole DC-11

<u>Depth ft.</u>	<u>Specimen</u>	<u>Density lbs/cu. ft.</u>	<u>τ psi</u>	
55	A1	<u>177</u>	<u>2750</u>	
	A2	<u>177</u>	<u>2750</u>	2750
144	B1	<u>176</u>	<u>2300</u>	2300
172	Specimens not Available			
196	C1	<u>176</u>	<u>3100</u>	
	C2	<u>177</u>	<u>3400</u>	3250
200	D1	<u>177</u>	<u>4340</u>	
	D2	<u>177</u>	<u>4350</u>	4350
227	E1	<u>176</u>	<u>3500</u>	
	E2	<u>175</u>	<u>3600</u>	3550

TABLE 3

Hole Inclination, Key Orientation and
Hydrofracturing Direction: Hole DC-11

<u>Test No.</u>	<u>Depth ft.</u>	<u>Hole Incl.</u>	<u>Inclin. Direct.</u>	<u>Key Orient.</u>	<u>From Key to Hfrac.</u>	<u>Hfrac. Direction</u>
1	55	20'	S10°E	S63°W	48° to R 132° to L	N69°W
6	144	30'	S38°E	N33°W	47° to L	N80°W
2	172.5	20'	S31°W	S18°W	68° to R 66° to L	N71°W
3	196	20'	S36°W	S29°E	175° to R 13° to L	N38°W
5	200	20'	S31°W	N46°E	-	-
4	227	30'	S30°W	N82°E	130° to L	N48°W

TABLE 4
In Situ Stress: Hole DC-11

<u>Test No.</u>	<u>Depth ft.</u>	<u>σ_v psi</u>	<u>σ_{Hmin} psi</u>	<u>σ_{Hmax} psi</u>	<u>σ_{Hmax} direction*</u>
1	55	65	115	2120	N70°W
6	144	175	235	2195	N80°W
2	172.5	210	140	1970	N70°W
3	196	240	175	2715	N40°W
5	200	245	210	3270	-
4	227	280	275	3525	N50°W

*Rounded to the nearest 5°.

FIG. 1 Typical pressure-time record

FIG. 2 Stress vs. depth

FIG. 3 Stereographic projection of hydrofractures

BOREHOLE INSTRUMENTATION LAYOUT FOR
HANFORD NEAR-SURFACE TEST FACILITY

Submitted to

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Attn: William Stromdahl

For Work Performed Under

P.O. No. 4099002

Submitted by

Terra Tek, Inc.
420 Wakara Way
Salt Lake City, Utah 84108

TR 78-35

Revised, August, 1978

SPECIFICATIONS FOR
HEATER AND INSTRUMENT BOREHOLES

1. Drilling Precision Required for All Experiments

The drilling precision required for the subsurface instrumentation and heater holes is as follows:

The collar (starting) positions of all instrument and heater boreholes must be within ± 25 mm (± 1 inch) of the specified locations and the directions of these boreholes must be aligned to within $\pm 0.5^\circ$. The total runout or deviation of any borehole is not to exceed $\pm 1^\circ$ from the planned direction. After completion of each borehole, its starting position must be measured to an accuracy of ± 20 mm and the runout measured to an accuracy of $\pm 0.5^\circ$. These accuracies are relative to all other boreholes in the same experiment, that is, either the full-scale or time-scaled heater experiments, and are not absolute accuracies.

To aid the drilling contractor in meeting these specifications three TP (Theodolite Points) will be provided in each drift for primary control.

It is the responsibility of the contractor to perform such surveys as are needed to meet the specifications. The post drilling survey should be completed by some one other than the drilling contractor.

2. General Layout of the Heater Experiments

Figures 1 and 2 show the experiment drift and the associated extensometer drift. Nominal opening dimensions are shown. The approximate positions of the two full-scale experiments (full-scale 1 and full-scale 2) and the time-scale experiment are shown. The minimum centerline distance between the two central heaters (Full-scale experiments) is 21 meters. (Two times the distance from the wall of the extensometer drift to the heater centerline plus one meter).

3. Full-Scale Heater Experiment #1

The locations of the holes drilled from the heater drift are as shown in Figures 3 through 8. All holes are vertical and are diamond drilled. The locations, diameters and lengths of the holes are tabulated in Tables 1-5. The locations of all holes have been specified by their radial distance from the center of the central heater appropriate to each experiment. The angular position is with respect to the center line of the heater drift. The 0° direction is that defined by looking along the drift center line toward the raise end. Positive angles are measured clockwise. The locations of the instruments in the holes are shown in Figures 4, 6, 7, and 8. The locations of the holes drilled from the extensometer drift are shown in Figures 9 - 12 and 19 - 20. All the extensometer holes are inclined upward and drilled normal to the main drift center line. Vertical angles are measured from the horizontal (holes inclined upward from the horizontal have positive inclinations). Since there are five layers of instrumentation in each vertical section, the following nomenclature will be used:

- Level 1 = Upper extensometer hole
- Level 2 = Upper USBM/IRAD
- Level 3 = Middle extensometer hole
- Level 4 = Lower USBM/IRAD
- Level 5 = Lower extensometer hole

The locations, diameters, lengths and inclinations of the holes are tabulated in Tables 6 and 7. The location of the instruments in the holes are shown in Figures 10 - 20.

TABLE 1

Water Model for Plan, from 1977, Table, Experiment #1

Number of holes = 9, 60° spacing, 40° tilt

HOLE	PLAN COORDINATES		DIAMETER 1 mm	NOMINAL LENGTH (m)	EXPERIMENTAL CHANNEL DROPS	
	ANGLE (Degrees)	RADIUS (M)				
H1						
H2	60.0	0.9				
H3	120.0	0.9				
H4	180.0	0.9				
H5	240.0	0.9				
H6	300.0	0.9				
H7	360.0	0.9				
H8	420.0	0.9				
H9	480.0	0.9				
TOTAL	42m (38mm)		38	6.0	6	8
	6m (457mm)				54	72

1. Nominal diameter. Exact specifications submitted later
2. Exact length will depend upon excavation dimensions.

TABLE 2

Subsidiary 11 - 11 Holes Drilled from Header Drift, Tail Race #1

Number of Holes = 11. All Holes Vertical

HOLE	PLAN COORDINATES		STEMTED 1 mm	STEMMED 1 mm	STEMMED 1 mm	STEMMED 1 mm
	ANGLE (Degrees)	RADIUS (M)				
T1	22.5	0.5	30	25	5	-
T2	67.5	0.5				
T3	135.0	0.5				
T4	180.0	0.5				
T5	202.5	0.7				
T6	225.0	0.6				
T7	315.0	0.7				
T8	337.5	0.4				
T9	22.5	3.0	30	25	5	-
T10	135.0	2.0				
T11	157.5	4.0				
TOTAL				25	55	

1. See Note Table 1.

2. See Note Table 2.

TABLE 3

Summary of Extensometer Holes Drilled from Heater Drift, Full Scale #1

Number of Holes = 14. All Holes Vertical

HOLE	PLAN COORDINATES		DIAMETER ¹ 1 & 3 (mm)	NOMINAL ² LENGTH (m)	INSTRUMENTATION CHANNELS	
	ANGLE (Degrees)	RADIUS (M)			TC	OTHER
E1	0	2.75	76	9.0	5	4 (DCDT)
E2	0	1.75				
E3	0	0.9				
E4	45	2.0				
E5	45	1.25				
E6	90	2.25				
E7	90	1.50				
E8	90	0.75				
E9	135	1.50				
E10	180	0.90				
E11	180	1.75				
E12	180	2.75				
E13	180	5.0				
E14	180	10.0				
TOTAL				126	70	56

1 and 2. See notes on Table 1.

3. A section having a length of 1m is to be reamed to a diameter of 100mm at hole collar.

TABLE 4

Summary of USBM/IRAD Holes Drilled from Heater Drift. Full Scale #1

Number of Holes - 12. All Holes Vertical

HOLE	PLAN COORDINATES		DIAMETER 1 (mm)	NOMINAL 2 LENGTH (m)	INSTRUMENTATION CHANNELS		
	ANGLE (Degrees)	RADIUS (M)			TC	OTHER	
U1 (C1)	0	1.5	38 ↓	5.5 ↓	2	3	2
U2	45	1.5			1		
U3 (C2)	67.5	2.25			2	3	2
U4 (C3)	90	1.25			2	3	2
U5	112.5	2.0			1	3	
U6	145	0.75			1	3	
U7 (C4)	135	3.0			2	3	2
U8 (C5)	157.5	1.75			2	3	2
U9	180	1.25			1	3	
U10 (C6)	180	2.25			2	3	2
U11	180	4.0			1	3	
C7	315	0.9			1	3	2
TOTAL				66	18	33	14

1 and 2. See Note Table 1.

TABLE 5

Monitor and Resistivity Hole Summary for Full Scale #1 Experiment

Number of Holes - 26 Vertical, 1 Horizontal

HOLE	PLAN COORDINATES		DIAMETER 1 (mm)	NOMINAL 2 LENGTH (m)	INSTRUMENTATION CHANNELS	
	ANGLE (Degrees)	RADIUS (M)			TC	OTHER
M1	308.7	0.4	56	10	-	-
M2	213.3	0.4				
M3	290.9	0.7				
M4	249.1	0.7				
M5	283.1	1.1				
M6	256.9	1.1				
M7	279.6	1.5				
M8	260.4	1.5				
M9	277.2	2.0				
M10	262.8	2.0				
M11	177.6	6.0				
M12	182.4	6.0				
M13	18.0	2.0				
M14	265.0	1.75				
M15	112.5	2.25				
M16	175.0	1.6		10	1	3
*M32			56	15		
TOTAL				175	1	3
R1			38	1.0		
R2						
R3						
R4						
R5						
R6						
R7						
R8						
R9						
R10			38	1.0		
TOTAL				10		

*Horizontal Hole

TABLE 7

Summary of Hole Locations for Stress Gages
Installed from Ext. Drift, Full Scale Heater Experiment #1

Number of holes: 6. (Horizontal)

HOLE	COLLAR COORD(m)			Inclination (degrees)	Diameter 1 (mm)	Nominal Length (m)	Instrumentation Channels		
	Angle (Degrees)	Radius (m)	Z(m)				TE	USBM	TRAD
U12	315	14.14	0.65	0	38	13	1	3	
U13(C9)	315	14.14	-0.65			13	2	3	2
U14(C10)	270	10.0	0.65			10	2	3	2
U15(C11)	270	10.0	-0.65			10	2	3	2
U16(C12)	225	14.14	0.65			13	2	3	2
U17(C13)	225	14.14	-0.65	0	38	13	2	3	2
TOTAL						72	11	18	10

1, 2. See note on Table 1

4. Full-Scale Heater Experiment #2

The locations of the holes drilled from the heater drift are as shown in Figures 21 through 24. All holes are vertical and are diamond drilled. The locations, diameters and lengths of the holes are tabulated in Tables 7-12. The locations of all holes have been specified by their radial distance from the center of the central heater appropriate to each experiment. The angular position is with respect to the center line of the heater drift. The 0^0 direction is that defined by looking along the drift center line toward the raise end. Positive angles are measured clockwise. The locations of the instruments in the holes are shown in Figures 22-26. The locations of the holes drilled from the extensometer drift are shown in Figures 27-30, 37 and 38. All the extensometer holes are inclined upward and drilled normal to the main drift center line. Vertical angles are measured from the horizontal (holes inclined upward from the horizontal have positive inclinations).

Since there are five layers of instrumentation in each vertical section, the following nomenclature will be used:

- Level 1 = Upper extensometer hole
- Level 2 = Upper USBM/IRAD hole
- Level 3 = Middle extensometer hole
- Level 4 = Lower USBM/IRAD hole
- Level 5 = Lower extensometer hole

The locations, diameters, and lengths of the holes are tabulated in Table 13 and 14. The location of the instruments in the holes are shown in Figures 28-38.

TABLE 6.

Summary of Hole Locations for Experiment #1.
Installed from left to right (all in same experiment #).

Number of holes = 30.

HOLE	COLLAR COORD. (m)		Inclination Degree	Inclination mm	Inclination mm	Distribution Channels	
	X(m)	Z(m)				70	Other (50%)
E15	-1.2	1.75	↓	↓	11	5	3
E16	-0.6	1.75			11	5	3
E17	0.6	1.75			11	5	3
E18	1.2	1.75			11	5	3
E19	1.8	1.75			11	5	3
E20	-1.2	-0.25	↓	↓	12	5	3
E21	-0.6	-0.25			12	5	3
E22	+0.6	-0.25			12	5	3
E23	1.2	-0.25			12	5	3
E24	1.8	-0.25			13	5	3
E25	-1.2	-2.0			13	5	3
E26	-0.6	-2.0			11	5	3
E27	0.0	-2.0			11	5	3
E28	0.6	-2.0			12	5	3
E29	1.2	-2.0			13	5	3
E30	1.8	-2.0	↓	↓	13	5	3
TOTAL					195	80	48

1, 2. See Note Table 1.

5. The X and Z coordinates are given with respect to the heater midplane. Positive X values are west of midplane. Positive Z values are above the midplane.

6. The inclination is with respect to the Horizontal. A positive inclination is inclined upward. Holes should be laid out with respect to end coordinates rather than by inclination.

3. See note on Table 3.

TABLE #1

Greater Hole Summary for Full Scale #2 Experiment.

Number of Holes = 9. All Holes Vertical.

HOLE	PLAN COORDINATES		DIAMETER (mm)	NOMINAL LENGTH (mm)	INSTRUMENTATION CHANNELS	
	ANGLE (DEGREES)	RADIUS (mm)			TO	OTHER
H11	22.5	0.9	38	6.0	6	8
H12	67.5	0.9				
H13	112.5	0.9				
H14	157.5	0.9				
H15	202.5	0.9				
H16	247.5	0.9				
H17	292.5	0.9				
H18	337.5	0.9				
TOTAL				54 (38mm) 6.0 (457mm)	54	72

1. Nominal diameter. Exact specs submitted later
2. Exact length will depend upon excavation dimensions.

TABLE 9.

Summary of Thermocouple Holes Drilled from
Heater Drift. Full Scale #2.

Number of Holes 11. All Holes Vertical.

HOLE	PLAN COORDINATES		DIAMETER 1 (mm)	NOMINAL LENGTH (m)	INSTRUMENTATION CHANNELS	
	ANGLE (DEGREES)	RADIUS (M)			TC	OTHER
T12	22.5	0.5	38	8	5	
T13	67.5	0.7				
T14	135	0.5				
T15	180	0.4				
T16	202.5	0.7				
T17	225	0.6				
T18	315	0.7				
T19	337.5	0.4				
T20	22.5	3.0				
T21	135	2.0				
T22	157.5	4.0	38	8	5	

Total

88

55

1 and 2. See note on Table 1.

TABLE 10.

Summary of Extensometer Holes Drilled from
Heater Drift, Full Scale #1.

Number of Holes 13. All Holes Vertical.

HOLE	PLAN COORDINATES		DIAMETER mm	HOLE LENGTH m	INSTRUMENTATION CHANNELS	
	ANGLE (DEGREES)	RADIUS (mm)			TC	OTHER
E32	0	2.75	76	4.3	A	4 (DCDT)
E33	0	2.75				
E34	0	1.75				
E35	45	2.0				
E36	45	1.25				
E37	90	2.25				
E38	90	1.50				
E39	90	0.75				
E40	135	1.50				
E41	180	0.90				
E42	180	1.75				
E43	180	2.75				
TOTAL				123.5	65	52

1 and 2. See note on Table.1.

3. A section having a length of 1m is to be reamed to a diameter of 100mm at hole collar.

TABLE 11.

Summary of Stress Meter Holes Drilled from
Heater Drift. Full Scale #2.

Number of Holes = 12. All Holes Vertical.

HOLE	PLAN COORDINATES		DIAMETER (mm)	NOMINAL LENGTH (m)	INSTRUMENTATION CHANNELS		
	ANGLE(DEGREES)	RADIUS(M)			TC	OTHER	
U17	0	4.0	38	5.5	1	3	-
U18(C14)	0	1.5			2	3	2
U19	45	1.5			1	3	-
U20(C15)	45	3.0			2	3	2
U21(C16)	67.5	2.25			2	3	2
U22(C17)	90	1.25			2	3	2
U23	112.5	2.0			1	3	-
U24	135	0.75			1	3	-
U25(C18)	157.5	1.75			2	3	2
U26	180	1.25			1	3	-
U27(C19)	180	2.25			2	3	2
C20	315	0.90	↓	↓	1	-	2
TOTALS				66	18	33	14

1 and 2. See note on Table 1.

TABLE 12.

Monitor Hole Summary for Full Scale #2 Experiment.

Number of Holes = 10. All Holes Vertical.

HOLE	PLAN COORDINATES		DIAMETER (mm)	VERTICAL DEPTH (m)	INSTRUMENTATION CHANNELS	
	$\bar{x}$ (m) Angle (Degrees)	RADIUS (M)			TC	OTHER
M 17	308.7	0.4	56	10 ↓	1	3
M 18	231.3	0.4				
M 19	290.9	0.7				
M 20	249.1	0.7				
M 21	283.1	1.1				
M 22	256.9	1.1				
M 23	279.6	1.5				
M 24	260.4	1.5				
M 25	277.2	2.0				
M 26	262.8	2.0				
*M 33	112.5	2.25	56	15		
TOTAL				115	1	3

1 and 2. See note on Table 1

7. See drawing (Figure 23)

* Horizontal Hole

TABLE 13.

Summary of Hole Locations for Extensometers
Installed from Ext. Drift. Full Scale Experiment #2.

Number of Holes = 16. (Horizontal)

HOLE	COLLAR COORD (m) ⁵		Inclination (Degrees) ⁶	Diameter (mm) ^{1,8}	Nominal Length (m) ²	Instrumentation Channels	
	X(m)	Z(m)				TC	Other
E44	-1.2	1.75	3.0 ↓	76 ↓	13	5	3 OCB
E45	-0.6	1.75			12	5	3
E46	0.6	1.75			11	5	3
E47	1.2	1.75			12	5	3
E48	1.8	1.75	3.0		13	5	3
E49	-1.2	-0.25	1.5 ↓		13	5	3
E50	-0.6	-0.25			11	5	3
E51	0.6	-0.25			12	5	3
E52	1.2	-0.25			12	5	3
E53	1.8	-0.25			13	5	3
E54	-1.2	-2.0			13	5	3
E55	-0.6	-2.0			11	5	3
E56	0.0	-2.0			11	5	3
E57	0.6	-2.0			12	5	3
E58	1.2	-2.0			13	5	3
E59	1.8	-2.0	1.5 ↓	↓	13	5	3
TOTAL					195	80	48

- 1 and 2. See note on Table 1.
 3. See note on Table 10.
 5. See note on Table 6.
 6. See note on Table 6.

TABLE 14.

Summary of Hole Locations for Stress Gages
Installed from Ext. Drift. Full Scale Heater Experiment #2.

Number of Holes = 6.

HOLE	COLLAR COORD. (m)			Inclination (Degrees)	Diameter (mm)	Nominal Length (m)	Instrumentation Channels		
	Angle Degree	Radius (m)	Z(m)				TC	Other	
								USBM	TRAD
U28	315	14.14	0.65	0	38	13	1	3	
U29(C22)	315	14.14	-0.65		38	13	2	3	2
U30(C23)	270	10.0	0.65		38	10	2	3	2
U31(C24)	270	10.0	-0.65		38	10	2	3	2
U32(C25)	225	14.14	0.65		38	13	2	3	2
U33(C26)	225	14.14	-0.65	0	38	13	2	3	2
TOTAL						72	11	18	10

1 and 2. See note on Table 1.

5 and 6. See note on Table 6.

5. Time-Scale Heater Experiment Details

The location of the holes drilled from the time-scale experiment drift are shown in Figures 39 - 43. All holes are vertical and are diamond drilled. The locations of all holes are specified by their X and Y distances from the center heater hole (H25). Positive X values are west of the centerline, positive Y values are south of the centerline. The locations, diameters and lengths of all the holes are tabulated in Tables 15 - 18. The location of the instruments in the holes are shown in Figure 40 - 43.

TABLE 15.

Heater Hole Summary - Time Scale Experiment.

Number of Holes = 13.

HOLE	PLAN COORDINATES		DIAMETER (mm)	APPROX. P. LENGTH (m)	INSTRUMENTATION CHANNELS	
	X (m)	Y (m)			TC	OTHER
H19	-7.0	-3.0	125	10.75		
H20	-7.0	0.0	125	10.75		
H21	-7.0	3.0	125	10.75		
H22	-3.5	-1.5	125	10.75		
H23	-3.5	1.5	125	10.75		
H24	0.0	-3.0	125	10.75		
H25	0.0	0.0	125	10.75		
H26	0.0	3.0	125	10.75		
H27	3.5	-1.50	125	10.75		
H28	3.5	1.50	125	10.75		
H29	7.0	-3.0	125	10.75		
H30	7.0	0.0	125	10.75	↓	↓
H31	7.0	3.0	125	10.75	6	8
TOTAL				140 m	78	104

- Coordinates are with respect to the center heater of the array being (0,0). The x axis is along the center line of the drift. The (-) x direction is toward the 'raise' end of the heater drift. The (+) Y direction is away from the portals.
- The average collar elevation of the 13 heater holes is calculated. The elevation of the hole bottom should be the same for all heaters. Because of floor roughness, the actual length drilled will be different for each hole.

TABLE 16.
Thermocouple Hole Summary - Time Scale Experiment.

Number of Holes = 25.

HOLE	PLAN COORDINATES		DIAMETER (mm)	NOMINAL ² LENGTH (m)	INSTRUMENTATION CHANNELS	
	X (m)	Y (m)			TC	OTHER
T23	-3.5	-1.10	38	12.5	5	9
T24	-3.5	-0.75				
T25	-3.0	1.5				
T26	-2.5	1.5				
T27	-1.75	-1.75				
T28	-1.75	0.0				
T29	-1.75	1.5				
T30	-0.875	0.0				
T31	-0.45	0.45				
T32	-0.23	-0.23				
T33	-0.23	0.23				
T34	0.00	-0.875				
T35	0.00	-0.45				
T36	0.00	1.75				
T37	0.00	2.25				
T38	0.45	0.0				
T39	0.45	0.45				
T40	0.875	-0.875				
T41	0.875	0.875				
T42	1.75	-1.75				
T43	3.15	-1.50				
T44	3.5	1.20				
T45	3.5	2.25				
T46	4.0	-1.50				
T47	4.5	-1.50				
TOTAL				312.5	125	0

TABLE 17.

Extensometer Hole Summary - Time Scale Experiment.

Number of Holes = 16.

HOLE	PLAN COORDINATES		DIAMETER (mm)	NOMINAL LENGTH (m)	INSTRUMENTATION CHANNELS	
	X (m)	Y (m)			TC	OTHER
E60	-3.5	0	76	13	5	3 DCDT
E61	-3.5	0.75				3
E62	-2.25	0				3
E63	-1.25	0				3
E64	0.0	-2.5				3
E65	0.0	-1.5				3
E66	0.0	0.5				3
E67	0.0	1.0				3
E68	0.75	0.0				3
E69	1.75	0.0				3
E70	1.75	1.5				3
E71	2.50	-1.5				3
E72	3.0	1.5				3
E73	3.5	-1.0				3
E74	3.5	0.0				3
E75	3.5	0.75				3
TOTAL				208	80	48

and 2. See Table 15.

6-11
BUDGET

<u>A. Personnel</u> ^(a)	<u>5/1/78 - 9/30/78</u>	<u>10/1/78 - 9/30/79</u>
1 Research Assistant @ \$1944/mo. (Mr. Juan Parra)		
100% summer (3 months ea. summer)	\$ 2,973 ++	\$ 3,123 ++
50% academic year (1 month)	472 **	
50% academic year (9 months)		4,460 **
1 Principal Elect. Technician @ \$1,724/mo. (Mr. Lamb)		
50% each month	3,577 *	10,997 *
Research Services Office Assistance ^(b)	<u>302 *</u>	<u>799 *</u>
<u>Total Personnel</u>	7,324	19,379
<u>B. Employee Benefits</u>		
22% of salaries marked *	853	2,595
2.77% of salaries marked ++	82	87
1% of salaries marked **	<u>5</u>	<u>45</u>
<u>Total Employee Benefits</u>	940	2,727
<u>C. Supplies and Expense</u>		
Miscellaneous components (electrodes, electronic components, etc.)	500	1,000
Rock preparation (hole drilling)	500	00
Miscellaneous (xeroxing, telephone, mail, etc.)	<u>500</u>	<u>500</u>
<u>Total Supplies and Expense</u>	1,500	1,500
<u>Total Estimated Cost for Each Period</u>	<u>\$9,764</u>	<u>\$23,606</u>
<u>Total Estimated Cost for 16 Months</u>	<u>\$33,370</u>	

(a) Current salary rates are shown; extensions include 5% projected salary increases effective July 1, 1978 and July 1, 1979.

(b) Includes direct payroll preparation, budget control, preliminary processing of material requisitions, expediting, property accountability, etc.

Table 13

Water hole geometry - Full scale experiment

Water hole #4 - (Vertical)

Water hole geometry					Instrumentation channels	
Water hole	x (m)	y (m)	Penetration (mm)	Nominal Length (m)	IC	Other
M1	-0.75	-1.0	48	10		
M2	-0.75	-1.5	48	10		
M3	-1.25	-1.0	48	10		
M4	-0.50	-0.5	36	10	1	3
Total				40	1	3

6. Borehole Instrumentation Summary

A summary of the types and quantities of holes and numbers and types of instrumentation channels for the two Full Scale Heater Tests and the Time-Scale Test are presented in Table 20.

TABLE 20
Hanford Waste Isolation Project
Hole and Instrumentation Channel Summary

FULL SCALE #1

Type*	Quantity	TC	EXT	SBM	TTBSG	IRAD	Other
H	9	54	-	-	-	-	72
T	11	55	-	-	-	-	-
E	14	70	56	-	-	-	2
E(H)	16	80	48	-	-	-	2
U, C	12	18	-	33	-	14	4
U, C (H)	6	11	-	18	-	10	-
M	16	1	-	-	3	-	-
M(H)	1	-	-	-	-	-	-
R	10	-	-	-	-	-	-
Total	95	289	104	51	3	24	80
FULL SCALE #2							
H	9	54	-	-	-	-	72
T	11	55	-	-	-	-	-
E	13	65	52	-	-	-	2
E (H)	16	80	48	-	-	-	2
U, C	12	18	-	33	-	14	4
U, C (H)	6	11	-	18	-	10	-
M	11	1	-	-	3	-	-
M (H)	1	-	-	-	-	-	-
Total	79	284	100	51	3	24	80
TIME SCALE							
H	13	78	-	-	-	-	104
T	25	125	-	-	-	-	-
E	16	80	48	-	-	-	2
U	10	10	-	30	-	-	2
M	4	1	-	-	3	-	-
Total	68	294	48	30	3	-	108
Grand Total	242	867	252	132	9	48	268

1576

- *
 H - Heater
 T - Thermocouple
 E - Extensometer
 U - USBM Gage
 C - IRAD Gage
 M - Geophysical/Monitor
 R - Resistivity
 (H) - Horizontal Hole

*TTBSG - Terra Tek Borehole Stress Gage

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TEST ROOM

TIME SCALE
EXPERIMENT

SECTION 3-3

TEST ROOM

WALL HEATER

22' 6"

12' 6"

22' 6"

12' 6"

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NOTES

METER
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USOM/HEAD UNIT

125

LEVEL 2

LEVEL 4

SCALE 20m=1m

LEVEL 2
U1, U4, U7, U8, U9, U11, and C7

LEVEL 4
U2, U5, U6, U9, U11, and C1, C2, C3, C4, C5, C6

NOTES: Thermocouples are located at each depth

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2. Thermocouples are located at the collar and anchors of all extensions.
- NOTES
1. The extensions are installed to a depth of 0.75m below the heater center line.

SCALE 2.1m = 1" 0"

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2. Thermocouples are located at the collar and center of all extensions.

NOTES 1. "E" notes to be drilled to a depth 4.1m below center center line.

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NOTES: 1. ALL MEASUREMENTS TO BE TAKEN TO A DEPTH
OF 3.0 M BELOW WATER SURFACE.

11-26

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ZONE	19	REVISIONS	DATE	APPROVED
		Added all floor	07-14-79	

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11-42
325076

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DATE	REVISION	BY	APPROVED BY
11-18-74	1	11-18-74	11-18-74
11-18-74	2	11-18-74	11-18-74
11-18-74	3	11-18-74	11-18-74

TerraTek

11-18-74

SCALE 1/2" = 1'

NOTES

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NOTES

SCALE 1" = 10'-0"

Terratek

25019

A B C D E F G

TerraTek

125721

NOTES

Male	Female
112	13.00
111	12.50
114	9.75
115	8.75
116	13.25
117	12.25

204555-1-

0 09- 08

LEVEL 2

LEVEL 4

15

U13-~~7~~ 3.00-
LEVEL 4

2000

42

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2 Thermocouples are located
 at the center of the room
 at all intersections
 NOTES 1 1/2" holes to be drilled
 to a depth of 4" below
 center of the hole

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2. Thermocouples are located at the collar and anchors of all extensometers

NOTES 1
- 3" holes to be drilled to a depth of 7" below heater center line

TerraTek

Tennantek

NOTES 1. - 1st Notes to be Delivered
To a Dep'ty Sec Below
Weather Center Line

Table 1

NOTES
MAY 1965
TTPV

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3. تعمیم

4

[illegible]

TerraTek

155030

Point	Number
100	1
101	2
102	3
103	4
104	5

NOTE: Thermocouples are located at the center and are not to be used for all measurements.

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DATE: 10/1/80
 DRAWN BY: J. L. BROWN
 CHECKED BY: J. L. BROWN
 APPROVED BY: J. L. BROWN

TerraTek

TYPE	NOMINAL LENGTH, IN.
202	11
203	11
204	11
205	11
206	11
207	11
208	11
209	11

NOTES
 Thermocouples are located at the collar and stumps of all piers.

11-54

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DATE 07-18-78

DESCRIPTION

SCALE 1/2

APPROVED

11-59

11-6-90

G F E D C B A

DATE	11-6-90
BY	11-6-90
NO. 11-6-90	11-6-90
11-6-90	11-6-90

LEVEL 1

LEVEL 3

LEVEL 5

1m 2.5m 0.5m

TerraTek

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385035

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NOTES

10 9 8 7 6 5 4 3 2 1

G F E D C B A

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NOTES

TemaTek

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Figure 35 - Vertical section
line 4, showing major positions
of pit installed from pit
to scale header test 1.

25037

NOTES

11-64

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NOTES
1. Thermocouples are located at each gage.

TerraTek

325039

ZONE 118 A
REVISIONS
DESCRIPTION
DATE APPROVED
07-18-78

11-65

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TermaTek

SCALE 1:1000
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

NOTES: ALL NOTES SUBJECT TO CHANGE BASED ON EXPERIENCE
GAINED AT THE STRIKE EXPERIMENT

Terra Tek

NOTES

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NOTES

Terratek

Tema Tek

From 1940 to 1945, the United States was in a state of war with Japan. During this time, the United States government was in a state of emergency and was authorized to take any action it deemed necessary to protect the national defense. This included the relocation of Japanese-Americans to internment camps. The United States government was in a state of emergency and was authorized to take any action it deemed necessary to protect the national defense. This included the relocation of Japanese-Americans to internment camps.

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

A B C D E F

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10 9 8

SCALE 1" = 1'

Terratek

NOTES: 1. ALL DIMENSIONS ARE IN FEET AND INCHES. 2. ALL DIMENSIONS ARE TO CENTER UNLESS OTHERWISE NOTED.

TerraTek

SEP 5 1978

Waste Storage - P.A.B.

[Handwritten signature]

200
10/1/78

TABLE 1

Calculated and experimental values of the α - β transition temperature of the polyimide-*o*-aminophenol system, $T_{\alpha\beta}$ (°C) as a function of the polyimide-*o*-aminophenol molar ratio, R

R	$T_{\alpha\beta}$ (°C)	
	Calculated	Experimental
0.0	100	100
0.1	100	100
0.2	100	100
0.3	100	100
0.4	100	100
0.5	100	100
0.6	100	100
0.7	100	100
0.8	100	100
0.9	100	100
1.0	100	100
1.1	100	100
1.2	100	100
1.3	100	100
1.4	100	100
1.5	100	100
1.6	100	100
1.7	100	100
1.8	100	100
1.9	100	100
2.0	100	100

Calculated from eq. (1) and eq. (2).

^a Values are means ± SD.

1 and 2. See note on Table 1
7. See drawing (Figure 23)
* Horizontal Hole, inclination = $+0.5^{\circ} - 0$

Figure 4

Estimated probabilities of a child being in the top 10% of the income distribution, conditional on the child's parents' income, for the 1980s and 1990s. The figure shows that the probability of a child being in the top 10% of the income distribution is higher for children of parents in the top 10% of the income distribution than for children of parents in the bottom 90% of the income distribution. This is true for both the 1980s and the 1990s.

Source: Author's calculations using data from the Panel Study of Income Dynamics.

Figure 4

- H - Heater
- T - Thermocouple
- E - Extensometer
- U - USB Gage
- C - IRAD Gage
- M - Geophysical/Monitor
- R - Resistivity
- (H) - Horizontal Hole

[†]TTBSG - Terra Tek Borehole Stress Gage

10 9 8 7 6 5 4 3 2 1

THE DISTANCE BETWEEN ADJACENT POINTS IS THE NUMBER OF
 SQUARES BETWEEN THEM. THE DISTANCE BETWEEN POINTS ON THE
 SAME ROW OR COLUMN IS THE NUMBER OF SQUARES BETWEEN THEM.
 ALL POINTS OF DATA AND WORKER ON THE MAP ARE

TerraTek

- MARKER (Blue Dot)
- MARKER (Blue Circle)
- ◇ MARKER (Blue Diamond)
- △ MARKER (Blue Triangle)

NOTES: 1. All points are on the map.