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MASTER
Earth Sciences Division
Collected Abstracts—1980

Robert N. Schock, Division Leader
A. L. Henry, Editor
B. F. Hornady, Editor

October 15, 1981

**Lawrence
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INTRODUCTION

This report is a compilation of abstracts of papers, reports, and talks presented during 1980 at national and international meetings by members of the Earth Sciences Division, Lawrence Livermore National Laboratory. The arrangement is alphabetical (by author). For a given report, a bibliographic reference appears under the name of each coauthor, but the abstract itself is given only under the name of the first author (indicated in capital letters) or the first Earth Sciences Division author.

ABSTRACTS

Abey, A. E., W. B. DURHAM, and D. A. Trimmer, Thermal Conductivity, Diffusivity and Expansion of Avery Island Salt at Pressure and Temperature (ITCC and ITES Conf., Chicago, IL, Nov. 7-9, 1979), Lawrence Livermore National Laboratory, Rept. UCRL-83789, Preprint (1980).

Abey, A., H. C. HEARD, D. Trimmer, and W. B. Durham, "Thermal, Thermal-Elastic, and Water Transport Behavior of Generic High-Level Waste Repository Rocks, Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 444 (1980). [UCRL-84044, Abstract]

Abey, A. E., and W. B. DURHAM, Thermal Properties of Two Rocks to 573 K and 50 MPa Confining Pressure, Lawrence Livermore National Laboratory, Rept. UCRL-85191, Abstract (1980).

Abey, A. E., and W. B. DURHAM, Thermal Conductivity and Diffusivity of Climax Stock Quartz Monzonite at High Pressure and Temperature, Lawrence Livermore National Laboratory, Rept. UCRL-85192, Abstract (1980).

Abey, A. E., and W. B. DURHAM, The Effect of Pressure and Temperature on the Thermal Properties of Two Rocks, Lawrence Livermore National Laboratory, Rept. UCRL-85285, Abstract (1980).

ACKERMAN, F. J., W. Sandholtz, J. Raley, J. Carley, L. Tripp, A. Rothman, and J. Campbell, Oil Shale Project Large Retort Run Summary L-3, Lawrence Livermore National Laboratory, Rept. UCID-18595 (1980).

ACKERMAN, F. J., W. Sandholtz, J. Carley, J. Raley, and L. Tripp, Oil Shale Project Run Summary, Small Retort Run S-16, Lawrence Livermore National Laboratory, Rept. UCID-18618 (1980).

ACKERMAN, F. J., W. Sandholtz, J. Raley, L. Tripp, and J. Carley, Oil Shale Project Run Summary, Small Retort Run S-18, Lawrence Livermore National Laboratory, Rept. UCID-18897 (1980).

ACKERMAN, F. J., W. Sandholtz, J. Raley, J. Carley, and L. Tripp, Oil Shale Project Run Summary Small Retort Run S-19, Lawrence Livermore National Laboratory, Rept. UCID-18898 (1980).

Ackerman, F. J., W. SANDHOLTZ, J. Raley, J. Carley, and L. Tripp, LLL Oil Shale Project Small Retort Run Summary, Run S-17, Lawrence Livermore National Laboratory, Rept. UCID-18899 (1980).

Ackerman, F. J., J. H. CAMPBELL, J. H. Raley, W. A. Sandholtz, and S. B. Libicki, Investigation of Critical Parameters in Modified In-Situ Retorting (13th Oil Shale Sympos., Golden, CO, April 16-18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83739, Preprint (1980).

ADAMSON, M., and K. Tonnessen, "Environmental Aspects of the Proposed UCG Project Site in Washington State," Proc. 6th Underground Coal Conversion Sympos. (Shangri-La, OK, July 13-17, 1980), pp. I.49-I.54. [UCRL-84084, Preprint]

Lawrence Livermore National Laboratory is conducting an environmental assessment of the proposed underground coal gasification experiment in the Tono Basin near Centralia, Washington. This analysis is funded by the Department of Energy.

To satisfy the provisions of the National Environmental Policy Act (NEPA), the following elements are included in the assessment: (1) description of the proposed action and alternatives, (2) description of the existing environment, (3) potential environmental impacts of the projects, and (4) agencies consulted to ensure coordination in evaluating effective mitigation measures.

Field reconnaissance and environmental data collected from both state and county agencies and from local individuals and organizations form the basis for an evaluation of the potential impact of the site evaluation. Principal areas of concern include the potential for damage due to air emissions and groundwater contamination, maintenance of surface water quality and minimization of disruption of wildlife habitat. Possible mitigation measures to protect environmental quality are recommended.

ADAMSON, M., and K. Tonnessen, Environmental Report: Proposed Underground Coal Gasification Experiment in the Tono Basin, Washington State, Lawrence Livermore National Laboratory, Rept. UCID-18648 (1980).

The United States Department of Energy (DOE) is sponsoring a program to select and characterize a potential underground coal gasification (UCG) experiment site in western Washington State. This activity is evaluated with reference to possible environmental impacts in accordance with the National Environmental Policy Act.

The following elements are integral parts of the analysis: (1) description of the proposed action and alternatives, (2) description of the existing environment, (3) potential environmental impacts of the projects, and (4) recommendations for measures to mitigate impacts.

Field reconnaissance and environmental data collected from both state and county agencies and from local individuals and organizations form the basis for an evaluation of the potential impact of the project on this riparian ecosystem. A cultural resource survey was also conducted as part of the site evaluation. Points of environmental sensitivity include the potential for damage due to air emissions and groundwater contamination, maintenance of surface water quality and minimization of disruption of wildlife habitat. Possible mitigation measures to protect environmental quality are recommended.

ADAMSON, M., "Siting Requirements," in Mock Site Radionuclide Transport Assessment, T. R. Donich, W. A. Murray, and W. J. O'Connell, Eds. (Lawrence Livermore National Laboratory, Rept. UCRL-52718, NUREG/CR-1553, 1980), pp. 3.1-3.16.

To characterize a site qualitatively, judgments must be made relative to performance objectives of the mock repository. LLNL developed some of the qualitative issues in an earlier project, prior to the drafting of NRC rule 10CFR60: Technical Criteria for Regulatory Geological Disposal of High-Level Radioactive Waste. Although the original purpose of this earlier project was different, and the mock site was chosen based on criteria other than those in 10CFR60, the site will be evaluated here in terms of 10CFR60 requirements.

The draft is divided into three subsections: (1) the general requirements of siting criteria; (2) the potentially adverse conditions caused by human activities, and geologic, geochemical, and hydrologic conditions; (3) the favorable siting conditions.

AKELLA, J., "Quartz $\rightarrow$ Coesite Transition and the Comparative Friction Measurements in Piston-Cylinder Apparatus Using Talc-Alsimag-Glass (TAG) and NaCl High-Pressure Cells: A Reply," N. Jb. Miner. Mh. 10, 478-480 (1980). [UCRL-80570, Preprint]

The paper written by Mirwald and Massonne is interesting though not very clear. The main purpose of the paper written by Akella (1979) is threefold. (1) The chemical hysteresis for the quartz $\rightarrow$ coesite reaction is negligible in quenching experiments lasting for more than an hour, and thus this transformation could be used by petrological communities for calibrating their apparatus. (2) A simple approach for determining the double value of friction, from an experimental petrological point of view, is to determine the transition point for a given reaction on both compression and decompression runs at a set temperature, and the true transition pressure will be midway between the compression and decompression transition points unless there are large scale anvil effects. (3) A high-pressure salt-cell is superior to a talc-alsimag-glass cell in producing more uniform pressure distribution around the sample. Secondly, the salt-cell has low double value of friction compared to the talc-alsimag-glass or talc-boron nitride-pyrophyllite, etc., type cells. However, this does not mean that the salt-cell does not have any friction!

AKELLA, J., Q. Johnson, and R. N. Schock, "Phase Transformations in Americium at High Pressure: Relation to Rare Earth Elements," J. Geophys. Res. 85, 7056-7058 (1980). [UCRL-83539, Rev. 1, Preprint]

The crystal structure of ^{243}Am has been investigated up to 18.0 GPa, using a diamond-anvil high-pressure apparatus. The normal dhcp form of Am, stable at 1 atm and room temperature, undergoes three-phase transformations below 18.0 GPa. The first transformation occurs at about 5.0 ± 1.0 GPa, the second occurs at about 10.0 ± 1.0 GPa, and the third occurs at about 15.0 ± 1.0 GPa. The structure of the Am phase at 5-GPa pressure is fcc. However, we are unable to determine the structure of the new phases at about 10.0- and 15.0-GPa pressure from our present data. The structural behavior of Am showing that Am undergoes a sequence of structural transformations somewhat similar to the lanthanide metals is discussed.

AKELLA, J., "High-Pressure Studies on Actinides Using a Diamond-Anvil Apparatus," Proc. AC10, 10Eme Journees des Actinides (Stockholm, Sweden, May 27-28, 1980), p. 258. [UCRL-84045, Abstract]

The diamond-anvil apparatus is an important tool for investigating phase transformations in materials up to 100.0 GPa. Pressure on the sample can be determined in situ by the ruby fluorescence method, and the crystallographic data of the sample under investigation can be obtained accurately by x-ray techniques.

In the present study, the crystal structure of ^{243}Am has been investigated up to 18.0 GPa in a diamond-anvil high-pressure apparatus. The stable form of Am at one atmosphere and room temperature is dhcp. At about 5.0 ± 1.0 GPa, Am undergoes phase transformation to fcc. Two other phase transformations at about 10.0 ± 1.0 GPa and 15.0 ± 1.0 GPa have been observed. However, the structures of these two later phases are not yet determined due to the complexity of the patterns. Americium undergoes phase transformations somewhat similar to the lanthanide metals.

Akella, J., N. STOUT, R. Reichlin, and F. J. Ryerson, "Crystal-Liquid Fractionation in a Trace Element Rich Magma," Trans. Am. Geophys. Union 61, 1142 (1980). [UCRL-84889, Abstract]

Anderson, G. D., M. E. HANSON, R. J. Shaffer, D. F. Towse, W. Lin, L. D. Thorson, and M. P. Cleary, LLL Gas Stimulation Program Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, Rept. UCRL-50036-79-4 (1980).

Anderson, G. D., M. E. HANSON, W. Lin, R. J. Shaffer, D. F. Towse, M. P. Cleary, D. R. Peterson, S. K. Wong, and B. C. Haimson, LLNL Gas Stimulation Program Quarterly Progress Report, January Through March 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50036-80-1 (1980).

Anderson, G. D., M. E. HANSON, and R. J. Shaffer, "Effects of Various Parameters on Hydraulic Fracture Geometry," Rept. SPE/DOE 8942, Proc. 1st

Sympos. Unconventional Gas Recovery (Pittsburgh, PA, May 18-20, 1980), pp. 163-172. [UCRL-83784, Preprint]

Anderson, G. D., M. E. HANSON, R. J. Shaffer, and L. D. Thorson, Some Effects of Stress, Friction, and Fluid Flow on Hydraulic Fracturing, Lawrence Livermore National Laboratory, Rept. UCRL-85003, Abstract (1980).

Anderson, G. D., M. E. HANSON, and R. J. Shaffer, "Theoretical and Experimental Research on Hydraulic Fracturing," J. Energy Resources Tech. 102, 92-98 (1980). [UCRL-80558, Preprint]

Anderson, G. D., and D. B. LARSON, "Plane Shock Wave Studies of Westerly Granite and Nugget Sandstone," Int. J. Rock Mech. Min. Sci. & Geomech. Abst. 17, 357-363 (1980). [UCRL-82264, Preprint]

Beiriger, W. J., G. S. SMITH, R. E. Elson, H. Newkirk, and C. L. Farrell, X-Ray Diffraction Studies of Phase Development in SYNROC "D" (Am. Ceram. Soc. Conf., Washington, DC, May 3-6, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85248, Abstract (1980).

X-ray powder diffractometry was used to study phase development in SYNROC D. The samples used generally came from parallel studies to establish optimal processing conditions. Results are discussed.

Bell, C., N. W. HOWARD, B. J. Qualheim, G. Hage, M. L. Higuera, and G. Pawloski, The LLL Continental Drilling for Scientific Purposes Data Base: DOE-Funded Drill Holes, Lawrence Livermore National Laboratory, Rept. UCRL-52909 (1980).

Bonner, B. P., and F. M. SEARS, Ultrasonic Attenuation Measurement by Spectral Ratios Utilizing Signal Processing Techniques, Lawrence Livermore National Laboratory, Rept. UCRL-83679, Preprint (1980).

A new approach using signal averaging and signal processing is described for measuring ultrasonic attenuation of compressional (P) and shear (S) waves in highly attenuative (low Q) materials. Broad-band ultrasonic pulses in the frequency range of 0.7-1.1 MHz are transmitted through a specimen to be characterized for comparison to a reference with low dissipation. Attenuation is calculated from the ratio of spectral amplitudes which are corrected for diffraction effects. An experimental example is given based upon measurements made on dry polycrystalline sodium chloride (halite or rock salt) from Avery Island, LA. The measured Q_p of compressional waves is 46 ± 5.5 and Q_s of shear waves is 12 ± 0.3 . This is a through transmission technique which gives results for materials so lossy that multiple echos cannot be detected.

Bonner, B., and F. M. SEARS, "Anelastic Loss in Rock Salt by Spectral Ratio and Time Domain Techniques," Trans. Am. Geophys. Union 61, 1101 (1980). [UCRL-84945, Abstract]

Ultrasonic measurements of the attenuation (Q^{-1}) of broad-band pulses in air-dry polycrystalline sodium chloride (average grain size of 7.5 mm) are compared using time and frequency domain techniques. The three anelastic techniques compared are (1) a ratio of the spectral amplitude of the transmitted pulse in a low-loss reference sample (aluminum) to that of the rock salt, which has a much greater acoustic loss, (2) the observation of pulse amplitude decay over a known path length relative to a reference, and (3) a pulse-broadening (rise time) technique with the empirical assumption that pulse broadening is proportional Q^{-1} .

The ultrasonic data measurement and acquisition system generates the pulse, which propagates through the sample, and then averages and digitizes it for signal processing by a microcomputer. The measurements are conducted at room temperature and pressure for P and S waves in the frequency range of 0.1 to 10.0 MHz. Scattering must be considered in this range of the ratio of the wavelength to average grain size.

The three methods give inconsistent results for Q^{-1} . Pulse broadening predicts the lowest Q^{-1} values. Q_p^{-1} generally decreases with increasing frequency while Q_s^{-1} is virtually constant.

Bonner, B., and D. L. KOHLSTEDT, "Transmission Electron Microscopy Observations of a Partially Melted Quartz Monzonite," Trans. Am. Geophys. Union 61, 396 (1980). [UCRL-84315, Abstract]

A fine-grained (0.1-mm) quartz monzonite obtained from Tuolumne County, California (Sierra Nevada batholith), was lightly deformed at $730 \pm 150^\circ\text{C}$ at a confining pressure of 180 MPa for 2 hours and subsequently examined by both conventional optical and transmission electron microscopy (TEM). The deformation experiment was part of a study of seismic attenuation at low stress amplitudes, <0.2 MPa. Monzonite cylinders 9 mm in diameter by 15.9 mm in length were desiccated for several weeks and were then vacuum dried at 300°C and 10^{-8} Torr for approximately 72 hours before they were sealed in copper capsules by electron beam welding. Indirect evidence, such as experience with lunar samples, indicates that trace amounts of water were present in the capsule during the experiment but at unknown pressure.

Optical examination of the recovered sample reveals extensive fracturing of quartz grains, which was presumably introduced by repeated cycling through the α - β quartz transition. Careful optical examination does not reveal the presence of any glass in the cycled specimen. However, TEM studies indicate the unambiguous presence of thin films of glass several hundreds of angstroms wide.

Bonner, B., D. TRIMMER, H. C. Heard, and A. Duba, "Effect of Pressure and Stress on Water Transport in Intact and Fractured Gabbro and Granite," J. Geophys. Res. 85, 7059-7071 (1980). [UCRL-83932, Preprint]

Bonner, B., and M. S. COSTANTINO, Ultrasonic Velocities and Strength of Frenchman's Flat Alluvium, Lawrence Livermore National Laboratory, Rept. UCID-18862 (1980).

Boro, C., D. TRIMMER, E. Arnold, and K. Keller, An Apparatus for Measuring Ultra-low Permeabilities at Pressure and Temperature, Lawrence Livermore National Laboratory, Rept. UCRL-84995, Abstract (1980).

BRAUN, R. L., R. G. Mallon, and H. Y. Sohn, Analysis of Multiple Gas-Solid Reactions During the Gasification of Char in Oil Shale Blocks, Lawrence Livermore National Laboratory, Rept. UCRL-85279, Preprint (1980).

In combustion retorting of oil shale, the required process energy is largely supplied by the combustion of char (the residual organic carbon and hydrogen from kerogen pyrolysis). Efficient use of this char is required in avoiding excessive combustion of oil. Accurate prediction of oil yield requires a good understanding of the important reactions of carbon with O_2 , CO_2 and H_2O . In this paper we focus on the latter two gasification reactions.

A mathematical model is presented for the major high-temperature chemical reactions occurring in the absence of O_2 within a block of spent oil shale: decomposition of dolomite and calcite, char pyrolysis, carbon gasification with CO_2 and H_2O , water-gas shift, and intrablock diffusive and convective flow of CO_2 , CO , H_2 and H_2O . To establish the validity of the computer model, experiments were performed on cylindrical blocks of oil shale having a mass of about 8 kg. The blocks were heated in an electric furnace and swept with heated gas of controllable composition which included steam. Maximum block surface temperatures of 747° and 815°C were used.

The computer model produced excellent simulations of the experimental carbon gasification reactions, not only with respect to total carbon reacted but also with respect to the radial distribution of the unreacted carbon. Accurate simulation of the carbon gasification reactions required the use of intrinsic rate coefficients that were substantially lower than those previously measured for powdered samples. The water-gas shift had almost negligible effect on the rate of carbon gasification in all runs. In addition, the effect of the discharge of gas from the block on the transfer of steam to the interior appears to be minor for the conditions used in these experiments. The rigorous block model described here will be a useful tool for exploring a wide range of operating conditions and for developing a simple model that can more readily be included in a comprehensive model of an entire retort.

BRAUN, R. L., Simulation of Modified In-Situ Retorting of Oil Shale (Joint AIChE & IMIQ Mtg., Acapulco, Mexico, Oct. 22-24, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84119, Abstract (1980).

The Lawrence Livermore Laboratory mathematical model for oil shale retorting has been applied to a wide range of conditions that are of interest to modified in-situ retorting. Properties of the retort bed, particularly shale composition and particle size, play an important role in determining the ultimate oil recovery. For a given shale composition, the inlet-gas properties can be selected to help control the retort operation and optimize the oil yield. Changes in the inlet-gas flow rate and composition to cope with extreme variations in oil shale grade that may be encountered as a function of depth in an in-situ retort are examined. The feasibility of

retorting through substantial intervals of very low-grade shale and the effects of liquid water influx into the retort are also discussed. In addition, the effects of using oxygen, diluted with steam or carbon dioxide, are presented. Significant improvements in the heating value of the effluent gas can be realized by elimination of nitrogen, condensation of steam, and separation of carbon dioxide.

BRAUN, R. L., J. H. Campbell, D. R. McKenzie, J. H. Raley, and M. L. Gregg, Proposed Operating Strategy for a Field MIS Oil Shale Retorting Experiment (RBOSC Retort 0), Lawrence Livermore National Laboratory, Rept. UCID-18524 (1980).

During the fall of 1979, the LLL retorting group developed a possible operating strategy for a field scale retort [similar to "Retort 0" proposed by the Rio Blanco Oil Shale Company (RBOSC)]. This retorting strategy was developed based on model calculations, pilot retort experiments, and laboratory work carried out at LLL. Specifically, we have carried out model calculations to predict the possible behavior of the retort for a wide range of operating conditions. From these calculations we recommend a set of operating conditions that appear to give the best overall retort performance. Also, since the retort will contain little or no instrumentation within the rubble bed, we have developed (and are continuing to develop) a performance monitoring strategy based solely on the exit gas and oil composition. Data from our pilot retorting operations and laboratory experiments provide the basis for this monitoring scheme. The purpose behind this exercise is to apply our knowledge to a practical field retort experiment and thereby increase our understanding and facilitate the transfer of our knowledge to the industrial sector.

In December of 1979, this operating strategy was presented to RBOSC during a two-day meeting at LLL. The results of this presentation are summarized in the following pages.

Braun, R. L., and A. E. LEWIS, "Retorting and Combustion Processes in Surface Oil-Shale Retorts," 15th Intersoc. Energy Conversion Eng. Conf. Proc. (Seattle, WA, Aug. 18-22, 1980), pp. 297-304. [UCRL-83788, Abstract]

BRYAN, J. B., D. E. Burton, L. A. Lettis, Jr., A. L. Bruce, and L. R. Moreno, Excavation of a Qattara Canal in Egypt: Two-Dimensional Nuclear Cratering Calculations, Lawrence Livermore National Laboratory, Rept. UCID-18535 (1980).

A series of single-charge nuclear cratering calculations have been performed by the Earth Sciences Division of the Lawrence Livermore Laboratory. Results from these calculations are being used by the CER Corporation of Las Vegas, Nevada, in a study of the technical feasibility of the Qattara Project. The project would use nuclear explosives with yields ranging between about 200 and 1750 kilotons to excavate a canal about 73 km long connecting the Mediterranean Sea with the below sea-level Qattara Depression in northwestern Egypt.

Before the Qattara calculations were begun, a post-shot cratering simulation of the Sedan event was performed to verify the calculational

approach and test new modeling developments in the TENSOR code. The Sedan event, detonated in 1962 at the Nevada Test Site, was selected because it was a documented nuclear excavation application with a large yield. The calculated crater dimensions were in close agreement (within 1%, 3%, and 3% for radius, depth, and volume, respectively) with the experiment.

Computer simulations of explosive excavations were carried out at four locations, N-1, N-2, N-3, and NN-4 near the proposed Qattara alignment. Holes were drilled in Egypt at these locations to depths of 372, 514, 632, and 701 m, respectively, to provide geophysical information needed to properly characterize each multi-layered site for computer calculations. The two-dimensional TENSOR computer code was used to simulate the dynamic phase as momentum was imparted to the mound region by single-charge nuclear sources ranging from 200 to 800 kilotons in energy. Final crater dimensions were calculated using a ballistic extrapolation followed by a slope stability adjustment. The results suggest that the charges should be buried near a scaled depth-of-burst of $40 \text{ m}/(\text{kt})^{1/3.4}$ for the canal excavation.

BRYAN, J. B., D. E. Burton, L. A. Lettis, Jr., L. K. Morris, and W. E. Johnson, "Calculations of Impact Crater Size Versus Meteorite Velocity," in Lunar and Planetary Science XI, Abstracts of Papers (Houston, TX, March 17-20, 1980), pp. 112-114. [UCRL-83831, Abstract]

Two-dimensional cratering calculations have been performed to study crater size at different impact velocities. The calculational approach has been discussed in earlier work which included a simulation of the formation of Barringer Crater in Arizona. Results for impacts with velocities ranging between 2 and 25 km/s are discussed. Values for kinetic energy lie between 3.3×10^{14} and 5.2×10^{16} J (80 to 12,000 kilotons). Most crater variables can be related using a power-law expression of the form $Y = AX^B$. However, one exception is the effective depth-of-burst EDOB which is used to relate impact and explosion craters. An extrapolation of a fit of impact velocity U and scaled effective depth-of-burst SEDOB for the higher velocity cases suggests a value nearly three times larger than the value $\text{SEDOB} = 11.6 \text{ m}/(\text{kt})^{1/3}$ for the 2 km/s case. The calculation indicates that for this low velocity impact the projectile essentially remains intact. In the higher velocity cases, melting and vaporization are important processes. Oberbeck obtained a similar value of $\text{SEDOB} = 10.6 \text{ m}/(\text{kt})^{1/3}$ from cratering experiments in quartz sand for explosion and impacts at 2 km/s. The apparent crater radius R_A increases with increasing kinetic energy W as $R_A \propto W^n$ where $n = 0.21$ for constant gravitational acceleration ($g = 9.8 \text{ m/s}^2$). This value is slightly greater than the exponent ($n = 0.181$) obtained by Gault and Wedekind from laboratory experiments.

Calculations such as those summarized here are very useful in helping extend cratering data from the laboratory scale where impact velocities are usually less than about 8 km/s to the higher impact velocities (11 to 72 km/s) which are involved in the formation of large impact craters. Calculations can help monitor variables that are difficult to measure. Future cratering calculations are planned to address material strength and gravitational effects.

BRYAN, J. B., D. E. Burton, and L. A. Lettis, Jr., Very Large Terrestrial Crater Formation Resulting from the Impact of an Apollo Asteroid (Am.

Geophys. Union, Toronto, Canada, May 22-27, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84030, Abstract (1980).

Recently, Alvarez et al. hypothesized that solar obscuration resulting from the impact of an asteroid was responsible for the Cretaceous-Tertiary extinction about 65 million years (my) ago. They estimated that this Apollo object was about 10 ± 3 km in diameter and produced a 175-km diameter crater. Such a crater would be larger than the largest recognized terrestrial craters at Sudbury, Ontario, Canada (age: 1840 ± 150 my) and Vredefort, South Africa (age: 1970 ± 100 my), each 140 km in diameter.

We are applying the computational approach used in modeling the formation of the Barringer Crater to this large impact. Impact conditions include a mass of 2.1×10^{15} kg and a velocity of 25 km/s, corresponding to a kinetic energy of 6.6×10^{23} J (about 160 teratons). The amount of material injected into the stratosphere by such an impact is of particular interest in the Alvarez hypothesis and will be modeled, as well as crater formation.

BRYAN, J. B., D. E. Burton, and M. S. Costantino, "Two Dimensional Cratering Calculations for Nuclear Excavation of a Qattara Canal in Egypt," Bull. Am. Phys. Soc. 25, 516 (1980). [UCRL-83830, Abstract]

A series of cratering calculations has been performed as part of a study addressing the feasibility of constructing a nuclear-excavated canal to link the Mediterranean Sea and the below sea level Qattara Depression in Egypt. Four holes were drilled to depths between 370 and 700 m along a proposed 73-km canal alignment. Core samples and geophysical logs were obtained to help provide both in-situ and laboratory data on the material properties which were used in calculations at these multilayered explosion sites. The two-dimensional TENSOR computer code was used to simulate the dynamic phase as momentum was imparted to the mound region by single-charge nuclear sources ranging from 200 to 800 kilotons in energy. Final crater dimensions were calculated using a ballistic extrapolation followed by a slope stability adjustment. The results suggest that the charges should be buried near a scaled depth-of-burst of $40 \text{ m/(kt)}^{1/3.4}$ for the canal excavation.

BRYAN, J. B., Some Predicted Peak Ground Motions for Nuclear Cratering Explosions Along the Qattara Alignment in Egypt, Lawrence Livermore National Laboratory, Rept. UCID-18529 (1980).

Peak free-field ground motions (displacement, particle velocity, acceleration, and radial stress) are predicted at various distances for single-charge nuclear explosive excavations along the Qattara Canal alignment in Egypt. These results, based on two-dimensional TENSOR computer simulations and scaled experimental data, help specify engineering design requirements for detonating nuclear explosive salvos which are required to efficiently excavate the Qattara Canal.

Bryan, J. B., D. E. BURTON, and L. A. Lettis, Jr., "Adaptation of an Implicit Integration Technique to the TENSOR Code, a Two-Dimensional Continuum Dynamics Code," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, October 22-24, 1980), p. 61.

Bryan, J. B., H. D. GLENN, R. W. Terhune, and L. R. Moreno, Destruction of the Peninsula Device (U), Lawrence Livermore National Laboratory, Rept. UCID-18511 CFRD (1980).

BURKHARD, N., Resolution and Error of the Back Projection Technique Algorithm for Geophysical Tomography, Lawrence Livermore National Laboratory, Rept. UCRL-52984 (1980).

The resolution and error properties of the Back Projection Technique (BPT) for geophysical tomography are examined. It is demonstrated that (a) the BPT algorithm always converges in the vector space corresponding to the non-zero eigenvectors, (b) the mean error in the solution after convergence is the projection of the difference between the mean values of the starting model and the real solution in the vector space corresponding to the zero eigenvectors, and (c) the covariance of the mean error is always finite. The resolving properties and error propagation characteristics of BPT for various tomographic views are discussed. In general, the resolving power and error propagation characteristics of BPT are improved with tomographic views which encircle the region under investigation. Finally, exploration strategy for geotomography with the BPT algorithm is discussed. The trade-off between the resolving area and parameter contrast, cell size, and data accuracy is examined.

BURKHARD, N. R., Frequency Cutoff Point for Geophone Arrays, Lawrence Livermore National Laboratory, Rept. UCRL-84026, Preprint (1980).

A geophone array designed to minimize the amplitude of surface and near-surface seismic waves will also act as a low-pass filter on the desired reflected seismic arrival. In this paper, I calculate the low-pass filter frequency cutoff point of any array for dipping horizons at various scaled horizon depths.

BURTON, D. E., J. B. Bryan, and L. A. Lettis, Jr., "Adaptation of an Implicit Integration Technique to the TENSOR Code, a Two-Dimensional Continuum Dynamics Code," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), p. 61.

The TENSOR code, a two-dimensional Lagrangian finite-difference code, has been used primarily for the solution of stress wave propagation problems in earth materials. Consequently, it utilizes nonlinear constitutive models considered appropriate for such material. A typical application is cratering which is characterized by shock waves at early times and nearly incompressible plastic flow at very late times. To more economically address this type of problem, an implicit Newmark time integration has been implemented. Problems associated with zone distortion have been reduced by an arbitrary Lagrange-Euler continuous rezoning scheme.

An iterative solution technique has been selected to reduce the impact of the implicit algorithm on the structure of the code. Methods such as MAC and its derivatives are inappropriate because of the involvement of deviatoric

stresses and the nonlinear compressible constitutive relations. Iterative stress corrections are then made directly from the constitutive routines. Because typical problems have been characterized by wide variations in zone size, the algorithm has been designed to allow nodes which satisfy explicit stability criteria to be integrated explicitly. Efficiency is further increased by omitting calculations at nodes which are relatively stationary during the implicit iteration.

The implementation of the scheme required certain other changes in the code structure which resulted in a 25% reduction in storage requirements. The implicit technique has been applied to a prototype cratering problem.

Burton, D. E., J. B. BRYAN, and L. A. Lettis, Jr., Very Large Terrestrial Crater Formation Resulting from the Impact of an Apollo Asteroid (Am. Geophys. Union, Toronto, Canada, May 22-27, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84030, Abstract (1980).

Burton, D. E., and T. R. BUTKOVICH, Calculating Shock Hugoniot and Release Adiabats for Composite Rock Materials (Am. Phys. Soc., Washington, DC, April 28-May 1, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83828, Abstract (1980).

Burton, D. E., J. B. BRYAN, and M. S. Costantino, "Two Dimensional Cratering Calculations for Nuclear Excavation of a Qattara Canal in Egypt," Bull. Am. Phys. Soc. 25, 516 (1980). [UCRL-83830, Abstract]

Burton, D. E., J. B. BRYAN, L. A. Lettis, A. L. Bruce, and L. Moreno, Excavation of a Qattara Canal in Egypt: Two-Dimensional Nuclear Cratering Calculations, Lawrence Livermore National Laboratory, Rept. UCID-18535 (1980).

Burton, D. E., J. B. BRYAN, L. A. Lettis, Jr., L. K. Morris, and W. E. Johnson, "Calculations of Impact Crater Size Versus Meteorite Velocity," in Lunar and Planetary Science XI, Abstracts of Papers (Houston, TX, March 17-21, 1980), pp. 112-114. [UCRL-83831, Abstract]

Burton, D. E., R. P. SWIFT, and L. R. Moreno, Calculations of the Stemming and Containment Phenomenology for the Hybla Fair Event (U), Lawrence Livermore National Laboratory, Rept. UCRL-52998 CFRD (1980).

Burton, D. E., and R. P. SWIFT, "Calculations Illustrating Stemming Closure and Containment Phenomenology for a Low Yield Nuclear Event," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), p. 49.

Burton, D. E., and R. P. SWIFT, Stemming and Containment Phenomenology for the Hybla Fair Event, Lawrence Livermore National Laboratory, Rept. UCID-18628 (1980).

BUTKOVICH, T. R., and D. E. Burton, Calculating Shock Hugoniot and Release Adiabats for Composite Rock Materials (Am. Phys. Soc., Washington, DC, April 28-May 1, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83828, Abstract (1980).

A method for combining gas equations of state with calculated shock Hugoniot equations of state to produce adiabatic release paths from the Hugoniot has been developed for silicate-carbonate-water bearing rocks. Numerical simulation of buried explosions require a complete equation of state for the rock materials over the pressure regime experienced. Pressures attained with high explosives can result in the removal of air-filled porosity and cause partial vaporization of the water component of the rock. In addition to this, nearby buried nuclear explosions, all of the rock minerals can be vaporized. The method described includes the removal of air-filled porosity, total vaporization of the silicate and carbonate components, total and partial vaporization of the water component and decomposition of the carbonate.

CARLEY, J. F., Dimensions, Exterior Surfaces, Volumes, Densities, and Shape Factors for Particles of Crushed Colorado Oil Shale, Lawrence Livermore National Laboratory, Rept. UCRL-84583, Preprint (1980).

Fifty oil-shale particles in each of two narrow screen fractions were measured individually to determine the length L , size W (second-largest principal dimension), mass, volume V , density, and exterior surface area A . From these were calculated the dimensionless characteristics L/W , sphericity, specific-surface ratio A/W^2 , and V/W^3 . In both sets, all size averages were slightly larger than the screen opening of the passing screen; thus, it seems clear that, for screen fractions where the opening ratio is 1:2 or closer, screen openings relate to the sizes of particles passing, rather than particles retained, as has long been assumed. Distribution functions were fitted to Fischer-assay grade, density, and all the dimensionless ratios. Over the 2.5:1 range of mean size studied, these ratios appear to be independent of particle size.

CARLEY, J. F., and B. H. Laswell, Residual Saturation and Dynamic Holdup of Shale Oil in Simulated In-Situ Beds of Oil Shale, Lawrence Livermore National Laboratory, Rept. UCRL-84543, Preprint (1980).

Measurements of residual saturation and dynamic holdup of shale oil (i.e., with steady flow of oil and air or nitrogen) were made in beds of crushed oil shale with void fractions from 0.37 to 0.53 and particle sizes from 0.17 to 7.6 cm. Residual saturation in gravity drainage appears not to be a capillarity phenomenon and may be related more closely to wetting-out of the particle surfaces than to meniscal pooling at points of contact. It correlates well for the above factor ranges with the "saturation function," $\gamma^2(1-\epsilon)^2/D_p \rho$ (γ = surface tension, ϵ = dry void fraction, D_p = surface-to-volume average particle size, and ρ = oil density). Dynamic holdup was always greater than the residual saturation. An equation for dynamic holdup, based on a falling-film concept, agreed with some aspects of experimental behavior but predicts values much lower than those observed. It appears that most of the liquid held up during steady drainage may not be involved in the flow.

Both residual saturation and dynamic holdup were only mildly reduced by raising the experimental temperature from 250 to 940C.

CARLEY, J. F., "Spontaneous Ignition in Preheated Beds of Spent Oil Shale," In Situ 4, 293-323 (1980). [UCRL-83612, Preprint]

Inert-gas preheating appears to be a good way to start the retorting of oil-shale rubbles in situ. This work was undertaken to determine a property that is important for that process: the temperature at which spent-shale char spontaneously ignites in air and diluted air. Spent Colorado oil shale, obtained from inert-gas retorting of 118- ℓ /Mg (28-gal/ton) oil shale, was preheated with nitrogen in a small reactor, then exposed to oxygen/nitrogen mixtures for periods of about 20 minutes. Temperatures recorded from embedded thermocouples and the concentrations of carbon oxides in the effluent gas were followed as indicators of the ignition process. The factors explored in a 23-factorial design were temperature of preheating, 300 and 350°C; average particle size, 0.46 and 1.80 cm; and concentration of oxygen in influent gas after changeover, 10.45 and 20.9 vol %. Two runs were made with the gas flow downward; in the other ten it was upward.

Rapidly rising temperatures, coupled with substantial concentrations of CO and CO₂ in the effluent gas indicated that ignition did occur in all the runs. In three runs, temperatures close to 600°C were recorded and there was evidence that even higher temperatures may have been reached in these and other runs. The rate of temperature rise increased with increasing oxygen concentration and particle size. CO and CO₂ both rose with increasing influent oxygen concentration, but the ratio of CO to CO₂ dropped sharply, possibly because of catalytic conversion of the one to the other. Responses were the same whether gas flow was upward or downward. The results obtained in this work, coupled with those of earlier simulation studies, indicate that inert-gas preheating should be a safe, economical and reliable method for initiating retorting in in situ oil shale rubbles.

Carley, J., F. J. ACKERMAN, W. Sandholtz, J. Raley, L. Tripp, A. Rothman, and J. Campbell, Oil Shale Project Large Retort Run Summary L-3, Lawrence Livermore National Laboratory, Rept. UCID-18595 (1980).

Carley, J., F. J. ACKERMAN, W. Sandholtz, J. Raley, and L. Tripp, Oil Shale Project Run Summary, Small Retort Run S-16, Lawrence Livermore National Laboratory, Rept. UCID-18618 (1980).

Carley, J., W. SANDHOLTZ, F. J. Ackerman, J. Raley, and L. Tripp, LLL Oil Shale Project Small Retort Run Summary, Run S-17, Lawrence Livermore National Laboratory, Rept. UCID-18899 (1980).

Carley, J., F. J. ACKERMAN, W. Sandholtz, J. Raley, and L. Tripp, Oil Shale Project Run Summary, Small Retort Run S-18, Lawrence Livermore National Laboratory, Rept. UCID-18897 (1980).

Carley, J., F. J. ACKERMAN, W. Sandholtz, J. Raley, and L. Tripp, Oil Shale Project Run Summary Small Retort Run S-19, Lawrence Livermore National Laboratory, Rept. UCID-18898 (1980).

Carley, J., O. R. WALTON, W. Patrick, and J. Peterson, DIBS Solid Flow Model (3rd Briefing on Oil Shale Tech. Res., Livermore, CA, Nov. 19-21, 1980), Lawrence Livermore National Laboratory, Misc. Pub.-144 (1980, pp. 608-621.

CARLSON, R. C., W. C. Patrick, D. G. Wilder, W. G. Brough, D. N. Montan, P. Harben, L. B. Ballou, and H. C. Heard, Spent Fuel Test-Climax: Technical Measurements Interim Report FY 1980, Lawrence Livermore National Laboratory, Rept. UCRL-53064 (1980).

The Spent Fuel Test-Climax (SFT-C), a test of the retrievable geologic storage of spent fuel assemblies from an operating commercial power reactor, is underway at the Nevada Test Site of the U.S. Department of Energy. Although the main thrust of the project is a demonstration of the feasibility of packaging, handling, storing, and retrieving the highly radioactive fuel assemblies, over 800 data channels have been installed to monitor the response of the rock to the heat and radiation produced by the fuel assemblies and to distinguish in that response the effect due to heat alone. Temperatures in the test array are tracking well with thermal modeling calculations performed before the test was started. The fuel assemblies have been in place since May 1980. The canisters have passed through skin temperature maxima of about 145°C and are currently declining in temperature. Evidence is emerging that the thermomechanical response of the rock surrounding the SFT-C is strongly affected by fractures and other discontinuities in the rock. Most of the effort to date has been in project construction, design, and installation of the instrumentation. Although the data are available in raw form for verification purposes, they are not as yet in suitable form for detailed analyses. Work continues on the data management aspects of the project and in continued monitoring of the test.

Carlson, R. C., J. R. HEARST, and J. W. Schmoker, "Effects of Terrain on Borehole Gravity Data," Geophysics 45, 234-243 (1980). [UCRL-80994, Preprint]

CARPENTER, D. W., H. F. Lutz, R. W. Martin, O. B. Nair, and R. Talbot, Review of Y/OWI/TM-36 Repository Design Performance in Salt, Granite, Shale or Basalt, Lawrence Livermore National Laboratory, Rept. UCID-18684, NUREG/CR-1802 (1980).

The report reviews the 23 volumes of Y/OWI-TM-36, "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations." Repository design, construction, and operation are addressed. The adequacy of design procedures and assumptions is discussed. Inappropriate design issues are identified. Areas of groundwater movement and thermomechanics that require additional numerical analyses are identified. Extensive comparison between NRC's Advanced Notice of Proposed Rulemaking of May 13, 1980, and the design presented in Y/OWI-TM-36 has been made.

CARPENTER, D. W., and R. W. Martin, Reference Repository Design Concept for Bedded Salt, Lawrence Livermore National Laboratory, Rept. UCID-18685 (1980).

This report presents a reference design concept for the subsurface portions of a nuclear waste repository in bedded salt. General geologic, geotechnical, hydrologic, and geochemical data as well as descriptions of the physical systems are provided for use on generic analyses of the pre- and post-sealing performance of repositories in this geologic medium. The design concepts are presented with the waste isolation objectives set forth in the U.S. NRC Draft Regulation 10 CFR 60 in mind.

The geology of bedded salt deposits and the regional and repository horizon stratigraphy are discussed. Structural features of salt beds, including discontinuities and dissolution features, are presented and their effect on repository performance is discussed.

Seismic hazards and the potential effects of earthquakes on underground repositories are presented. The effect on structural stability and worker safety during construction from hydrocarbon and inorganic gasses is described.

Geohydrologic considerations including regional hydrology, repository scale hydrology and several hydrological failure modes are presented in detail as well as the hydrological considerations that affect repository design. The geotechnical aspects of stress state, rock mechanics, thermal and radiological effects of bedded salt and associated strata are discussed at length. Geochemical reactions affecting both the rock mass properties and waste migration are presented. The physical repository system is described and the types and inventories of nuclear waste to be stored in the reference design are discussed. The structural performance of a repository includes its thermomechanical response and some discussion of scale effects and structural modeling.

Operational phase performance is discussed with respect to operations, ventilation system, shaft conveyances, waste handling and retrieval systems and receipt rates of nuclear waste. Support facilities are discussed that are necessary for the operation of an underground facility handling radioactive materials. Operational accident scenarios are presented, and very general estimates of radiological accidents during emplacement or retrieval are made based on the nuclear industry and statistics for underground non-metal mines.

Performance analysis of the post-sealing period of a nuclear repository is discussed, and parameters to be used in such an analysis are presented along with regulatory constraints. Some judgments are made regarding hydrologic failure scenarios.

Finally, the design and licensing process, consistent with the current licensing procedure, is described in a format that can be easily understood.

CARPENTER, D. W., K. P. Puchlik, A. L. Ramirez, J. L. Wagoner, K. G. Knauss, and P. W. Kasameyer, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume I: Text and Appendices A-E, Lawrence Livermore National Laboratory, Rept. UCRL-53065, Vol. I (1980).

and

CARPENTER, D. W., A. L. Ramirez, and J. Wagoner, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas,

Volume II: Appendix F, Lawrence Livermore National Laboratory, Rept.
UCRL-53065, Vol. II (1980).

In April, 1979, geoscience personnel at Lawrence Livermore National Laboratory (LLNL) initiated comprehensive geologic, seismologic, and hydrologic investigations of the LLNL site and nearby areas. These investigations have two objectives: (1) to obtain data for use in preparing a Final Environmental Impact Report for LLNL, pursuant to the National Environmental Policy Act, and (2) to obtain data for use in improving the determination of a design basis earthquake for structural analysis of LLNL facilities.

The first phases of these investigations have been completed. Work completed to date includes a comprehensive literature review, analyses of three sets of aerial photographs, reconnaissance geophysical surveys, examination of existing LLNL site borehole data, and the logging of seven exploratory trenches, segments of two sewer trenches, a deep building foundation excavation, a road cut, and an enlarged creek bank exposure. One absolute age date has been obtained by the ^{14}C method and several dates of pedogenic carbonate formation have been obtained by the $^{230}\text{Th}/^{234}\text{U}$ method. A seismic monitoring network has been established, and planning for a site hydrologic monitoring program and strong motion instrument network has been completed. The seismologic and hydrologic investigations are beyond the scope of this report and will be discussed separately in future documents.

Additional subsurface exploration within LLNL is being undertaken to assess the possibility of ground failure during a major earthquake; this work will be done concurrent with the planned hydrologic investigation. Appropriate geophysical and age determination studies will be performed in support of future field reconnaissance and exploration.

COSTANTINO, M. S., and B. Bonner, Ultrasonic Velocities and Strength of Frenchman's Flat Alluvium, Lawrence Livermore National Laboratory, Rept. UCID-18862 (1980).

Compressional and shear wave speeds and longitudinal stress and strain were measured under undrained triaxial stress for Frenchman's Flat alluvium. Nine of the thirteen samples were tested in as-received conditions, and four were reconstituted in various ways. No difference in the measured properties of the virgin and reconstituted samples was found. Maximum shear stresses less than 0.1 MPa were observed at longitudinal strains up to 7-10% in the fully saturated samples at a confining pressure of about 10 MPa. Further increase in longitudinal strain resulted in a dramatic increase in the maximum shear stress to values greater than 3 MPa. This increase in strength is a result of an increase in effective stress as the sample dilates and the pore fluid pressure decreases. Sound speeds for compressional (v_p) and shear (v_s) waves increased dramatically during hydrostatic loading, then remained constant under triaxial loading to more than 10% axial strain. Under triaxial loading conditions, v_p ranged between 1.77 and 2.48 km/sec with an average $v_p = 2.18 + 0.23$ km/sec. v_s ranged from 0.74 to 1.02 km/sec with $v_s = 0.90 + 0.10$ km/sec. The ratio v_p/v_s , taken for each sample, ranged from 1.82 to 2.71 with $v_p/v_s = 2.39 + 0.30$. No significant changes in v_p and v_s were observed in the dilatant region.

COSTANTINO, M. S., Interim Report: Laboratory Measurements of Differential Stress Using Acoustic Double Refraction, Lawrence Livermore National Laboratory, Rept. UCID-18586 (1980).

This interim report describes the progress made in the period 1 October, 1980-29 February, 1980, in evaluating Acoustic Double Refraction (ADR) as a diagnostic of in-situ stress. It includes the definition of the project, a literature review, a brief discussion of the theoretical basis of the ADR effect, and an account of the hardware and software used to make the measurements. Aside from two, small, utility computer programs, the laboratory experiment is ready for its first test of signal acquisition and analysis.

Costantino, M. S., J. B. BRYAN, and D. E. Burton, "Two Dimensional Cratering Calculations for Nuclear Excavation of a Qattara Canal in Egypt, Bull. Am. Phys. Soc. 25, 516 (1980). [UCRL-83830, Abstract]

CROW, N. B., "Control Technologies for Induced Subsidence and Seismicity," in An Assessment of Geothermal Development in the Imperial Valley of California, W. Morris and J. Hill, Eds. (Dept. Energy, Washington, DC, DOE/EV-0092, 1980), pp. 88-109.

This is an assessment of the potential for environmentally significant induced subsidence and seismicity from geothermal production in the Imperial Valley. Data now available characterize natural activity. During production, recommended monitoring will allow increasingly more accurate prediction of potential environmental effects.

Subsidence. Normally, subsidence occurs in shallow, widespread bowls, typically a few tenths of a meter deep and a few kilometers across. Occasionally, a small, steep-sided bowl will occur; such features have a greater potential for environmental damage. Subsidence related to fluid withdrawal can be controlled by maintenance of reservoir pressure through injection of fluid to the reservoir. Motion is slow, a few cm/yr, allowing time for remedial action. If unacceptable rates of subsidence do occur, limitation of production would be an effective control.

A study of Imperial Valley subsidence sensitivity shows most geothermal areas would be little affected by likely amounts of induced subsidence. However, at Heber, an irrigation canal might require fairly simple modifications, and at the Salton Sea field existing dikes may have to be raised.

Seismicity. If induced seismicity does occur, the most probable cause would be injection of spent geothermal fluids. Elsewhere, very large amounts of fluid have been injected into deep subsurface reservoirs; no documented seismicity has resulted, except for two cases in Colorado, where much fluid was injected at pressures far higher than required to fracture the reservoir rock. At Rangely, when injection pressures were kept below a threshold, activity ceased.

If injection pressures are kept well below the fracture pressures of the reservoir rocks in the Imperial Valley, the risk of induced seismicity will probably be low.

Crow, N., H. WOLLENBERG, and S. Vonder Haar, "The Geologic Setting of the Salton Trough," in Continental Scientific Drilling Program Thermal Regimes: Comparative Site Assessment Geology of Five Magma-Hydrothermal Systems, F. Goff and A. C. Waters, Eds. (Los Alamos Scientific Laboratory, Rept. LA-8550-OBES, UC-66b, 1980), pp. 61-81.

The Salton Trough is a rift valley, the landward extension of the Gulf of California. The system of right-lateral, strike-slip transform faults and cross faults, which offsets the East Pacific Rise in the Gulf, also extends on-shore and appears to control the locus of active hydrothermal systems in the Mexicali and Imperial valleys. The crystalline basement underlying the trough, composed predominantly of Mesozoic granitic rock, is overlain by up to 6 km of sedimentary rocks, primarily lacustrine deposits and deltaic sediments associated with the ancestral Colorado River. Pleistocene volcanic activity was superimposed on the sedimentary sequence, with present-day surface manifestations in the form of obsidian-rich rhyolitic domes at the south end of the Salton Sea and the rhyodacitic cone of the Cerro Prieto volcano. The Cerro Prieto geothermal field, presently producing 150 MW (electrical), and the Salton Sea geothermal field of high economic potential are two prominent hydrothermal systems currently under study by publicly supported projects. Information is being obtained at each site on its thermal, hydrologic, and lithologic settings to depths of several kilometers. Use of existing drill holes or deeper drilling for scientific purposes will permit determination of the sources of heat for the geothermal systems, be they dike swarms, magma chambers, and/or deep hydrologic circulation into zones of very high conductive heat flow. Most importantly, information from such drill holes will considerably advance our knowledge of the thermal regimes associated with this region of continental-oceanic transition.

DENNY, M. D., A. J. Piwinski, and P. W. Rodgers, Initial Siting Study for the Regional Seismic Test Network (U), Lawrence Livermore National Laboratory, Rept. UCID-18778 SNSI (1980).

(Unclassified abstract) The Regional Seismic Test Network (RSTN) is a full-scale test of the concept of the system involving the installation of five National Seismic Station (NSS) type stations in North America. The RSTN should model the proposed Comprehensive Test Ban Treaty (CTBT) network as closely as possible with regard to both regional propagation and the functioning of detection, location, and identification algorithms. We envision three levels of approximation, i.e., zeroth-order: match spacing between stations; first-order: zero-order plus match regional geophysical parameters about each station; second-order: zeroth- and first-order plus match geophysical properties for regions common to multiple stations. We characterized the proposed CTBT network in terms of the zeroth and first-order terms. Only a rudimentary attempt at a second-order approximation was made since appropriate analogs were difficult to obtain. With this characterization, we looked for analogs in the North American continent and found that a reasonable, but not perfectly analogous network was possible in the U.S.

DUBA, A., Electrical Properties of Rocks and Minerals at High Pressures and Temperatures (Ger. Sci. Found., Bonn, W. Germany, Oct. 2, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85069, Abstract (1980).

The electrical conductivity of iron-bearing silicates is weakly dependent on oxygen fugacity within the temperature-oxygen fugacity field in which no iron valence change is allowed to occur. However, an oxidizing atmosphere can cause anomalously high apparent conductivity, most likely the consequence of the production of interconnected, highly conductive, magnetite at dislocations, sub-grain boundaries, and on sample surfaces. A reducing atmosphere causes reduced conductivity, most likely the consequence of the production of isolated iron-nickel particles at dislocations and subgrain boundaries. The oxidation process, particularly, has affected many literature data on conductivity at high pressure and temperature.

Since the electrical conduction mechanism in silicates is temperature dependent, measurement of the pressure derivative of conductivity should be made at temperatures expected at that pressure. Most literature data on pressure derivatives are shown to be irrelevant to the problem of mantle conductivity because of the low temperature at which they were made. All other measurements of pressure derivatives of conductivity of silicates have been made at unknown oxygen fugacity. Thus, at this time, no reliable conductivity pressure derivatives exist.

DUBA, A., and H. C. Heard, "Effect of Hydration on the Electrical Conductivity of Olivine," Trans. Am. Geophys. Union **61**, 404 (1980). [UCRL-84031, Abstract]

The electrical conductivity (σ) of the [010] direction of peridot from St. John's Island, Egypt, has been measured to 1500°C in atmospheres of controlled oxygen fugacity (f_{O_2}) between the Fe-FeO and FeO-Fe₃O₄ buffers produced by gas mixtures of both H₂/CO₂ and CO/CO₂. We observe a small dependence of σ on f_{O_2} and similar σ at a given f_{O_2} for either gas composition above about 1250°C. However, below this temperature, the σ at a given f_{O_2} is much higher for H₂/CO₂ (by as much as a factor of 10) than for CO/CO₂ mixtures. At temperatures below ~1250°C, the activation energy for conduction is lower for mixtures containing H₂, becoming as little as 40% of the value at similar temperature- f_{O_2} in CO/CO₂. These results indicate that electrical conductivity of olivine is not independent of the gas mixture used to control f_{O_2} . Similar dependencies are also to be expected for other transport properties such as creep, optical absorption, and ionic diffusion. Since gas mixtures involving H₂ have f_{H_2O} of magnitude similar to f_{O_2} , significant concentrations of other defect types (e.g., OH⁻, H⁺, H₃O⁺, etc.) will exist in addition to oxygen defects. Recently, Kohlstedt and Hornack have demonstrated that the creep rates of San Carlos olivine is dependent on H₂/CO₂ mixture ratios used to control f_{O_2} . Until the role of hydrogen in silicate structures at high temperatures is more fully understood, we would caution against the use of H₂/CO₂ buffers in controlling oxidation in iron-bearing silicates, especially if some defect-sensitive property is being measured.

DUBA, A., The Electrical Conductivity of Basalt (5th Workshop Electromagnetic Induction in Earth and Moon, Istanbul, Turkey, Aug. 18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84600, Abstract (1980).

Literature data on the electrical conductivity of basalt span more than three orders of magnitude at any temperature above 700°C. Since these data are the results of more than ten separate investigations, it seems reasonable to assume that difference between sample materials is the reason for the large degree of uncertainty. However, electrical conductivity data for samples from the same piece of fine-grained Picture Gorge basalt vary almost as much as the literature data, depending only on experimental conditions. At a given temperature, the conductivity may vary almost three orders of magnitude, depending on the oxygen partial pressure in equilibrium with the sample and the rate at which temperature is changed. The time dependence of the conductivity of this basalt is complicated. At temperature below about 975°C, the conductivity decreases with time in equilibrium with oxygen partial pressure less than that of air. At temperature greater than 975°C, the conductivity increases with time at all oxygen partial pressures. These results indicate that the electrical conductivity of basalt and, by implication, most rocks, is influenced by reaction in the solid state which complicates the determination and interpretation of the measurement.

Duba, A., and J. N. BOLAND, Reduction of Olivine in the Solid State: Implications for Planetary and Meteoritic Evolution, Lawrence Livermore National Laboratory, Rept. UCRL-85067, Preprint (1980).

Production of spherical iron-nickel precipitates in single crystal olivine at temperatures several hundred degrees below melting indicates that solid-state reduction is a plausible explanation for the occurrence of some of the iron particles in lunar rocks and meteorites. The possibility that solid-state reduction plays an important role in the formation of planetary cores is discussed.

DUBA, A., W. D. Daily, R. J. Lytle, and A. J. Piwinskii, "A Model for the Electrical Conductivity Distribution During In-Situ Oil Shale Retorting," Trans. Am. Geophys. Union 61, 1130 (1980). [UCRL-85013, Abstract]

A model of the electrical conductivity distribution in an in-situ oil shale retort has been developed. The model is based on the temperature distribution calculated for in-situ retorting of rubblized oil shale. This temperature distribution was used to calculate the conductivity profile of the retort using laboratory electrical conductivity measurements by several investigators for oil shale rock up to 1000°C. Assuming that laboratory conductivity measurements of the solid (rock) phase alone represent the complex chemical and physical environment of a retort, we find that the combustion zone should provide an electrical anomaly 10^9 more conductive than the preretort shale. Injection of air to drive the retort produces a calculated temperature profile with a highly conductive region increasing in thickness from 5 to 15 meters between days 5 and 10 after the retort begins. Injection of a mixture of 50% air and 50% steam results in a narrower high temperature region and a resulting electrical anomaly of 2-3 m thickness which is nearly independent of time during the retort. The magnitude of the electrical conductivity changes associated with retorting of oil shale indicates that electrical techniques can be employed as a remote monitoring and diagnostic tool.

Duba, A., D. TRIMMER, B. Bonner, and H. C. Heard, "Effect of Pressure and Stress on Water Transport in Intact and Fractured Gabbro and Granite," J. Geophys. Res. **85**, 7059-7071 (1980). [UCRL-83932, Preprint]

Duba, D., R. N. SCHOCK, and R. L. Stocker, Defect Production and Electrical Conductivity in Olivine (Lunar & Plan. Sci. Conf., Houston, TX, March 17-21, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83879, Preprint (1980).

DURHAM, W. B., A. E. Abey, and D. A. Trimmer, Thermal Conductivity, Diffusivity and Expansion of Avery Island Salt at Pressure and Temperature (ITCC and ITES Conf., Chicago, IL, Nov. 7-9, 1979), Lawrence Livermore National Laboratory, Rept. UCRL-83789, Preprint (1980).

Preliminary data on the thermal properties of a coarse-grained rock salt from Avery Island, Louisiana, indicate that hydrostatic pressure to 50 MPa has little effect on the thermal conductivity, diffusivity, and linear expansion at temperatures from 300 to 573 K. The measurements were made in a new apparatus under conditions of true hydrostatic loading. At room temperature and effective confining pressure increasing from 10 to 50 MPa, thermal conductivity and diffusivity are constant at roughly 7 W/mK and $3.6 \times 10^{-6} \text{ m}^2/\text{s}$, respectively. At 50 MPa and temperature increasing from 300 to 573 K, both conductivity and diffusivity drop by a factor of two. Thermal linear expansion at 0 MPa matches that at 50 MPa, increasing from roughly $4.2 \times 10^{-5}/\text{K}$ at 300 K to 5.5×10^{-5} at 573 K. The lack of a pressure effect on all three properties is confirmed by previous work. Simple models of microcracking suggest that among common geological materials, the lack of pressure dependence is unique to rock salt.

DURHAM, W. B., D. Ricoult, and D. L. Kohlstedt, "Slip System Interaction in Single-Crystal Olivine," Trans. Am. Geophys. Union **61**, 1128 (1980). [UCRL-84946, Abstract]

To investigate processes involved in multiple slip, specifically to determine the influence of the presence of dislocations of one slip system upon the action of another slip system, a series of single crystal creep experiments was performed in which two loading directions were applied sequentially. Eleven runs were made on five single crystals. The runs were conducted at 1600°C under 0.1 MPa of $\text{H}_2 + \text{CO}_2$ ($\text{H}_2:\text{CO}_2$ volume ratio 70:30) and differential stresses (σ_1) of 25 to 35 MPa.

Three orientations of σ_1 were used: $[110]_c$ (the "c" refers to cubic indices), wherein only the (010)[100] slip system is activated; $[101]_c$, wherein (001)[100] and to a lesser extent (100)[001] are activated; and $[111]_c$, wherein an undetermined (0kℓ)[100] slip system(s) is activated. Each orientation produces its own characteristic "fingerprint" dislocation structure at steady state. Three interaction sequences were studied: $[110]_c \rightarrow [101]_c$, $[101]_c \rightarrow [110]_c$, and $[101]_c \rightarrow [111]_c$. In no case was the deformation at the second orientation slowed by that at the first; for the first two cases, initial deformation during the second step was slightly faster than steady state levels. Deformation induced microstructures as seen by

optical and transmission electron microscopy generally indicated the blending of one fingerprint into another, with the gradual replacement of the first fingerprint by the second. Some intermediate structures did form, but in no case were unusually high density tangles of dislocations observed. These observations suggest that dislocation movement under multiple slip is no slower than under single slip.

DURHAM, W. B., and A. E. Abey, Thermal Conductivity and Diffusivity of Climax Stock Quartz Monzonite at High Pressure and Temperature, Lawrence Livermore National Laboratory, Rept. UCRL-85192, Abstract (1980).

The measurement of thermal properties of rocks under elevated temperature and confining pressure has been initiated because of recent interest in developing nuclear waste repositories in deep underground rock formations. Accurate prediction of rock response to thermal loading by varying amounts of nuclear waste requires that rock properties be known at conditions appropriate to the repository. Extensive data exist regarding the thermal transport properties of rock at ambient pressure, but because rocks tend to sustain microfracturing and increased porosity during heating, there is a possibility that room pressure conductivity and diffusivity may be deflected from values at pressure.

Previously reported data on rock salt indicate a minor dependence of thermal conductivity and diffusivity upon pressure below pressures of 20 MPa. More recently, testing has begun on samples of Climax Stock (Nevada) quartz monzonite, a dense, large-grained, granite-like rock. Current measurements show the following: in rock which has not been previously heated, thermal conductivity measures 3.0 W/mK at 300 K with no dependence upon confining pressure between 10 and 50 MPa. Heating at 50 MPa from 300 to 423 K results in a linear drop in conductivity from 3.0 to 2.4 W/mK. No effect has been perceived upon the room temperature thermal properties following heating to 373 K at 50 MPa. The effects of higher temperatures at 50 MPa and of heating at lower pressures have not yet been measured. Based on rock salt behavior and the tendency for crystalline rocks to form microfractures as temperature increases and as pressure decreases, a measurable effect of heating at low pressure upon the thermal conductivity and diffusivity of the quartz monzonite is anticipated.

DURHAM, W. B., and A. E. Abey, Thermal Properties of Two Rocks to 573 K and 50-MPa Confining Pressure, Lawrence Livermore National Laboratory, Rept. UCRL-85191, Abstract (1980).

Measurement of thermal conductivity, thermal diffusivity, and thermal linear expansion have been made on two rock types, a rock salt and a quartz monzonite, at temperatures from 300 to 573 K and confining pressures from 10 to 50 MPa. The samples were taken from deep rock formations under study as possible sites for a nuclear waste repository. The rock salt was taken from a domal salt formation at Avery Island, Louisiana; the quartz monzonite from the Climax Stock, Nevada Test Site, Nevada. The testing temperature and pressures are meant to bracket conditions expected in the repository.

In both rock types, the thermal properties show a strong dependence upon temperature and a weak or non-dependence upon confining pressure. Thermal

conductivity and diffusivity both decrease with increasing temperature in approximately linear fashion for samples which have not been previously heated. At 50 MPa in both rocks, this decrease closely matches the measured or expected intrinsic behavior of the material. A pressure dependence has been detected in the rock salt and is suggestive of microfracture porosity playing a role in thermal transport. Decreasing pressure at a fixed temperature of 350 K or higher causes conductivity to decrease slightly. The pressure effect is distinctly non-linear; it is most pronounced in the range 10-20 MPa and disappears entirely above 30 MPa. Diffusivity shows a corresponding but positive non-linear pressure dependence. Preliminary indications from the quartz monzonite suggest that conductivity and diffusivity at low pressure and temperature may decrease as a result of heat treatment above 400 K.

DURHAM, W. B., and A. E. Abey, The Effect of Pressure and Temperature on the Thermal Properties of Two Rocks, Lawrence Livermore National Laboratory, Rept. UCRL-85285, Abstract (1980).

An apparatus has been constructed to make simultaneous measurements of thermal conductivity, thermal diffusivity, and thermal linear expansion of large-grained rocks under conditions of elevated temperature (to 573 K) and hydrostatic pressure (to 50 MPa). Interest in making such measurements has been stimulated by the desire to understand rock properties in the immediate neighborhood of a mined nuclear waste repository. Two rocks have been tested to date, a domal salt from Avery Island, Louisiana, and a quartz monzonite from the Climax Stock, NTS, Nevada. The bulk thermal properties of the rock salt under pressure are generally a close match to previously measured intrinsic thermal properties of single crystals measured at 0.1 MPa. There is a dependence of thermal conductivity upon pressure below 20 MPa and above 340 K: a pressure change from 20 to 10 MPa causes a 10-15% drop in conductivity. The quartz monzonite is incompletely tested, but shows no pressure dependence at room temperature despite previous heating under 50-MPa pressure to temperatures as high as 423 K. The values for conductivity and diffusivity of the quartz monzonite are approximately half those for the salt at all temperatures to 423 K.

Durham, W. B., H. C. HEARD, D. Trimmer, and A. Abey, "Thermal, Thermal-Elastic, and Water Transport Behavior of Generic High-Level Waste Repository Rocks," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 444 (1980). [UCRL-84404, Abstract]

Durham, W. B., A. S. KUSUBOV, R. N. Schock, J. F. Schatz, and T. J. Ahrens, "Explosive-Induced Damage in Porous Sandstone," in High Pressure Science and Technology, Vol. 2, B. Vodar and Ph. Marteau, Eds. (Pergamon Press, Oxford, 1980), pp. 917-923. [UCRL-83448, Preprint]

EMERSON, D., and J. Eichelberger, "Geology of the Long Valley Caldera, California," in Continental Scientific Drilling Program Thermal Regimes: Comparative Site Assessment Geology of Five Magma-Hydrothermal Systems, F.

Goff and A. C. Waters, Eds. (Los Alamos Scientific Laboratory, Rept. LA-8550-OBES, UC-66b), pp. 29-35.

Long Valley Caldera is a large Quaternary silicic volcanic complex that lies at the boundary of Sierra Nevada escarpment on the west and the Basin and Range tectonic province to the east. Silicic volcanic rocks and associated sediments overlie a faulted basement of Mesozoic granite and Paleozoic metasediments. Surface hydrothermal phenomena include sulfur fumaroles at Casa Diablo and a variety of hot springs as hot as 63°C. Extensive subsurface investigations with both shallow and deep wells show that modest-size hydrothermal systems, as hot as 169°C, are perched in permeable aquifers above colder rocks at shallow stratigraphic levels in the Caldera. Thermal gradients in deep wells are not known to be above 37°C/km. In contrast, limited geophysical data suggest that a magma reservoir extends from 7 km to as much as 25 km beneath the surface. A deep drill hole (5-8 km) might resolve these contradictions and provide data for either confirming or rejecting the geophysical interpretations.

EMERSON, D., "A Summary of the Geology of the Roosevelt Hot Springs Thermal Area, Utah," in Continental Scientific Drilling Program Thermal Regimes: Comparative Site Assessment Geology of Five Magma-Hydrothermal Systems, F. Goff and A. C. Waters, Eds. (Los Alamos Scientific Laboratory, Rept. LA-8550-OBES, UC-66b, 1980), pp. 51-60.

Roosevelt Hot Springs discharges from a deep 260°C water-dominated geothermal reservoir that lies west of the Mineral Mountains, Utah. These mountains, which consist of a large fault-block of Precambrian basement and Paleozoic rocks intruded by Tertiary granitic rocks, sit at the east margin of the Basin and Range and west margin of the Colorado Plateau tectonic provinces. Rhyolitic domes, flows, and pyroclastics 0.8-0.5 Myr old surmount the crest of the Mineral Mountains. The young igneous activity, in combination with seismic P-wave delay data, suggests the presence of a silicic magma reservoir in the shallow crust. The hydrothermal system is localized along a variety of high- and low-angle fault systems that may direct fluid flow westward away from the postulated magmatic heat source. Hydrothermal alteration of granitic rocks has produced secondary mineralization that may include K-feldspar, chlorite, calcite, and pyrite. Silica sinter is a common spring deposit. The object of a deep borehole at Roosevelt Hot Springs would be to seek evidence of the magmatic heat source and to learn how it is coupled to the hydrothermal system.

Followill, F. E., J. M. MILLS, JR., and R. F. Rohrer, Locations and Mechanisms for Aftershocks of the January, 1980, Livermore, California, Earthquake Sequence (Am. Geophys. Union, Toronto, Ontario, May 21, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85306, Abstract (1980).

Followill, F. E., and J. M. MILLS, JR., "Microearthquakes in the Livermore Valley," in Energy and Technology Review, Lawrence Livermore National Laboratory, Rept. UCRL-52000-80-2 (1980), pp. 1-9.

GLENN, H. D., H. R. Kratz, and D. D. Keough, High-Energy (Mach 130) Air-Shock Propagation in Steel and Grout Pipes (Am. Phys. Soc., Washington, DC, April 21-24, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83776, Abstract (1980).

Voitenko compressors were used to generate ~ 4.5 cm/ μ s air shocks in a steel and a grout outlet pipe. Diaphragm burst times and time-of-arrival data of shock-front luminosity along the 2-cm-i.d. exit pipes are provided by fiber-optic ports. Pressure profiles were obtained for this high enthalpy shock propagation for the first time and at many locations in both experiments. In the interval between 10 and 250 cm from the diaphragm, the velocity and peak pressure of the shock front attenuated from ~ 4.5 to 0.5 cm/ μ sec and ~ 21 to 0.2 kb, respectively. Over this distance the shock propagation gave nearly identical results for both experiments. This rapid attenuation of the shock front velocity and pressure is attributed to ablation and entrainment of wall material. The results indicate that the shock propagation is independent of wall composition to the extent of materials considered over the 250-cm distance of the outlet pipes.

GLENN, H. D., Brightness Temperature Measurements for High-Energy Jet Propagation (U) (Defense Nucl. Agency Sympos. Fiber Optics in Nucl. Environ., Adelphi, MD, March 25-27, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83609, Preprint (1980) and Defense Nuclear Agency, Rept. DNA 5308P-1, SRD (1980).

(Abstract unclassified) This paper describes the use of fiber optics to measure times of arrival and brightness temperature profiles for high-energy gas jets. Voitenko compressors have been used to produce high-energy air and oxygen jets through steel pipes 2 cm in i.d. and 350 cm in length containing air initially at 0.02 Torr or less. Reduction of the time-of-arrival data indicated that velocities for the various identified jet components ranged between 2.40 and 7.97 cm/ μ sec. The fiber optics emplacement design and brightness temperature calibration procedure are described. Maximum brightness temperatures of 93,000 and 136,000°K have been measured for air and oxygen jets, respectively, as they started down the exit pipes. Brightness temperature profiles have been obtained to 50 μ sec behind the jet front. The results suggest that delayed entrainment of wall material was the predominant factor in reducing pressures and temperatures in the slower components of the jet.

GLENN, H. D., R. W. Terhune, J. B. Bryan, and L. R. Moreno, Destruction of the Peninsula Device (U), Lawrence Livermore National Laboratory, Rept. UCID-18511, CFRD (1980).

HANSON, J. M., "Reservoir Response to Tidal and Barometric Effects," Trans. Geothermal Resources Council, Salt Lake City 4, 337-340. [UCRL-84461, Preprint]

Solid earth tidal strain and surface loading due to fluctuations in barometric pressure have the effect, although extremely minute, of dilating or

contracting the effective pore volume in a porous reservoir. If a well intersects the formation, the change in pore pressure can be measured with sensitive quartz pressure gauges. Mathematical models of the relevant fluid dynamics of the well-reservoir system have been generated and tested against conventional well pumping results or core data at the Salton Sea Geothermal Field (SSGF), California and at the Raft River Geothermal Field (RRGF), Idaho. Porosity-total compressibility product evaluation based on tidal strain response compares favorably with results based on conventional pumping techniques. Analysis of reservoir response to barometric loading using Auto Regressive Integrated Moving Average (ARIMA) stochastic modeling appears also to have potential use for the evaluation of reservoir parameters.

Hanson, J. M., P. W. KASAMEYER, and L. W. Younker, "Age of the Salton Sea Geothermal System as Inferred from the Thermal Data," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 458 (1980). [UCRL-85117, Abstract]

Hanson, J., L. YOUNKER, and P. Kasameyer, "Application of Hydrothermal Modeling to the Selection of Deep Drilling Sites in the Salton Sea Geothermal Field," Trans. Am. Geophys. Union 61, 1149 (1980). [UCRL-84961, Abstract]

HANSON, M. E., G. D. Anderson, R. J. Shaffer, and L. D. Thorson, Some Effects of Stress, Friction, and Fluid Flow on Hydraulic Fracturing, Lawrence Livermore National Laboratory, Rept. UCRL-85003, Abstract (1980).

We are conducting a DOE-funded research program which is aimed at understanding the hydraulic fracturing process, especially those phenomena and parameters which strongly affect or control the fracture geometry. Our theoretical and experimental studies consistently confirm the well known fact that in-situ stress has a primary effect on fracture geometry and that fractures propagate perpendicular to the least principal stress. In addition, we find that the state of bonding between reservoir materials can affect fracturing. We have examined different cases of bonding, from well-bonded to unbonded with variable friction on the interfaces. In the well-bonded case, we found that the variation in mechanical properties can cause significant changes in the stress field. We have also quantified some of the effects on fracture geometry due to frictional slippage along interfaces. We found that variation of friction along an interface can result in abrupt steps in the fracture path. These effects have been seen in the mine back of emplaced fractures and are demonstrated both theoretically and in the laboratory. Further experiments and calculations are starting to indicate the possible control of the fracture height by the vertical change in the horizontal stresses.

HANSON, M. E., G. D. Anderson, R. J. Shaffer, D. F. Towse, W. Lin, L. D. Thorson, and M. P. Cleary, LLL Gas Stimulation Program Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, Rept. UCRL-50036-79-4 (1980).

This report summarizes the research and activities of the LLL Gas Stimulation Program during the first quarter of FY 1980. We have continued our theoretical model development and application. Analyses of frictional interfaces, with similar materials on both sides of the interface, show that frictional slippage along the interface tends to draw a pressurized fracture toward the interface. Increasing friction along the interface changes the position at which the pressurized fracture is affected by the interface. The dynamic effects of propagation near a well-bonded interface between two dissimilar materials are not significantly modified by the velocity of the dynamically propagating fracture for fracture by velocities below the body wave speeds. We have shown the pressure evaluation of the fracturing fluid in a crack. One notable feature of these calculations is the rather sudden increase in fluid pressure at the fracture tip just after the fluid reaches it. Frictional interface experiments using various lubricants on the interface show distinct changes in the frictional coefficient; however, these tests indicate that the interface must support about 350 psi (24 GPA) in shear (frictional) stress before a fracture will penetrate the interface. Our studies of the occurrence and mechanics of natural fractures in the western reservoirs show that in a relaxed tectonic setting, one principal stress is most often nearly vertical and the other two are horizontal. Local stresses that control small fractures such as joints may be different from, although compatible with, the regional stresses. Fractures are controlled by the physical environment, the stresses, and changes in stresses due to burial and uplift. Jointing frequency is greater in weak and thinly bedded rocks and is directly related to the intensity of folding.

HANSON, M. E., G. D. Anderson, W. Lin, R. J. Shaffer, D. F. Towse, M. P. Cleary, D. R. Peterson, S. K. Wong, and B. C. Haimson, LLNL Gas Stimulation Program Quarterly Progress Report, January Through March 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50036-80-1 (1980).

This report summarizes the research and accomplishments of the LLNL Gas Stimulation Program during the second quarter of FY 1980. We have continued to analyze the effects of dynamics and fractures on hydraulic fracture propagation near interfaces. We have also begun some analysis of the propagation of penny-shaped cracks including an averaged flow description in the cracks. Poiseuille flow descriptions of Newtonian fluids were used to model the fluid flow and pressure distribution in the crack. Frictional effects and measurements were emphasized in the laboratory experiments. These results show that variation in friction along an interface can result in abrupt steps in the fracture path. We have also completed a laboratory study of the effects of fluid viscosity on fracture orientation under various stress states. Results from these experiments indicate that the fluid viscosity does not significantly affect the fracture orientation; however, increases in fluid viscosity result in higher breakdown pressures. We have continued to study the relation between natural fractures and structural geology in the Piceance Basin.

HANSON, M. E., G. D. Anderson, and R. J. Shaffer, "Theoretical and Experimental Research on Hydraulic Fracturing," J. Energy Resources Tech. 102, 92-98 (1980). [UCRL-80558, Preprint]

We are conducting a joint theoretical/experimental research program on hydraulic fracturing. Newly developed two-dimensional numerical models (which include complete descriptions of the elastic continuum and porous flow fluids) have been applied to analyze the effects of pore pressure on the fracturing process. By means of small-scale experiments, we are acquiring a better understanding of the effects of the in-situ stress field, the porosity and permeability of the solid, and the presence of interfaces or layering in the solid. Experimentally, we have been studying the growth of cracks near an interface in several materials, including polymethylmethacrylate (PMMA), Nugget sandstone, and Indiana limestone. Results have shown that the mechanical properties of the interface relative to the properties of the materials on either side are important. A crack will not cross a well-bonded interface between two pieces of PMMA, even in the presence of a 13.79-MPa (20000-psi) normal load. Cracks will cross a well-bonded interface from PMMA to limestone, but not vice versa. Similarly, cracks will propagate across a bonded interface from Nugget sandstone to limestone, but not the other way. Pressure-driven cracks will cross an unbonded interface between limestone blocks at normal loads as low as 3.45 MPA (500 psi).

HANSON, M. E., G. D. Anderson, and R. J. Shaffer, "Effects of Various Parameters on Hydraulic Fracture Geometry," Rept. SPE/DOE 8942, Proc. 1st Sympos. Unconventional Gas Recovery (Pittsburgh, PA, May 18-20, 1980), pp. 163-172. [UCRL-83784, Preprint]

We are conducting a theoretical-experimental program on the hydraulic fracturing process. A primary objective of the program is to determine those reservoir properties or characteristics which can control the created fracture geometry. Theoretical models have been applied to analyze some aspects of the dynamics of fracturing near material interfaces. The results of these calculations indicate that variation of material properties across a well bonded interface can cause dynamic material response resulting from the fracturing which could enhance propagation across the interface. Effects of friction have also been analyzed theoretically; however, in the frictional calculations the wave mechanics have been ignored. These calculations have shown that frictional slip along the interface tends to draw a pressurized fracture toward the interface; this motion tends to reduce the chances of penetrating the material across the frictional interface.

Small scale laboratory experiments are performed to study the effects of frictional characteristics on hydraulic fracture growth across unbonded interfaces in rocks. Various lubricants and mechanical preparation of the interface surfaces are used to vary the coefficients of friction on the interface surfaces. It is found that the frictional shear stress that the interface surface can support determines whether a hydraulically driven crack will cross the interface. Experiments are also being performed to study the effects of pre-existing cracks, which perpendicularly intersect the unbonded interface, on hydraulic crack growth across the interface. It is also found that the presence of these pre-existing cracks impedes the propagation of the hydraulic fracture across the interface. These experimental results on the effects of friction on the interface and the effects of pre-existing cracks on hydraulic fracture penetration of interfaces are consistent with the predictions of the numerical model calculations.

HANSON, M. E., and R. J. Shaffer, "Some Results from Continuum Mechanics Analyses of the Hydraulic Fracturing Process," Soc. Pet. Eng. J. 20, 86-94 (1980). [UCRL-81707, Preprint]

We are developing and applying theoretical, numerical models to analyze the hydraulic fracturing process. Applications include fracturing near interfaces, effects of existing fractures near interfaces, pore-pressure effects, and stress-field changes due to embedded lenses. For a well-bonded interface, the calculations indicate that the stress-intensity factor of the leading crack tip decreases as the crack approaches a higher modulus material. As the tip crosses the interface into the higher modulus material, the stress-intensity factor abruptly increases to a higher value than it had in the lower modulus material. When the situation is reversed, the intensity factor increases as the tip approaches the interface and then abruptly decreases when the tip crosses the interface. Further calculations show that when existing cracks are present near the interface, the effects of the change in material properties across the bonded interface are reduced. In addition, our analysis shows that increases in pore pressure due to leakage of fluids from the fracture into the surrounding media cause the stress-intensity factor to drop; a decrease in the stress-intensity factor means a reduction in the tendency to break. In other calculations we analyzed the stress-field disturbance caused by lenses of one material that are embedded in another material. These calculations show that in regions that are not tectonically relaxed, the stress field is modified by the lenses. We conclude that the fracture geometry is modified by the presence of embedded lenses under these conditions.

Hanson, M. E., R. N. SCHOCK, R. P. Swift, and O. R. Walton, "In Situ Fracture Related to Energy and Resource Recovery," in High Pressure Science and Technology, B. Vodar and P. Marteau, Eds. (Pergamon Press, Oxford, 1980), pp. 902-912. [UCRL-82731, Preprint]

Hanson, M. E., R. W. TERHUNE, and C. R. McKee, Explosion Phenomenology and Permeability Enhancement in Earth Media, Lawrence Livermore National Laboratory, Rept. UCRL-84784, Abstract (1980).

HEARD, H. C., and L. Page, "Thermal Expansion and Elastic Moduli of Westerly and Stripa Granites to 350°C and 55 MPa," Trans. Am. Geophys. Union 61, 1113 (1980). [UCRL-84947, Abstract]

The coefficient of thermal linear expansion (α), Young's modulus (E) and bulk modulus (K) have been determined for the Westerly and Stripa granites to temperatures (T) of 350°C and pressures (P) to 55 MPa. Using conventional triaxial apparatus, displacement measurements were made on 3 samples from each of 3 orthogonal directions for both rocks. Comparison between the directional values at any P, T, and those from the 9-sample population, indicated that both granites are isotropic in α , E, and K. Values for α were neither constant nor a monotonic function of P or T. In both granites over the P range investigated, α typically increased from $6-12 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$ at 400°C to $10-16 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$ at 325°C. In both rocks over the T range investigated, increasing P from 6 to 55 MPa generally decreased α by $1-5 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$.

Both E and K for both rocks decreased with T and increased with P in a non-linear fashion. From 190 to 350°C, E decreased by up to a factor of 2 and K decreased by 2-3, depending on P. From 6 to 55 MPa, E increased by 3-6 and K increased by 3-5, depending on T. Assuming elasticity, the calculated Poisson's ratio ranged from 0.25-0.40 at 190°C, decreasing to 0.15-0.25 at 350°C (depending both on the rock and P). In both rocks, all measurements are consistent with microcracks controlling the thermoelastic response by opening with T and closing with P. Such determinations of α , E and K are necessary for input to computational models for prediction of the thermomechanical response of a high level radioactive waste repository constructed at depth.

Heard, H. C., A. ARIELI, and A. K. Mukherjee, Deformation Modeling in NaCl at Intermediate and Elevated Temperatures, Lawrence Livermore National Laboratory, Rept. UCRL-85066, Preprint (1980).

The flow stress dependence on temperature and strain rate of annealed, isotropic polycrystalline NaCl has been determined at temperatures of 296-673 K (0.28-0.63 T_M) and strain rates of 10^{-1} - 10^{-8} s $^{-1}$.

At elevated temperatures ($T > 0.44 T_M$) and relatively low stress, the Na⁺ diffusion-controlled climb of dislocations was found to be the rate-controlling deformation mechanism, and the experimental data could be fitted by a power-law function. In the same range of temperatures, at high stresses the deformation process is controlled by dislocation climb creep due to Cl⁻ ion diffusion. At intermediate temperatures and low strain rates and at elevated temperatures and high strain rates, the deformation was rate-controlled by the lattice resistance to the dislocation glide motion (Peierls mechanism).

The constitutive equations for each deformation mechanism, as well as that for the transition from one deformation mechanism to another, were developed in terms of strain rate, temperature, and stress. The implications of the transition from one deformation mechanism to another over a wide range of temperatures on the deformation modelling for this material are discussed. The application of such analysis to understand and predict the rheological behavior of halite aggregates in nature in buried salt deposits is considered.

HEARD, H. C., and S. H. Kirby, Activation Volume for Steady-State Creep in Polycrystalline CsCl: Cesium Chloride Structure, Lawrence Livermore National Laboratory, Rept. UCRL-84752, Preprint (1980).

Annealed polycrystalline samples of CsCl have been deformed in triaxial compression at 150 to 400°C (T), at 0.1 to 400 MPa confining pressure (P), and at constant strain rates ($\dot{\epsilon}$) ranging from 10^{-2} to 10^{-6} s $^{-1}$. Stress-strain data from these tests show mainly an elastic-plastic response but with minor work hardening occurring at the lower temperatures and at the higher rates. At the values of T, P, and $\dot{\epsilon}$ investigated, the steady-state flow stress (σ) ranged from 1.3 to 65 MPa. At a similar T and $\dot{\epsilon}$, σ at 400 MPa was two to four times that at low P. This σ increase with P is related to intracrystalline plasticity, not to dilatancy.

Measured values of $\dot{\epsilon}$, T, P, and σ from 39 tests were fitted to a flow law of the form $\dot{\epsilon} = B\sigma^N \exp [-(Q^* + PV^*)/RT]$ with Q^* the activation energy and

V^* the activation volume for steady-state flow. A least-squares fitting routine was used to calculate B , N , Q^* , and V^* . At one standard deviation and in SI units, $\log B$ is -19.87 ± 0.71 , N is 4.42 ± 0.29 , Q^* is 150 ± 9 kJ/mol, and V^* is $53 \pm 5.5 \cdot 10^{-6}$ m³/mol. Calculation of V^*_c from an empirical relation based on T_m/T and measured dT_m/dP on melting of the CsCl phase yields a much larger activation volume: $83 \cdot 10^{-6}$ m³/mol. Previously the V^*_c has been calculated by Keyes' method based on the shear and bulk moduli in isotropic materials or on this method as corrected for cubic solids. The range of values for V^*_c (17 to $74 \cdot 10^{-6}$ m³/mol) is so broad, they are of little use in estimating V^* . Values for Q^* and V^* determined here are shown to be consistent with the measured activation energy and activation volume for self-diffusion in CsCl.

Heard, H. C., D. J. BARBER, and H. R. Wenk, Deformation of Dolomite Single Crystals from 20-800°C (Int. Conf. Effect of Deformation on Rocks, Gottingen, W. Germany, April 9-12, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83869, Preprint (1980).

The stress-strain behavior of single crystal dolomite has been determined in uniaxial compression at 700-MPa effective pressure, 200 to 800°C, and at a strain rate of $1-3 \times 10^{-5}$ s⁻¹. Six orientations of the principal stress axis to the crystallographic symmetry axes were tested.

HEARD, H. C., D. Trimmer, W. B. Durham, and A. Abey, "Thermal, Thermal-Elastic, and Water Transport Behavior of Generic High-Level Waste Repository Rocks," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 444 (1980). [UCRL-84404, Abstract]

Prediction of the physical response of a rock mass at depth to the construction of a high-level radioactive waste repository requires (1) accurate definition of the initial structural geologic elements of the mass and the in-situ conditions (e.g., stress field, elastic moduli, permeability, etc.); (2) laboratory and field data on the thermal diffusivity, κ , on the thermal conductivity, λ , on the coefficient of thermal linear expansion, α , on the relevant elastic moduli (e.g., for an isotropic medium, compressibility, β , and Young's modulus, E), on the permeability, k , and on the tensile strength, shear strength, and the frictional behavior of the rock mass or its elements with all measurements determined within the range of expected temperature, pressures, and differential stress; and (3) computational models based on the physicochemical processes responsible for the thermal transport, water transport, and the subsequent rock mass or structural-element displacement.

Measurements of α , β , E , κ , λ , and k are currently being determined on a suite of crystalline igneous rocks and salt at simulated in-situ pressures, stresses, temperatures, and water pressures which may be expected in such a repository constructed at depths to 2 km and for waste-rock temperatures up to 350°C. Rocks under study include a quartz monzonite, three granites, a gneissic granite, a gabbro, and a bedded salt. Representative results will be presented for α , β , E , κ , λ , and k from each rock at pressures to 50 MPa and temperatures to 350°C.

HEARD, H. C., and W. Lin, "Mechanical Behavior of Devonian Shale at High Pressures," Soc. Exploration Geophys. Tech. Prog. (Houston, TX, Nov. 19, 1980), p. 50 (1980). [UCRL-83793, Abstract]

Prediction of the effects of hydraulic or high explosive fracturing for stimulation of fluid production from low permeability rocks requires a fracture model and certain equation of state (EOS) (mechanical properties) for input to the calculation codes. For such a study on the Devonian Shale of the eastern United States, we report here new EOS measurements taken on four shale members of this unit from 807-1233-m depth in the Columbia Gas Transmission well 20403, Huntington, West Virginia. For each member we have determined (1) the tensile strength parallel and perpendicular to bedding, 0.1 MPa; (2) the uniaxial stress failure envelope in compression to 300-MPa confining pressure, parallel and perpendicular to bedding; (3) the uniaxial stress failure envelope in extension to 400-600-MPa confining pressure, parallel and perpendicular to bedding; (4) the pressure-volume behavior to 4 GPa; (5) the loading path in uniaxial strain (compression) beginning at 20- and 50-MPa confining pressure, loading direction both parallel and perpendicular to bedding; and (6) the shear and compressional wave velocities to confining pressures to 1.0 GPa. Measurements were made parallel, at 45°, and perpendicular to bedding.

Heard, H. C., and CLINE, C. F., "Mechanical Behavior of Polycrystalline BeO, Al₂O₃, and AlN at High Pressure," J. Mater. Sci. **15**, 1889-1897 (1980). [UCRL-82319, Preprint]

The mechanical behaviour of various types of BeO, Al₂O₃, and AlN has been investigated at confining pressures up to 1.25 GPa, at 250°C, and at strain rates of 3 to 7 x 10⁻⁵ sec⁻¹. The stress-strain data taken in uniaxial compressive-stress loading indicate the BeO aggregates undergo a transition from brittle fracture at low pressures to plastic flow at high pressures. Depending on the fabrication process, this transition pressure in BeO occurs at 0.4 to 0.7 GPa. Concurrently, the ultimate compressive strength of BeO increases from 1.0 to 1.9 GPa at 0.1-MPa pressure to over 4.0 GPa at 1.0 GPa. Alumina remains brittle at all pressures up to 1.25 GPa; its strength increases from 4.5 GPa at 0.1-MPa pressure to over 6.0 GPa at 1.25 GPa. Aluminium nitride behaves similarly to BeO, having a brittle-ductile transition at 0.55 GPa. Its ultimate strength increases from 3.2 GPa at 0.1-MPa pressure to 4.7 GPa at 0.8 GPa. The distortional strain energy (proportional to the area under the stress-strain curve) absorbed by each material during compression at pressure was calculated and compared to available data from the literature. Alumina shows a degraded energy absorption with pressure, but both BeO and AlN yield a strongly enhanced performance at moderate pressures. Beryllium oxide and AlN thus appear to be promising structural materials for certain applications where high strengths and ductilities are required at moderate pressures.

HEARD, H. C., "Thermal Expansion and Inferred Permeability of Climax Quartz Monzonite to 300°C and 27.6 MPa," Int. J. Rock Mech. Min. Sci. & Geomech. Abs. **17**, 289-296 (1980). [UCRL-83697, Preprint]

The coefficient of linear thermal expansion (α) has been evaluated for Climax Stock quartz monzonite at effective pressures (P) of 0, 13.8 and 27.6 MPa (0-276 bars) and at temperature (T) from 19 to 300°C. The samples evaluated were deliberately chosen to include imperfections such as healed fractures and large phenocrysts characteristic of the Climax pluton near the site of a high-level waste repository demonstration test at the Nevada Test Site. Values for α are neither constant with nor a simple function of T or P. For the range of T investigated, α ranges from 10 to 15.10⁻⁶ °C⁻¹ at 0 MPa, from 7 to 13.10⁻⁶ °C⁻¹ at 13.8 MPa, and from 7 to 12.10⁻⁶ °C⁻¹ at 27.6 MPa. These values of α are greater than those expected for a similar but crack-free rock. Observations on the heated rock indicate that the thermal expansion is accompanied by new microcrack formation. At the temperatures to be expected in the wall rock near a waste canister, this increase in crack porosity is inferred to increase local permeability by factors of 2-5.

Heard, H. C., and D. TRIMMER, "Compaction and Permeability of Oil Shale Aggregates at High Temperatures," Soc. Petrol. Eng. J. 20, 95-104 (1980). [UCRL-80104, Preprint]

Heard, H. C., R. C. CARLSON, W. C. Patrick, D. G. Wilder, W. G. Brough, D. N. Montan, P. Harben, and L. B. Ballou, Spent Fuel Test-Climax: Technical Measurements Interim Report FY 1980, Lawrence Livermore National Laboratory, Rept. UCRL-53064 (1980).

Heard, H. C., and A. DUBA, "Effect of Hydration on the Electrical Conductivity of Olivine," Trans. Am. Geophys. Union 61, 404 (1980). [UCRL-84031, Abstract]

Heard, H. C., D. TRIMMER, B. Bonner, and A. Duba, "Effect of Pressure and Stress on Water Transport in Intact and Fractured Gabbro and Granite," J. Geophys. Res. 85, 7059-7071 (1980). [UCRL-83932, Preprint]

Heard, H. C., and L. PAGE, Elastic Moduli, Thermal Expansion, and Inferred Permeability of Climax Quartz Monzonite and Sudbury Gabbro to 500 C and 55 MPa, Lawrence Livermore National Laboratory, Rept. UCRL-85253, Preprint (1980).

HEARST, J. R., J. W. Schmoker, and R. C. Carlson, "Effects of Terrain on Borehole Gravity Data," Geophysics 45, 234-243 (1980). [UCRL-80994, Preprint]

The effect of terrain on gravity measurements in a borehole and on formation density derived from borehole gravity data is studied as a function of depth in the well, terrain elevation, terrain inclination, and radial distance to the terrain feature. The vertical attraction of gravity g_T in a borehole resulting from a terrain element is small at the surface and reaches an absolute maximum at a depth of about one and one-half times the radial

distance to the terrain element, then decreases at greater depths. The effect of terrain on calculated formation density is proportional to the vertical derivative of g_T and is maximum at the surface, passes through zero where $|g_T|$ is greatest, and reaches a second extremum of opposite sign to the first and of much lower magnitude. Accuracy criteria for borehole-gravity terrain corrections show that elevation accuracy requirements are most stringent for a combination of nearby terrain features and near-surface gravity stations. Sensitivity to terrain inclination is also greatest for this combination. The measurement of the free-air gradient of gravity, commonly made slightly above the ground surface, is extremely sensitive to topographic irregularities within about 300m of the measurement point. The effect of terrain features 21.9 to 166.7 km from the well [Hammer's (1939) zone M through Hayford-Bowie's (1912) zone O] on calculated formation density is nearly constant with depth. At these distances, the terrain correction will be equivalent to a dc shift of about $0.053 \text{ g/cm}^3/1000\text{m}$ of average elevation above or below the correction datum. The effect of topography beyond 166.7 km is not likely to exceed 0.01 g/cm^3 .

HEARST, J. R., and P. W. Kasameyer, Acoustic Logging for Fractures (2nd Chem. Cong. of N. Am. Continent, Las Vegas, NV, Aug. 25-28, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83747, Abstract (1980).

There is reason to believe that the presence of fractured zones near, but not necessarily intersecting, a borehole can reduce the amplitude of the coda, or late-time portion, of the signal from a long-sweep acoustic log. We have used a variable-color display instead of a conventional variable-density display to show amplitude versus time and depth in a total waveform acoustic log. Amplitude changes are much easier to see than in the conventional display. We find that early decreases in coda amplitude can sometimes be associated with gas shows in Devonian shales. The shows are likely to occur in fractured zones, so these results support the idea of using a "coda log" to locate fractured zones. In other parts of the coda logs, large amplitudes are seen at times much later than the normal end of the coda. Plots of the times of these amplitudes versus depth indicate they are related either to mode conversions at bed boundaries or reflections from individual fractures. We can also sometimes obtain similar apparent reflections by displaying the difference between the amplitude of a waveform and its running depth average. Therefore, it appears that coda logs may also be useful in locating individual fractures that do not necessarily intersect the hole.

HELM, D. C., Conceptual Aspects of Subsidence Due to Fluid Withdrawal, Lawrence Livermore National Laboratory, Rept. UCRL-82311, Preprint (1980).

A saturated reservoir or confined aquifer system responds to fluid withdrawal as a dynamic unit whose elemental volumes not only compress due to decrease in porosity but move horizontally and vertically in order for the system to remain contiguous.

Recent trends in the conceptual aspects of subsidence due to fluid withdrawal are towards developing a practical three-dimensional theory of reservoir movement. One approach to developing an adequate theory is to couple volume strain within a reservoir to calculated stress change. Transient displacement of reservoir material in a direction of interest is the

sum of appropriate directional components of volume strain. It is not an integral sum of volume strain itself. To find directional components of strain in three dimensions requires so many parameters that, using this approach, a solution for matrix movement becomes intractable under most field conditions.

An alternative approach to developing a three-dimensional theory is proposed in this paper. It couples reservoir velocity fields in three dimensions to appropriate force fields. The generally neglected effect of the gravitational force field on transient movement of solids is included in the analysis. After calculating the transient velocity field of a saturated granular medium, it is conceptually possible to estimate the displacement of solids by integrating velocity over an appropriate interval of time.

HELM, D. C., "Field-Based Computational Techniques for Predicting Subsidence Due to Fluid Withdrawal," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 445 (1980). [UCRL-84398, Abstract]

Choice of a predictive technique for land subsidence should be based on availability of appropriate field data. If only the depth and thickness of compressible beds can be estimated, a simple hand calculation is available as a predictive technique and for many purposes is adequate. An example of such a technique uses Schatz, Kasameyer, and Cheney's depth-porosity model. If field measurements of water-level fluctuations and the resulting time-dependent compression and expansion of adjacent beds are locally available, use of a more refined predictive technique is justified. An example of such a technique used Poland and Tolman's aquitard-drainage model in conjunction with a field-based method of parameter evaluation (such as Riley's method of estimating specific storage and vertical hydraulic conductivity). Poland and Tolman's conceptual model and Riley's parameter evaluation method have been combined with a one-dimensional finite difference scheme to form a powerful predictive technique. This technique has been successfully applied to sites in California and Texas. Use of a computer code allows prediction of observed time lags in nonlinear compression and expansion of sedimentary materials in response to arbitrary sequences of rising and falling water levels.

HELM, D. C., Techniques for Prediction of Subsidence: Other Types of Models, Lawrence Livermore National Laboratory, Rept. UCRL-85127, Preprint (1980).

A variety of prediction techniques have been discussed--empirical, semi-theoretical, and theoretical. The empirical and semi-theoretical techniques require induced subsidence to have already begun. Empirical and semi-theoretical methods offer reasonable parameters that link subsidence to some other measurable phenomenon in the field. The theoretical techniques which have been discussed to this point require the results of laboratory tests in order to predict subsidence.

Two other techniques for subsidence prediction will now be discussed. This will be followed by a discussion of the role of the unpumped overburden. One technique, which uses a depth-porosity model, is too primitive to require induced subsidence to have already begun. This is its power; it can give a rough approximation of potential ultimate subsidence of an area where the

local confined aquifer system has not yet been stressed. The second technique that will be discussed uses an aquitard drainage model. In contrast to the depth-porosity model, this second technique requires compressible beds to be stressed in the field. It is sufficiently sophisticated not to require laboratory tests on soil specimens. Neither the depth-porosity model nor the aquitard-drainage model requires laboratory tests; each uses its own independent field-based method for parameter evaluation.

HENRY, A. L., and L. L. Schwartz, Earth Sciences Division Collected Abstracts--1979, Lawrence Livermore National Laboratory, Rept. UCRL-52906 (1980).

This report is a compilation of abstracts of papers, internal reports, and talks presented during 1979 at national and international meetings by members of the Earth Sciences Division, Lawrence Livermore Laboratory. The arrangement is alphabetical (by author). For a given report, a bibliographic reference appears under the name of each coauthor, but the abstract itself is given only under the name of the first author (indicated in capital letters) or the first Earth Sciences Division author.

A topical index at the end of the report provides useful cross references, while indicating major areas of research interest in the Earth Sciences Division

HEUZE, F. E., and T. G. Barbour, New Models for Rock Joints and Interfaces, Lawrence Livermore National Laboratory, Rept. UCRL-85222, Preprint (1980).

This paper presents two new developments and refinements in the modeling of rock structure: a new model for axisymmetric interfaces such as found in shaft and footing designs, for example, and a new model for the dilatant effects of rock joints, such as encountered in underground caverns and reinforced rock slopes. The new models were incorporated into a finite element program, and test-case analyses were performed. The results indicate that the use of the new model can lead to safer estimates of footing settlements and shaft lining stresses, as well as to more economical design of rock reinforcement. We also note that, because the new dilatant joint provides a refined estimate of joint opening and closing, it can be applied as well to the analysis of hard rock hydraulics, in which the flow is very sensitive to fracture aperture.

HEUZE, F. E., W. C. Patrick, R. V. De La Cruz, and C. F. Voss, In-Situ Geomechanics, Climax Granite, Nevada Test Site, Lawrence Livermore National Laboratory, Rept. UCRL-85308, Preprint (1980).

The in-situ modulus of the Climax Granite, in the Spent Fuel Test (SFT-C) area of the Nevada Test Site, was estimated, using six different approaches. A best estimate of $E_f = 26$ GPa was obtained from the comparison between the various approaches. The best estimate of laboratory modulus obtained in comparing three different sources was $E_l = 70$ GPa. Thus, the modulus reduction factor for the Climax granite appears to be $E_f/E_l = 0.37$. In turn, the estimate of in-situ rock mass deformability was used to back-calculate in-situ values for the normal stiffness of the granite joints.

A new analysis of former stress measurements by the U.S. Geological Survey showed that the horizontal stresses in the vicinity of SFT-C vary greatly with azimuth. An unexplained feature of the stresses at SFT-C is the fact that the vertical stress appears to be only 65 to 70 percent of the calculated lithostatic stress. From the three-dimensional stress ellipsoid at mid-length in the tunnels, assuming a plane strain condition, we were able to estimate an in-situ Poisson's ratio of the rock mass as $\nu = 0.246$. Two techniques were applied at Climax in a new attempt to measure the stresses around the heater and canister drifts, the undercoring method and the borehole jack fracturing approach. The former appears to give reasonable estimates of tangential stresses in the roof of the heater drifts. The latter appears to give low results for vertical stresses in the pillars.

Specific recommendations were made for future rock mechanics tests to further characterize the mechanical properties of the Climax granite and the in-situ stresses at SFT-C.

HOWARD, N. W., B. J. Qualheim, G. Hage, M. L. Higuera, G. Pawloski, and C. Bell, The LLL Continental Drilling for Scientific Purposes Data Base: DOE-Funded Drill Holes, Lawrence Livermore National Laboratory, Rept. UCRL-52909 (1980).

The investigation of such topics as deep continental basins and basement structures, as well as studies of the earth's crust in general, are dependent on data from deep holes. An information system has been set up to collect data from existing and proposed deep drilling holes. This report contains such information about holes that have been drilled, or are planned for drilling, with funding from DOE. Parameters of the data base are described; information for DOE-funded holes forms the bulk of the report. Output of data now in the system is available on request.

HOWARD, N. W., Containment Prospectus for the SERPA Event (U), Lawrence Livermore National Laboratory, Rept. KTP 80-17 CFRD (1980).

ISHERWOOD, D., E. Raber, D. Coles, and R. Stone, Program Plan: Field Radionuclide Migration Studies in Climax Granite, Lawrence Livermore National Laboratory, Rept. UCID-18838 (1980).

This program plan describes the field radionuclide migration studies we plan to conduct in the Climax granite at the Nevada Test Site. Laboratory support studies are included to help us understand the geochemical and hydrologic processes involved in the field. The program plan begins with background information (Section 1) on how this program fits into the National Waste Terminal Storage Program Plan and discusses the needs for field studies of this type. The objectives stated in Section 2 are in direct response to these needs, particularly the need to determine whether laboratory studies accurately reflect actual field conditions and the need for field testing to provide a data base for verification of hydrologic and mass transport models. The technical scope (Section 3) provides a work breakdown structure that integrates the various activities and establishes a base for the technical approach described in Section 4. Our approach combines an interactive system

of field and laboratory migration experiments with the use of hydrologic models for pre-test predictions and data interpretation. Section 5 on program interfaces identifies how information will be transferred to other related DOE projects. A schedule of activities and major milestones (Section 6) and the budget necessary to meet the project objectives (Section 7) are included in the program plan. Sections 8 and 9 contain brief descriptions of how the technical and program controls will be established and maintained and an outline of our quality assurance program. This program plan is an initial planning document and provides a general description of activities. An Engineering Test Plan containing detailed experimental test plans, an instrumentation plan, and equipment design drawings will be published as a separate document.

KASAMEYER, P. W., L. W. Younker, and J. M. Hanson, "Age of the Salton Sea Geothermal System as Inferred from the Thermal Data," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20 1980) 12, 458 (1980). [UCRL-85117, Abstract]

A simple horizontal flow model explains many of the geophysical features associated with the Salton Sea Geothermal Field in southern California and allows us to estimate the age of the presently observed hydrothermal system.

Earthquake swarms and the magnetic anomaly are indirect evidence for the igneous activity which is the direct source of heat for the system. Analysis of equilibrium temperature profiles for wells in the field indicates that heat transfer mechanisms can be modeled as a three-zone system. The uppermost zone is a thermal cap, characterized by a high temperature gradient consistent with conduction. Zone 2 is a permeable aquifer, characterized by low thermal gradients. The third zone is an impermeable base. Within the aquifer, vertical permeability is low and horizontal permeability is high, suggesting that lateral flow of pore fluid in the confined aquifer carries heat away from the inferred zone of intrusion.

An analytic model incorporating these transport mechanisms has been developed. Fundamental components of the model include lateral spreading of hot water beneath an impermeable cap and subsequent conductive heat transfer from the hot fluid through the cap to the surface. Surface gradient and cap temperature profiles are calculated for a range of cap/aquifer thickness ratios and system ages. The system age is estimated by minimizing the variance between the observed surface heat flow data and the model. Within this preferred solution space, models in agreement with the inferred aquifer geometry are identified. Age estimates range from 3500 years to 12000 years, consistent with the hypothesis that the Salton Sea Geothermal Field is a very young system.

Kasameyer, P., L. YOUNKER, and J. Hanson, "Application of Hydrothermal Modeling to the Selection of Deep Drilling Sites in the Salton Sea Geothermal Field," Trans. Am. Geophys. Union 61, 1149 (1980). [UCRL-84961, Abstract]

Kasameyer, P. W., L. W. YOUNKER, and J. D. Tewhey, Geological, Geophysical, and Thermal Characteristics of the Salton Sea Geothermal Field,

California, Lawrence Livermore National Laboratory, Rept. UCRL-84230, Preprint (1980).

Kasameyer, P. W., and J. R. HEARST, Acoustic Logging for Fractures (2nd Chem. Conf. of N. Am. Continent, San Francisco, CA, Aug. 25-28, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83747, Abstract (1980).

Kasameyer, P. W., D. W. CARPENTER, K. P. Puchlik, A. L. Ramirez, J. L. Wagoner, and K. G. Knauss, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume I: Text and Appendices A-E, Lawrence Livermore National Laboratory, Rept. UCRL-53065, Vol. I (1980).

KNAUSS, K. G., and T.-L. Ku, "Desert Varnish: Potential for Age Dating Via Uranium-Series Isotopes," J. Geol. 88, 95-100 (1980). [UCRL-82331, Preprint]

Trace metals and natural radioisotopes are measured in an unusually thick and presumed ancient desert varnish from the Colorado Plateau in Utah. Uranium and thorium concentrations in the sequence: varnish-altered rind-heartrock (Shinarump formation sandstone) indicate that uranium with little accompanying thorium is derived from external sources. The varnish forms a closed system for ^{230}Th and ^{231}Pa with equilibrium values for both $^{230}\text{Th}/^{234}\text{U}$ and $^{231}\text{Pa}/^{235}\text{U}$. Selective leaching of the ferromanganese oxides followed by analysis of both the leachate and silicate residue is proposed to allow age determinations.

KNAUSS, K., Radon-Gas Extraction and Counting System for Analyzing Radon and Radium in Groundwater in Seismically Active Areas, Lawrence Livermore National Laboratory, Rept. UCRL-53088 (1980).

A high concentration of radon in groundwater has attracted recent attention as a precursor of seismic activity. We have constructed a system that extracts and counts radon gas from solid, liquid, and gas samples. The radon is extracted in a closed system onto activated charcoal. The desorbed radon is then measured in a phosphored acrylic cell by scintillation counting of gross alpha radiation. The efficiency of the total system (extraction plus counting) is $\pm 3\%$ or better. Compact design and sturdy construction make the system completely portable and well suited to field operations in remote locations. Results are given for radon and radium in groundwaters in the Livermore area.

Knauss, K., A. F. WHITE, W. S. Baldrige, and T. M. Gerlach, Comparative Assessment of Five Potential Sites for Hydrothermal Magma Systems: Geochemistry, Lawrence Berkeley Laboratory, Rept. LBL-11410 (1980).

The object of the thermal regimes part of the Continental Scientific Drilling Program (CSDP), sponsored by the U.S. Department of Energy (DOE), is

the development of a fundamental understanding of hydrothermal-magma systems through the utilization of drilling to obtain samples, data and to conduct down hole experiments. The rationale and scientific basis for this endeavour has been presented in the NAS/NRC Workshop Report on CSDP (1979). The goals are the understanding of heat and mass transfer within, and between, magma and hydrothermal regimes and the evaluation of hydrothermal-magma systems in space and time. Their attainment rests on the ability to characterize and interpret hydrothermal-magma systems at depth in terms of physical, thermal, mechanical and mineralogical properties. Both dedicated scientific drill holes and add-on experiments in existing drill holes or in holes planned primarily for other purposes can be used in achieving the program goals.

In the CSDP, the effective use of financial and personnel resources will require focusing on a particular subset of a large number of potential hydrothermal magma systems. To accomplish this purpose, an Interlaboratory Working Group (IWP) comprising four DOE laboratories, Lawrence Berkeley Laboratory, Lawrence Livermore National Laboratory, Los Alamos Scientific Laboratory and Sandia Laboratory, was formed to assess various sites in a comparative fashion. IWP has selected five possible sites for detailed and comparative site analysis. These sites are The Geysers-Clear Lake Region, California, Long Valley, California, Rio Grande Rift, New Mexico, Roosevelt Hot Springs, Utah, and Salton Trough, California. The comparative site-assessment document prepared by IWP is divided into sections encompassing geology, geochemistry, geophysics, and heat and mass transport. Each sub-report, issued by an individual laboratory but including contributions by personnel of all laboratories, contains a section A, an introduction and discussion of general scientific questions, and a section B, a review of the information available concerning each site. Section C, which contains specific recommendations on individual sites, is being issued as a separate document.

The following document covers parts A and B of the geochemistry sub-report.

KNAUSS, K. G., and T. L. Steinborn, Review of Geochemical Measurement Techniques for a Nuclear Waste Repository in Bedded Salt, Lawrence Livermore National Laboratory, Rept. UCID-18664 (1980).

A broad, general review is presented of geochemical measurement techniques that can provide data necessary for site selection and repository effectiveness assessment for a radioactive waste repository in bedded salt. The available measurement techniques are organized according to the parameter measured. The list of geochemical parameters includes all those measurable geochemical properties of a sample whose values determine the geochemical characteristics or behavior of the system. For each technique, remarks are made pertaining to the operating principles of the measurement instrument and the purpose for which the technique is used. Attention is drawn to areas where further research and development are needed.

Knauss, K. G., D. W. CARPENTER, K. P. Puchlik, A. L. Ramirez, J. L. Wagoner, and P. W. Kasameyer, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume I: Text and Appendices A-E, Lawrence Livermore National Laboratory, Rept., UCRL-53065, Vol. I (1980).

KUSUBOV, A. S., and R. P. Swift, "Rock Fracture at Intermediate Loading Rates," Trans. Am. Geophys. Union 61, 373 (1980). [UCRL-84033, Abstract]

Laboratory conditions have been identified to initiate and sustain multiple fractures in a rock similar to the tight low permeable beds containing natural gas and oil. Experiments were conducted in 13-cm diameter by 15-cm long cylinders of Nugget sandstone, and the fractures were generated by compressing water with a piston in a 1.4-cm diameter borehole. The investigated pressure range was from 15-70 MPa with loading rates varying from 0.2-80 MPa/ms. Preliminary results indicate that 60-MPa input pressure pulses with loading rates of 60 MPa/ms are most effective in generating multiple fractures without splitting the sample. Pressures measured in the borehole were on the order of 10 MPa less than the input pressures, possibly, due to borehole expansion and transient water intrusion in the rock sample. Input pressure pulses in excess of 70 MPa with loading rates of 60 MPa/ms as well as input pressure pulses in excess of 50 MPa with loading rates of 15 MPa/ms fracture the rock samples in two while generating only two additional short cracks. Fully saturating the rock samples with water prior to loading had little effect on the crack formation.

KUSUBOV, A. S., W. B. Durham, R. N. Schock, J. F. Schatz, and T. J. Ahrens, "Explosive-Induced Damage in Porous Sandstone," in High Pressure Science and Technology Vol. 2, B. Vodar and Ph. Marteau, Eds. (Pergamon Press, Oxford, 1980), pp. 917-923. [UCRL-83448, Preprint]

We have conducted a combined laboratory and computational effort to study the effect of overburden pressures on explosively damaged porous sandstone. We found that it was difficult to establish a dependence on confining pressure. The predominant effect of the explosion was compaction around the cavity, and macroscopic fractures were conspicuously absent.

Kusubov, A. S., and R. P. SWIFT, "Technique for Studying Multiple Fractures Produced at Intermediate Loading Rates," The State of the Art in Rock Mechanics, Proc. 21st U.S. Sympos. Rock Mechanics (Rolla, MO, May 28-30, 1980), pp. 682-690. [UCRL-83653, Preprint]

LARSON, D. B., and G. D. Anderson, "Plane Shock Wave Studies of Westerly Granite and Nugget Sandstone," Int. J. Rock Mech. Min. Sci. & Geomech. Abst. 17, 357-363 (1980). [UCRL-82264, Preprint]

Plane shock wave experiments were performed by using a light-gas gun on dry and water-saturated Westerly granite and dry Nugget sandstone. Changes in the slopes of the shock velocity versus particle velocity curves at 2 to 3 GPa and 1 to 2 GPa for dry granite and for dry sandstone, respectively, are attributed to the onset of pore collapse. However, there is little apparent loss of shear strength in either dry rock over the stress range of the experiments (i.e., 9.3 GPa in Westerly granite and 9.2 GPa in Nugget sandstone). Agreement between the shock wave data and quasistatic, uniaxial strain data for the dry rocks implies the absence of rate-dependence in uniaxial strain. The shock data on saturated granite agree well with those

for dry granite, thus suggesting there was no loss in shear strength as a result of pore pressure buildup.

LARSON, D. B., Studies of Seismic Source Decoupling Using Scale Model Experiments (Am. Geophys. Union, Toronto, Ontario, May 22-27, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83996, Abstract (1980).

Experimental free-field measurements, made in a variety of scale-model experiments in NaCl, are being analyzed to provide a better understanding of the processes involved in cavity decoupling. The available data are being transformed to reduced velocity potential in the frequency domain for convenience in making comparison. The results from small-scale experiments using LX04 explosive as the energy source are compared with results from the Cowboy series of field tests using pelletized TNT and with the Salmon and Sterling experiments using nuclear explosives. These experimental results are also compared with simple elastic theory and show significant deviations from the predictions of that theory.

LARSON, D. B., Experimental Studies of Cavity Decoupling Using Chemical Explosives (Am. Phys. Soc., Washington, DC, April 21-24, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83786, Abstract (1980).

We are using scale-model experiments with chemical explosives in NaCl to study cavity decoupling. This approach is based upon our observation that shock-wave effects follow simple cube root scaling in NaCl. Our objective in this research is to find the yield-decoupling factor and how it changes with frequency. To provide the data necessary for our analysis, we are using in-material particle velocity gauges as our diagnostic system. To get yield-decoupling data, we are performing small-scale experiments to (a) determine the effect of cavity size, (b) determine the effect of overburden pressure, (c) compare results from mined and explosively formed cavities, and (d) determine the effect of non-spherical cavities.

LEWIS, A. E., "Oil Shale: A Framework for Development," 13th Oil Shale Sympos. Proc. (Golden, CO, April 16-18, 1980), pp. 232-237. [UCRL-83738, Preprint]

The price escalation of petroleum in recent times has removed the economic barrier to shale oil production, or soon will. A technological base for production is available which can be rapidly developed to the size and quality needed. The resource base in the Piceance Creek Basin of Colorado can support production of 1 to 5 million barrels of oil per day for hundreds of years.

Institutional problems are the major remaining impediment to the development of oil shale. The small part of the resource in private hands is economically marginal and cannot support large production rates or the most efficient methods. The best land is owned by the Federal Government and is unavailable under present laws and policies. The lack of an integrated federal policy and an implementation plan prevents the development that is now technically and economically practical.

One possible solution is a Piceance Basin Authority chartered by Congress to efficiently manage this resource and coordinate the federal governmental

responsibility for oil shale resource development and conservation, water development, environmental control, and land use policy. It should be located in Colorado for an effective interaction with State and local authorities where both have responsibility.

Government lands must be made accessible on a scale suitable to the technology and in a way that is acceptable to the public and to industry. Government and industry can then cooperate in a unitized, coordinated development of the resource and the area. With access to the resource and a clear government responsibility for area-wide, non-commercial planning and development, industry can provide the technology and capital for production and marketing of shale oil on an economically competitive basis.

I believe that we will want production from oil shale soon, and for a long time to come. Now is the time to establish the objectives and the institutional framework necessary for both commercial production and non-commercial area development.

LEWIS, A. E., and R. L. Braun, "Retorting and Combustion Processes in Surface Oil-Shale Retorts," 15th Intersoc. Energy Conversion Eng. Conf. Proc. (Seattle, WA, Aug. 18-22, 1980), pp. 297-304. [UCRL-83788, Abstract]

The Lawrence Livermore Laboratory mathematical model for a batch oil-shale retorting process has proved useful in understanding in situ retorting in a bed of oil-shale rubble. An improved level of understanding of the physical and chemical processes has been obtained in recent years and provides the basis for the model. This model has been modified to calculate the retorting of shale moving through a retort as required for a continuous process in surface equipment.

Calculations were made in which the retorting process that releases oil from the raw shale is physically separated from the combustion process that recovers energy from the spent shale by burning the residual carbon. Calculations were also made for the retorting and combustion processes combined in one unit. Results of the calculations illustrate the advantages and disadvantages of inert gas and combustion retorts. Temperature control and the efficient use of energy from the nonliquid products of pyrolysis are key problems in surface retorting processes. The quantity of gas produced by combustion of char with air is insufficient to retort shale without large temperature gradients. Steep temperature gradients, in turn, may result in difficulty in controlling temperature and in loss of oil yield. We believe that application of this model can contribute to improvements in surface processing.

LIN, W., Parametric Analyses of the Transient Method of Measuring Permeability, Lawrence Livermore National Laboratory, Rept. UCRL-84290, Preprint (1980).

Numerical calculations are made to compare the permeability determined by the simplified transient method with a more general numerical approach to the transient method. The simplified method sometimes gives a permeability greater than the numerical method. The difference in apparent permeability between the two depends on the porosity, compressibility, and size of the rock sample used in the experiment.

Lin, W., C. CHU, and C. Wang, "Strength of Saturated Clayey Gouge, Its Dependence on Strain Rate and Permeability," Trans. Am. Geophys. Union 61, 1120 (1980).

The behavior of active faults is thought to be controlled in part by the mechanical properties of fault gouge. Experiments on clayey gouge in rock joints to approximate natural faults have been carried out under 2-kb confining pressure to determine the relationship between shear strength, strain rates, and drainage conditions. Permeability of clayey gouge is determined at pressures up to 250 bar. Experimental results show that (1) at a given loading rate, a thinner clayey gouge sample is stronger than a thicker one; (2) in experiments in which drainage conditions vary, better drained samples support greater deviatoric stresses; and (3) permeability decreases with pressure, reaching 0.1 nino-darcy at about 250 bar.

In order to explain the differences in shear strength, numerical analysis based on a one-dimensional consolidation model is used to estimate the pore pressure in the clayey gouge as a function of loading rate and drainage condition. The observed differences in shear strength are interpreted in terms of the excess pore pressures generated in the clayey gouge under different loading rates and drainage conditions.

LIN, W., Mechanical Behavior of Mesaverde Shale and Sandstone at High Pressure, Lawrence Livermore National Laboratory, Rept. UCRL-84994, Abstract (1980).

Prediction of the effects of hydraulic or high explosive fracturing for the stimulation of fluid recovery from low permeability rocks requires a fracture model and certain mechanical properties for input to the calculation codes. For such a study on the Western tight-gas-sands, we report here new rock mechanics measurements taken on Mesaverde shale (source rock) and sandstone (reservoir rock) from about 350-m depth (Colorado) and 1600-m depth (Wyoming). For each sandstone and shale, we have determined (1) the tensile strength parallel and perpendicular to bedding, 0.1-MPa pressure; (2) the uniaxial stress failure envelope in compression to 300-MPa confining pressure, parallel and perpendicular to bedding; and (3) the pressure-volume behaviors to 1.2 GPa.

The results for (1) indicate, in general, the tensile strength of Wyoming sandstone is about three times that of Colorado sandstone. For both sandstones, the tensile strength is isotropic with respect to bedding. The tensile strength of both shales (perpendicular to bedding) is about 30-50% greater than that measured parallel to bedding. The shale from Wyoming has a tensile strength about 25-50% greater than that from Colorado.

Strengths and failure modes in compression (2) show that the transition between brittle failure and ductile deformation occurs at a confining pressure of about 0.1 GPa for the Colorado sandstone, 0.25 GPa for all other rocks tested. No significant anisotropy in compressive strength is observed for these rocks except the Colorado shale. Colorado shale has about 40-50% strength anisotropy with loading perpendicular to bedding stronger than that parallel to bedding. However, the inhomogeneity of this rock may affect the measured strength anisotropy. The relative strengths of these rocks are that in Colorado the shale is about 50-70% stronger than the sandstone, the Wyoming sandstone is about 50% stronger than that from Colorado, and the Wyoming shale is about 20-30% stronger than that from Colorado.

Pressure-volume (3) loading indicates that $-V/V_0$ at 1.2 GPa for the sandstone from Colorado is about 6-7%; for the other rocks tested, it is about 3-4%.

LIN, W., and C. Wang, "P-Wave Velocities in Rocks at High Pressure and Temperature and the Constitution of the Central California Crust," J. R. astr. Soc. 61, 379-400 (1980). [UCRL-81249, Preprint]

Velocities of compressional waves are determined for central California rocks at pressures up to 0.7 GPa (7 kb) and temperatures up to 450°C. These data are used to interpret the seismic velocity structure of the crust in the California Coast Ranges. The seismic data on both sides of the San Andreas fault are consistent with the following model; besides some patches of surface sediments, the upper 10-15 km of the crust on the north-east side consists predominantly of sedimentary and metasedimentary rocks of the Franciscan assemblage; the lower crust, of a thickness of 15-20 km, may be composed of gabbroic or other mafic rocks. Across the fault on the south-west side, the entire crustal section is probably a granitic complex similar to that exposed on the surface. The proposed model is shown to be consistent with the observed gravity anomaly.

Lin, W., M. E. HANSON, G. D. Anderson, R. J. Shaffer, D. F. Towse, L. D. Thorson, and M. P. Cleary, LLL Gas Stimulation Program Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, Rept. UCRL-50036-79-4 (1980).

Lin, W., M. E. HANSON, G. D. Anderson, R. J. Shaffer, D. F. Towse, M. P. Cleary, D. R. Peterson, S. K. Wong, and B. C. Haimson, LLNL Gas Stimulation Program Quarterly Progress Report, January Through March 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50036-80-1 (1980).

Lin, W., and H. C. HEARD, "Mechanical Behavior of Devonian Shale at High Pressure," Soc. Exploration Geophys. Tech. Prog. (Houston, TX, Nov. 19, 1980), p. 50. [UCRL-83793, Abstract]

MALLON, R. G., Economics of Shale Oil Production by Radio Frequency Heating, Lawrence Livermore National Laboratory, Rept. UCRL-52942 (1980).

A conceptual facility for the production of shale oil by radio frequency (RF) heating has been designed to evaluate the economic feasibility of this technique. In the proposed procedure, the shale is processed in situ without being rubble or explosively fractured. Metal electrodes inserted in a set of vertical drill holes are energized by a group of RF oscillators. The holes bound a block of shale that is to be retorted. The electric field is developed in such a way that heating within the block is almost uniform, and heating outside the block is very low. Retorting of the shale results in a pressure buildup of the hydrocarbon fluids. The oil and gas move horizontally (parallel to bedding planes), then down the electrode holes to a collection

manifold. The facility schedule is planned so that off-peak electric power from existing generating stations can be used to operate the oscillators. Thus, the cost of power and the capital requirements for the facility are held to a minimum. Oil production costs and capital requirements indicate that the proposed procedure is economically attractive. The two principal costs are purchase of electric power, and mining operations. The largest capital requirement is oscillators and associated electrical equipment.

Mallon, R. G., R. L. BRAUN, and H. Y. Sohn, Analysis of Multiple Gas-Solid Reactions During the Gasification of Char in Oil Shale Blocks, Lawrence Livermore National Laboratory, Rept. UCRL-85279, Preprint (1980).

MAO, N., and A. Ramirez, New Developments in Measurements Technology Relevant to the Studies of Deep Geological Repositories in Bedded Salt, Lawrence Livermore National Laboratory, Rept. UCID-18687 (1980).

This report presents new developments in measurement technology relevant to the studies of deep geological repositories for nuclear waste disposal during all phases of development, i.e., site selection, site characterization, construction, operation, and decommission. Emphasis has been placed on geophysics and geotechnics with special attention to those techniques applicable to bedded salt. The techniques are grouped into sections as follows: tectonic environment, state of stress, subsurface structures, fractures, stress changes, deformation, thermal properties, fluid transport properties, and other approaches.

Several areas that merit further research and development are identified. These areas are in-situ thermal measurement techniques, fracture detection and characterization, in-situ stress measurements, and creep behavior. The available instrumentation should generally be improved to have better resolution and accuracy, enhanced instrument survivability, and reliability for extended time periods in a hostile environment.

Mao, N., and C. WANG, "Mechanical Properties of Clays at High Pressure," J. Geophys. Res. 85, 1462-1468 (1980).

The mechanical properties of pre-consolidated clays are studied at high pressures under undrained, triaxial conditions. At confining pressures equivalent to those at midcrust, different clays have the following common characteristics which differ significantly from those at low pressures: (1) the clays possess significant strength of several hundred bars (10 bars = 1 MPa); (2) the constitutive relations are marked by ductile yielding and strain hardening, followed by a broad peak strength and a gradual decrease in strength at greater deformation; and (3) the change in volume during shearing is small. On the other hand, the behavior of montmorillonite differs from that of the other clays (illite, chlorite, and kaolinite) in the following ways: (1) its peak strength at a given confining pressure is about half of the strengths of the other clays; (2) its peak strength occurs at a shortening of 20-25% (for 30% shortening); and (3) the fracture surfaces of some montmorillonite samples deformed at relatively low confining pressures show features resembling those in natural clayey fault gouge, whereas at higher

confining pressures, montmorillonite and the other clays remain unfractured at shortening up to 30-40%.

Mao, N., and J. V. CANDY, Site Characterization: A Spatial Estimation Approach, Lawrence Livermore National Laboratory, Rept. UCID-18688 (1980).

In this report we consider the application of spatial estimation techniques or kriging to groundwater aquifers and geological borehole data. We investigate the adequacy of these techniques to reliably develop contour maps from various data sets.

The estimator is developed theoretically in a simplified fashion using vector-matrix calculus. The practice of spatial estimation is discussed and the estimator is then applied to two groundwater aquifer systems and used also to investigate geological formations from borehole data. It is shown that the estimator can provide reasonable results when designed properly.

Mao, N., and J. V. CANDY, Nuclear Waste Repository Characterization: A Spatial Estimation/Identification Approach, Lawrence Livermore National Laboratory, Rept. UCRL-84163, Preprint (1980).

In this paper we consider the application of spatial estimation techniques or kriging to a groundwater aquifer and geological borehole data. We investigate the adequacy of these techniques to reliably develop contour maps from various data sets.

The estimator is developed theoretically in a simplified fashion using vector-matrix calculus. The practice of spatial estimation is discussed and the estimator is then applied to a groundwater aquifer system and a deep geological formation. It is shown that the various statistical models must first be identified from the data and evaluated before reasonable results can be expected.

Mao, N., and A. L. RAMIREZ, New Developments in Measurement Technology Relevant to the Studies of Deep Geological Repositories in Domed Salt and Basalt, Lawrence Livermore National Laboratory, Rept. UCRL-52747 (1980).

MCKAGUE, H. L., Summary of Measured Medium Properties of Paleozoic Rocks at the DOE Nevada Test Site, Lawrence Livermore National Laboratory, Rept. UCRL-52884 (1980).

Selected measurements of the bulk density, grain density, sonic velocity, water content, porosity, and saturation of Paleozoic rocks beneath Yucca Flat have been compiled. The bulk density and sonic velocity data show these measurements to be within the range established by similar measurements in other areas. Comparisons with values used in TENSOR calculations suggest that the values used in most calculations are sufficiently conservative for containment evaluation.

MILLER, D. G., J. A. Rard, L. B. Eppstein, and R. A. Robinson, "Mutual Diffusion Coefficients, Electrical Conductances, Osmotic Coefficients, and

Ionic Transport Coefficients l_{ij} for Aqueous CuSO_4 at 25°C ," J. Solu. Chem. 9, 467-496 (1980). [UCRL-83465, Preprint]

Experimental thermodynamic and transport data are presented for aqueous CuSO_4 solutions at 25°C from low concentrations to near saturation. Included are diffusion coefficients (Rayleigh interferometry), electrical conductances (DC method), and osmotic coefficients (isopiestic). These data and corresponding literature data are critically compared, as are literature density data. The resulting best values, together with previously compared transference number results, provide an extensive set of critically reviewed data for aqueous CuSO_4 . Onsager coefficients l_{ij} have been calculated for this salt and are compared with data for other valence types.

MILLER, D. G., Explicit Relations of Velocity Correlation Coefficients to Onsager l_{ij} 's to Experimental Quantities, and to Infinite Dilution Limiting Laws for Binary Electrolyte Solutions, Lawrence Livermore National Laboratory, Rept. UCRL-84940, Preprint (1980).

The relation of velocity correlation coefficients (f_{ij}) to the Onsager formalism of irreversible thermodynamics is considered for a binary electrolyte. Explicit expressions are derived relating Woolf-Harris f_{ij} (1) to solvent-fixed Onsager l_{ij} , (2) to experimental quantities, and (3) to dilute solution limiting laws. The f_{ij} equations are more complex than l_{ij} equations. Since velocity correlation integrals are the theoretical basis for f_{ij} , limiting law expressions are used to investigate the behavior of these integrals at infinite dilution. All ion-ion integrals become infinite there. This implies that direct computer simulations may not be possible, and that some other correlation function approach may be more suitable for the electrolyte problem.

MILLER, D. G., Electrolytes: Transport Properties and Non-Equilibrium Thermodynamics, Lawrence Livermore National Laboratory, Rept. UCRL-85232, Preprint (1980).

This paper will briefly review (1) the application of non-equilibrium thermodynamics to transport in electrolyte solutions, and (2) some recent experimental work and results for mutual diffusion in electrolyte solutions.

Miller, D. G., L. W. BARR, and R. Mills, "Tracer (Self)-Diffusion of Potassium Ion in $\text{NaCl-KCl-H}_2\text{O}$ Mixtures at 25°C ," J. Solu. Chem. 9, 75-80 (1980).

Tracer (self)-diffusion coefficients of K^+ have been measured using the diaphragm cell in seven compositions of the $\text{NaCl-KCl-H}_2\text{O}$ system. These data complete the full set of isothermal vector transport properties for five of these compositions.

Miller, D. G., and J. G. ALBRIGHT, "Analysis of Gouy Interference Patterns from Binary Free-Diffusion Systems When the Diffusion Coefficient and Refractive Index Have $C^{1/2}$ and $C^{3/2}$ Terms, Respectively," J. Phys. Chem. 84, 1400-1413 (1980). [UCRL-83501, Preprint]

Gouy fringe patterns are treated by numerical integration and analytical techniques for binary electrolyte systems whose diffusion coefficients D and refractive indices n have concentration dependences including $1/2$ and $3/2$ powers. If one initial solution is pure water, skewing from the ideal case (constant D , linear n) is substantial; correction factors are large; and no averages of experimental quantities will yield $D(\bar{C})$. Refractive-index effects were much larger than expected. Analytical results include extension of the Gosting-Fujita theory to yield fringe positions and proof that $f(\zeta)^{2/3}$ is a proper extrapolation function to get D_A . Numerical integration results show (1) that the Gosting-Onsager theory for ideal systems is better than previously believed at high fringe numbers or low total number of fringes, (2) that masks are more important than previously assumed, and (3) that calculated corrections to experimental quantities can be least squared successfully in terms of variables suggested by the analytical theory. As $\bar{C}/(\Delta C/2)$ increases (C_0 moves away from infinite dilution), analytical results approach the numerical values. Proper analyses of dilute electrolyte data require several experiments to obtain the concentration-dependent correction factors. Examples for KCl and $CaCl_2$ are given.

Miller, D. G., and A. B. BAILEY, Technique for the Evaluation of Wall Interference at Transonic Speeds, Lawrence Livermore National Laboratory, Rept. UCRL-84453, Preprint (1980).

Wall effects and condensation effects on the measurement of aerodynamic data in cryogenic and other transonic wind tunnels can be evaluated using existing free-flight sphere drag data. New measurements at higher Reynolds numbers would be desirable.

Miller, D. G., and J. A. RARD, "Mutual Diffusion Coefficients of $BaCl_2$ - H_2O and KCl - H_2O at $25^\circ C$ from Rayleigh Interferometry," J. Chem. & Eng. Data **25**, 211-215 (1980). [UCRL-83065, Preprint]

Miller, D. G., and J. A. RARD, Isopiestic Determination of the Osmotic Coefficients of Aqueous Na_2SO_4 , $MgSO_4$, and Na_2SO_4 - $MgSO_4$ at $25^\circ C$, Lawrence Livermore National Laboratory, Rept. UCRL-84238, Preprint (1980).

Miller, D. G., and J. A. RARD, Isopiestic Determination of the Osmotic and Activity Coefficients of Aqueous $MgCl_2$ Solutions at $25^\circ C$, Lawrence Livermore National Laboratory, Rept. UCRL-84462, Preprint (1980).

MILLS, J. M., Jr., F. E. Followill, and R. F. Rohrer, Locations and Mechanisms for Aftershocks of the January, 1980, Livermore, California, Earthquake Sequence (Am. Geophys. Union, Toronto, Ontario, May 21, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85306, Abstract (1980).

The principal shocks and aftershocks of the January, 1980, Livermore, California, earthquake sequence appear to be clustered into at least three

epicentral regions. Permanent and portable three-component digital seismic stations provided horizontal and vertical ground motion data for P- and S-waveforms. The focal mechanism of this sequence indicate predominantly strike-slip motion. Relocation of these events indicates activity on more than one fault during the first few weeks following the principal earthquakes.

MILLS, J. M., Jr., and F. E. Followill, "Microearthquakes in the Livermore Valley," in Energy and Technology Review, Lawrence Livermore National Laboratory, Rept. UCRL-52000-80-2 (1980), pp. 1-9.

Data on hundreds of microearthquakes that have occurred locally since January 1980 have enabled us to construct a tectonic model of the Livermore Valley.

In January 1980, only a few months after our Livermore Valley seismic network went into operation, two damaging earthquakes occurred. We immediately augmented the network (which had been installed as a supplement to the central California seismic network) with additional permanent and temporary seismic stations to improve our ability to determine the depth and location of the swarms of small earthquakes expected to follow. Between January and September of 1980, we recorded hundreds of microearthquakes (too small to be felt), ranging in magnitude from 1 to 3 on Richter's local magnitude scale. By analyzing the locations, magnitudes, and focal mechanisms of these microearthquakes, we have been able to identify various source regions in the Livermore Valley and to characterize the pattern of seismic activity in each.

MONTAN, D. N., Thermal Analysis for a Spent Reactor Fuel Storage Test in Granite (Int. Sympos. Sci. Basis Nucl. Waste Management, Boston, MA, Nov. 16-20 (1980), Lawrence Livermore National Laboratory, Rept. UCRL-83995, Preprint (1980).

The Lawrence Livermore Laboratory is conducting a test in which spent fuel assemblies from an operating commercial nuclear power reactor are emplaced in the Climax granite at the U.S. Department of Energy's Nevada Test Site. In this generic test, eleven canisters of spent PWR fuel are emplaced vertically along with six electrical simulator canisters on 3-m centers, 4 m below the floor of a storage drift which is 420 m below the surface. Two adjacent parallel drifts contain electrical heaters, operated to simulate (in the vicinity of the storage drift) the temperature fields of a large repository. This test, planned for up to five years duration, uses fairly young fuel (~2.5 years out of core) so that the thermal peak will occur during the time frame of the test and will not exceed the peak that would not occur until ~40 years of storage had older fuel (5-15 years out of core) been used.

This paper describes (briefly) the calculational techniques and summarizes (in more detail) the results of a large number of thermal calculations used in the concept, basic design, and final design of the spent fuel test. The calculational techniques ranged from simple analytic solutions of the diffusion equation through rather extensive superposition of analytic solutions, to detailed 2- and 3-dimensional finite-difference calculations in which the canisters, the storage holes, the storage hole liners, various shield plugs, and the drifts, with transport including thermal radiation, natural convection, and forced ventilation through the drifts could be properly modeled. The

results of the preliminary calculations show the effects of spacing and spent fuel age. The more detailed finite-difference calculations show a number of interesting results. Either radiation or convection is sufficient to make the drifts much better thermal conductors than the rock that was removed to create them. The combination of radiation and convection causes the drift surfaces to be nearly isothermal even through the heat source is below the floor. With a nominal ventilation rate of $2 \text{ m}^3/\text{s}$ and an ambient rock temperature of 230°C , the maximum calculated rock temperature (near the center of the heat source) is about 1000°C while the maximum air temperature in the drift is around 400°C . This ventilation ($1 \text{ m}^3/\text{s}$ through the main drift and $1/2 \text{ m}^3/\text{s}$ through each of the side drifts) will remove about one-third of the heat generated during the first five years of storage.

Montan, D. N., R. C. CARLSON, W. C. Patrick, D. G. Wilder, W. G. Brough, P. Harben, L. B. Ballou, and H. C. Heard, Spent Fuel Test-Climax: Technical Measurements Interim Report FY 1980, Lawrence Livermore National Laboratory, Rept. UCRL-53064 (1980).

Moran, B., W. G. HOOVER, D. J. Evans, R. B. Hickman, A. J. C. Ladd, and W. T. Ashurst, "Lennard-Jones Triple-Point Bulk and Shear Viscosities, Green-Kubo Theory, Hamiltonian Mechanics, and Nonequilibrium Molecular Dynamics," Phys. Rev. A **22**, 1690-1697 (1980).

A new Hamiltonian method for deformation simulations is related to the Green-Kubo fluctuation theory through perturbation theory and linear-response theory. Numerical results for the bulk and shear viscosity coefficients are compared to corresponding Green-Kubo calculations. Both viscosity coefficients depend similarly on frequency, in a way consistent with enhanced "long-time tails."

Moran, B., W. G. HOOVER, and J. Levatin, "A Probability Problem," J. Recreational Math. **13**, 225 (1980).

A gambling casino in Puerto Rico wishes to start an "almost fair" game with a set of identical six-sided dice. The house throws N dice and bets that each number from 1 to 6 will be represented at least once.

- a. What is the smallest number of dice which will give the house a winning percentage at even odds?
- b. What is the probability, as a function of N , that the house will win on a single throw?
- c. What is the smallest number of 16-sided dice which will give a probability of greater than .5 that each number from 1 to 16 will appear at least once?
- d. (By the Editor) How does one construct a fair 16-sided die?

Moran, B., B. L. HOLIAN, W. G. Hoover, and G. K. Straub, "Shock-Wave Structure Via Nonequilibrium Molecular Dynamics and Navier-Stokes Continuum Mechanics," Phys. Rev. A **22**, 2798-2808 (1980). [UCRL-84314, Preprint]

A strong steady dense-fluid shock wave is simulated with 4800-atom nonequilibrium molecular dynamics. The resulting density, stress, energy, and temperature profiles are compared with corresponding macroscopic profiles we derive from Navier-Stokes continuum mechanics. The differences found are relatively small.

Moreno, L., J. B. BRYAN, D. E. Burton, L. A. Lettis, and A. L. Bruce, Excavation of a Qattara Canal in Egypt: Two-Dimensional Nuclear Cratering Calculations, Lawrence Livermore National Laboratory, Rept. UCID-18535 (1980).

Moreno, L. R., R. P. SWIFT, and D. E. Burton, Calculations of the Stemming and Containment Phenomenology for the Hybla Fair Event (U), Lawrence Livermore National Laboratory, Rept. UCRL-52998 CFRD (1980).

Moreno, L. R., H. D. GLENN, R. W. Terhune, and J. B. Bryan, Destruction of the Peninsula Device (U), Lawrence Livermore National Laboratory, Rept. UCID-18511 CFRD (1980).

MORRISON, F. A., JR., and S. K. Griffiths, On the Transient Convective Transport from a Body of Arbitrary Shape, Lawrence Livermore National Laboratory, UCRL-84323, Preprint (1980).

The net rate of transient convective heat transfer from a body at uniform temperature in steady flow is shown to be invariant to pointwise reversal of the flow. Such reversal is physically possible in both creeping and potential flows. Creeping flow and the unseparated potential flow of a low Prandtl number fluid yield physically important transfer problems. Additionally, the theorem is applicable to problems for which flow reversal has no physical significance; numerical reversal of any incompressible streaming flow will leave the net transfer rate unchanged. The proof is not based on symmetry and places no restriction on the shape of the body. It remains valid over the entire range of Reynolds and Peclet numbers even though local transfer rates may differ significantly in the two directions of flow. The theorem applies to the analogous mass transport and is generalized to include a homogeneous first order reaction decreasing the concentration.

MORRISON, F. A., JR., Unsteady Transport from a Drop in Axisymmetric Straining Flow, Lawrence Livermore National Laboratory, Rept. UCRL-84324, Preprint (1980).

In order to understand heat and mass transfer from bodies in nonuniform flows, considerable theoretical interest is currently directed at transport in straining flows. While most of the studies to date treat rigid bodies, Gupalo and Riazantsev analyzed transport from a spherical drop. In particular, they treated the steady high Peclet number transport outside a drop in axisymmetric creeping straining flow, finding that the Nusselt number is proportional to the square root of the Peclet number. This note describes the more general case of transient transport with resistance both inside and outside the drop.

MURRAY, W. A., Permeability Testing of Fractures in Climax Stock Granite, NTS (Repos. Sealing Field Testing Workshop, Santa Fe, NM, Sept. 18-19, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85231, Preprint (1980).

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

Murray, W. A., T. R. DONICH, and W. J. O'Connell, Mock Site Radionuclide Transport Assessment, Lawrence Livermore National Laboratory, Rept. UCRL-52718, RW (1980).

A process for selection, characterization, and performance analysis of a mock site for a nuclear waste repository is assessed against the qualitative and quantitative criteria set forth in the NRC draft rule 10CFR60. The performance analysis for long term radionuclide transport from the repository to the accessible environment utilized simplified models of resaturation/repressurization, package breach time, dissolution function, and radionuclide transport in groundwater. The transport model is a series of one-dimensional stream tubes leading from the repository to a discharge point at the ground surface. Model parameters were determined from field or generic data by simplified methods such as contour sketching and flow mass balance. The impact of parameter uncertainties was assessed by a Monte Carlo method. The mock site, located in a sedimentary rock sequence of low permeability at a depth of approximately 350 meters below ground surface, was qualitatively satisfactory for most of the 10CFR60 criteria, but was determined to be unsatisfactory because of economically exploitable resources and extensive borehole exploration in the area. Quantitatively, the overall performance was found to be unsatisfactory because of the short breakthrough times (less than 1000 years) of technetium and iodine to the accessible environment. A nonparametric correlation analysis showed that the parameters for the waste dissolution/leaching rate and canister breach time control the uncertainty in the breakthrough time for these isotopes. For the actinides and most fission products, the regional geologic parameters--retardation factors and effective porosity--were most important.

NAKANISHI, K. K., and H. J. Patton, "Body-Wave Spectral Analysis of Aftershocks of the Mt. Diablo-Greenville Earthquake Sequence January, 1980," Trans. Am. Geophys. Union 61, 294 (1980). [UCRL-84025, Abstract]

We have carried out a spectral analysis on P- and S-waves of selected aftershocks of the Mt. Diablo-Greenville earthquake sequence to measure corner frequencies, low frequency amplitude levels, and high frequency rolloffs. These events were recorded on our three-component short-period digital seismic network operating in the Livermore Valley within 40 km of the epicenters. The

USGS local magnitudes of these events are between 1.2 and 2.7. Preliminary results are that (1) S-wave corner frequencies are higher than P-wave corner frequencies, (2) seismic moments, M_0 , and local magnitudes, M_L , are related by the formula, $\log M_0 = 1.2 M_L + 16.8$, and (3) high frequency rolloff of S-wave spectra varies from -4.5 to -2.2 and appears to be correlated to epicentral distance. These results are discussed with respect to the regional dependence of moment-magnitude relationships and models of earthquake faulting.

NAKANISHI, K., The Effect of Focal Depth and Source Type on Synthetic Crustal Phases (NATO Adv. Study Inst. Ident. Seismic Sources, Oslo, Norway, Sept. 8-18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84886, Abstract (1980).

The effects of different parameters such as focal depth, source type, and source to receiver distance on synthetic crustal phases are investigated by using the summation of P-SV normal modes. A layer ($V_p = 6.1$, $V_s = 3.55$ km/sec, 30 km thick) over halfspace ($V_p = 7.8$, $V_s = 4.5$ km/sec) model is used in which 387 modes are computed for frequencies from D.C. to 1.28 Hz. The model used is non-attenuating and represents the Western U.S. Three different source types are used: an isotropic explosion, a strike-slip on a vertical fault plane earthquake, and a dip slip on a 45° dip fault plane earthquake. The sources are point forces with a step time function and equal long-period moments. Focal depths at 0, 1, 2, 5, 10 and 20 km are considered for source to receiver distances from 150 to 500 km. Displacement time series indicate that P_g and the surface wave train, which is a combination of L_g and R_g , appear as the dominant arrivals. For both the explosion and earthquake sources, P_n does not appear as a significant arrival except for distances greater than 400 km. P_g does not exhibit an obvious amplitude or waveform dependence on focal depth for any source type except for the deepest sources where there may be interference from the surface reflection. The P_g amplitudes are nearly equal for explosions and earthquake sources at all depths. This is in contrast to R_g which has a very strong dependence on focal depth for the explosion and earthquake models. The behavior of L_g is difficult to determine because it has nearly the same group velocity as R_g for this model. As with P_g , L_g does not have a strong focal depth dependence. It also appears that L_g is much more highly excited for earthquake sources than explosions as evidenced by the predominance of high frequencies in the L_g - R_g waveform for earthquakes.

PAGE, L., and H. C. Heard, Elastic Moduli, Thermal Expansion and Inferred Permeability of Climax Quartz Monzonite and Sudbury Gabbro to 500 C and 55 MPa, Lawrence Livermore National Laboratory, Rept. UCRL-85253, Preprint (1980).

Young's modulus (E), bulk modulus (K), and the coefficient of thermal linear expansion (α), have been determined for Climax monzonite to temperatures (T) of 500°C and pressures (P) to 55 MPa and for Sudbury gabbro to 300°C and 55 MPa. Using conventional triaxial apparatus, displacement measurements were made on 9 samples of each rock: 3 samples from each of 3 orthogonal directions. Comparison of directional values at any P , T and those from the 9-sample population indicated that both rocks are isotropic in E , K ,

and α . For each rock, both E and K decreased with T and increased with P in a nonlinear manner. In the monzonite, E and K decreased by up to 60% as P decreased from 55.2 to 6.9 MPa isothermally, while the gabbro indicated a decrease up to 70% over the same pressure range. As T increased isobarically, E and K for the monzonite decreased by up to a factor of $\sim 80\%$ from 19-500°C. The moduli of the gabbro decreased by as much as 70% from 19-300°C.

The values of α for the monzonite increased with T and decreased with P in a nonmonotonic fashion, with most measured values for α greater than values calculated for the crack-free aggregate. Depending on P, α in the monzonite increased from $8-11 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$ at 400 to $22-25 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$ at 475°C. For the gabbro, α also generally decreased with increasing P_0 . Values ranged from $6-11 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$, showing a nonlinear trend and very little net increase over the T range from 19-300°C. Calculated permeability of these rocks based on the α determinations indicated that permeabilities may increase by up to a factor of 3 over the temperature interval 19 to 300°C, and the permeability of the monzonite is inferred to increase by up to a factor of 8 by 500°C. In both rocks, most measurements are consistent with microcracks controlling the thermoelastic response by opening with T and closing with σ and P. Such determinations of E, K, and α are necessary for input to computational models for prediction of the thermomechanical response of a high level radioactive waste repository constructed at depth.

PAGE, L., A. J. Piwinskii, C. Bazan, G. S. Smith, and S. Wootton, Hydrothermal Investigation of SYNROC Formulations from 150 to 610 C at 100-MPa Water Pressure, Lawrence Livermore National Laboratory, Rept. UCID-18873 (1980).

The static leaching behavior of seven formulations of SYNROC and two preparations of hollandite have been investigated under hydrothermal conditions. Each formulation was tested at several times (1 to 60 days) and temperatures (150° to 610°C) at 100-MPa water pressure, using distilled water as the fluid. Both cored and powdered samples were employed in the hydrothermal experiments. Leach rates ($\text{g SYNROC/m}^2 \cdot \text{day}$) were calculated on the basis of element concentrations observed in the leachate. Post-run SEM and XRD observations of some core specimens revealed crystalline precipitates occurring on core surfaces, which we interpreted to be metastable phases and/or precipitates that were formed during quenching. As a result, calculated leach rates based on some elements in the fluid phase are not true leach rates. The temperature dependence of apparent leach rate was erratic. The time dependence of apparent leach rate was consistent and well defined for all SYNROC formulations; it decreased as a function of time. Analysis of hydrothermal results suggests that runs of 30 to 60 days are required to approach, or to attain, steady-state apparent leach rates. Sample form appears to have a demonstrable effect on leaching behavior. For comparable run conditions, powders generally have lower apparent leach rates but have a higher percentage of material leached than cores. The mineral hollandite appears to be very resistant to hydrothermal leaching, with only titanium found in the leachate.

Page, L., and H. C. HEARD, "Thermal Expansion and Elastic Moduli of Westerly and Stripa Granites to 350°C and 55 MPa," Trans. Am. Geophys. Union 61, 1113 (1980). [UCRL-84947, Abstract]

PATRICK, W. C., and W. G. Brough, Response of Borehole Extensometers to Explosively Generated Dynamic Loads, Lawrence Livermore National Laboratory, Rept. UCRL-53087 (1980).

Commercially available hydraulically anchored multiple-point borehole extensometers (MPBX) were evaluated with respect to response to dynamic loads produced by explosions. This study is part of the DOE-funded Spent Fuel Test --Climax (SFT-C) currently being conducted in the Climax granitic stock at the Nevada Test Site. The SFT-C is an investigation of the feasibility of short-term storage and retrieval of spent nuclear reactor fuel assemblies at a plausible repository depth in granitic rock. Eleven spent fuel assemblies are stored at a depth of 420 m for three to five years and will be retrieved. MPBX units are employed in the SFT-C to measure both excavation-induced and thermally induced rock displacements. Long-term extensometer reliability in this hostile environment is essential to obtain valid data during the course of the test.

Research to date conclusively shows that units of this type continue to function reliably although subjected to accelerations of 1.8 g, and implies that they function well although subjected to accelerations in excess of 100 g. MPBX survivability during the first four months (without heat) was about 90 percent.

Patrick, W. C., and D. G. WILDER, Geotechnical Status Report for Test Storage of Spent Reactor Fuel in Climax Granite, Nevada Test Site (Sympos. Geol. Disposal of High-Level Radioactive Wastes, AEG Mtg., Oct. 20, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85096, Abstract (1980).

Patrick, W. C., R. C. CARLSON, D. G. Wilder, W. G. Brough, D. N. Montan, P. Harben, L. B. Ballou, and H. C. Heard, Spent Fuel Test-Climax: Technical Measurements Interim Report FY 1980, Lawrence Livermore National Laboratory, Rept. UCRL-53064 (1980).

Patrick, W. C., F. E. HEUZE, R. De La Cruz, and C. F. Voss, In-Situ Geomechanics, Climax Granite, Nevada Test Site, Lawrence Livermore National Laboratory, Rept. UCRL-85308, Preprint (1980).

Patrick, W., O. R. WALTON, J. Carley, and J. Peterson, DIBS Solid Flow Model (3rd Briefing on Oil Shale Tech. Res., Livermore, CA, Nov. 19-21, 1980), Lawrence Livermore National Laboratory, Misc. Pub.-144 (1980), pp. 6098-6121.

PATTON, H. J., Surface-Wave Generation by Underground Nuclear Explosions Releasing Tectonic Strain, Lawrence Livermore National Laboratory, Rept. UCRL-53062 (1980).

Seismic surface-wave generation by underground nuclear explosions releasing tectonic strain is studied through a series of synthetic radiation-pattern calculations based on the earthquake-trigger model. From

amplitude and phase radiation patterns for 20-s Rayleigh waves, inferences are made about effects on surface-wave magnitude, M_s , and waveform character. The focus of this study is a comparison between two mechanisms of tectonic strain release, strike-slip motion on vertical faults and thrust motion on 45° dipping faults. The results of our calculations show that Rayleigh-wave amplitudes of the dip-slip model at F values between 0.75 and 1.5 are significantly lower than amplitudes of the strike-slip model or of the explosion source alone. This effect translates into M_s values about 0.5 units lower than M_s of the explosion alone. Waveform polarity reversals occur in two of four azimuthal quadrants for the strike-slip model and in all azimuths of the dip-slip-thrust model for F values above about 3. A cursory examination of waveforms from presumed explosions in eastern Kazakhstan suggests that releases of tectonic strain are accompanying the detonation of many of these explosions. Qualitatively, the observations seem to favor the dip-slip-thrust model, which, in the case of a few explosions, must have F values above 3.

PATTON, H. J., "Reference Point Equalization Method for Determining the Source and Path Effects of Surface Waves," J. Geophys. Res. **85**, 821-848 (1980).

A reference point equalization method is presented for the determination of source and propagation effects of surface waves. The method works on seismic events located in a small source region, allowing the assumption that all events share the same path effects to a given receiver. Two steps in the method are initialization and iteration. Initialization obtains the first reference event in order to compute initial estimates of phase velocity and attenuation coefficient. Iteration simultaneously refines the propagation parameters and determines source parameters of new earthquakes. This method was applied to nine earthquakes in the Pamir Mountains, Central Asia (reference point: 39.58°N, 73.55°E).

Source parameters were determined using the linear moment tensor inversion on 26- to 60-s Rayleigh wave complex spectra. It was necessary to modify the straight least squares inversion method because of its sensitivity to even just a few bad data points in the data set. Residuals obtained from repeated application of the moment tensor inversion over trial focal depths showed two minima, one at depths less than 20 km and the other at depths greater than 70 km, with values of the residuals at these minima close enough to cast doubt on the determination of focal depth. The inversion generally gave three-couple force systems having significant nonzero intermediate component. These features of the source parameter inversions are discussed in light of errors in the data set. Propagation parameters, in particular, the phase velocities, show good qualitative correlation with geologic and geographic features on the Eurasian continent.

PATTON, H. J., "Crust and Upper Mantle Structure of the Eurasian Continent from the Phase Velocity and Q of Surface Waves," Rev. Geophys. & Space Phys. **18**, 605-625 (1980).

A review of studies using surface waves to determine crust and upper mantle structures of the Eurasian continent is presented. The results of these studies have assisted in the analysis of a new set of propagation data

for lateral variation of phase velocity and Q on the continent. A Rayleigh wave phase velocity regionalization based on crustal conditions and topography is proposed involving five continental provinces: Indian Shield, Northern Platforms and Shields, Forelands and Coastal Plains, Tectonic, and Plateau. Phase velocities in the Indian Shield are 20% higher than velocities in the Plateau province at 26-s period and 5% higher at 90-s period. Stable platforms of northern Asia have significantly higher phase velocities than those of tectonic provinces out to 150-s period. Shear velocity structures that incorporate published crustal structures and satisfy the regionalized dispersion curves and reported S_n velocities are presented. Surface wave amplitudes are shown to be strongly affected by horizontal refraction, causing focusing of ray paths, defocusing, and multipathing. Three very different average Rayleigh wave Q curves over periods of 25-60s are obtained for stable northern platforms and tectonic provinces east and west of Central Asia. Interpretations of the observations are given in terms of intrinsic Q of the medium. The Q models as well as shear velocity models are discussed in the light of Eurasia's tectonic history.

Patton, H. J., and K. K. NAKANISHI, "Body-Wave Spectral Analysis of Aftershocks of the Mt. Diablo-Greenville Earthquake Sequence," Trans. Am. Geophys. Union 61, 294 (1980). [UCRL-84025, Abstract]

Patton, H. J., and E. S. SCHAFFER, Surface-Wave Study of Secondary Sources of Yucca Valley Underground Explosions (Am. Geophys. Union, San Francisco, CA, Dec. 8-12, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84939, Abstract (1980).

Pawloski, G., N. W. HOWARD, B. J. Qualheim, G. Hage, M. L. Higuera, and C. Bell, The LLL Continental Drilling for Scientific Purposes Data Base: DOE-Funded Drill Holes, Lawrence Livermore National Laboratory, Rept. UCRL-52909 (1980).

PIWINSKII, A. J., and N. D. Stout, "Entropy of Molten SiO_2 , CaSiO_3 , and $\text{CaMgSi}_2\text{O}_6$ at 0.1 MPa to 2600 K," Trans. Am. Geophys. Union 61, 407 (1980). [UCRL-84001, Abstract]

The entropy, S_T - S_{298} , of anhydrous melts of SiO_2 , CaSiO_3 , and $\text{CaMgSi}_2\text{O}_6$, was calculated from enthalpy data which were determined at 0.1 MPa to 2600K using a drop calorimeter. For molten SiO_2 between 1900 and 2600K, S_T - S_{298} (J/g.K) = $1.289 \ln T - 7.34$. For CaSiO_3 liquids from 1850 to 2600K, S_T - S_{298} (J/g.K) = $1.395 \ln T - 7.95$. For molten $\text{CaMgSi}_2\text{O}_6$ between 1695 and 2600K, S_T - S_{298} (J/g.K) = $1.499 \ln T - 8.54$. These new experimental results indicate that assuming entropy additivity can lead to large errors. Using data of Kelley (1960, U.S. Bureau Mines Bull. 584) and JANAF Tables for $\text{SiO}_2(\text{s})$, $\text{CaO}(\text{s})$, and $\text{MgO}(\text{s})$, the calculated (S_T - S_{298}) at 2000K for CaSiO_3 and $\text{CaMgSi}_2\text{O}_6$ by additivity is approximately 28 and 30%, respectively, higher than that obtained from experimental data. Using the Lacy network-forming index R , where $R=O/(\text{Si}+\text{Al})$ and is the ratio of molecular percent of non-bridging oxygens to the network-forming cations, as a

structure-sensitive indicator, these silicate melt entropy data, together with our earlier results on entropies of molten silicate rocks, suggest that a structural change takes place in silicate liquids at $R \approx 2.05$. This may mark the initial breakup of silica-rich networks because of melt depolymerization by network modifying cations. In addition, the new entropy results show no indication of the putative change in the structure of molten CaSiO_3 at approximately 1973K, which was suggested by the viscosity and electrical conductivity results of Bockris and his colleagues.

PIWINSKII, A. J., and H. C. Weed, "Dynamic Viscosity of Some Silicate Melts to 1688°C Under Atmospheric Pressure," Thermochemica Acta 37, 189-195 (1980). [UCRL-83126, Preprint]

The dynamic viscosity of six anhydrous silicate melts, obtained by fusing rocks collected from the Department of Energy's Nevada Test Site, has been measured from 1120 to 1688°C under atmospheric pressure using a rotational cup viscometer of the Couette type. The melts exhibit Newtonian behavior in this temperature interval. Melt viscosities decrease in the order: tuff > alluvium > basalt. Activation energy for viscous flow in the interval 1120-1688°C ranges from 268 to 393 kJ.

Piwinskii, A. J., and R. CONDIT, "Oxygen Grain Boundary Diffusion in Olivine," Am. Ceram. Soc. Bull. 59, 827 (1980). [UCRL-84541, Abstract]

We are measuring oxygen grain boundary diffusion in olivine, $(\text{Mg,Fe})_2\text{SiO}_4$, in order to understand creep in the earth's mantle. Our data, which supplements published bulk diffusion data, employ the oxygen-18 isotope; it is traced along preferred diffusion paths using $^{180}(\text{p,n})^{18}\text{F}$ radioactivation followed by autoradiography.

Piwinskii, A. J., and R. H. CONDIT, "Diffusion in Silicate Minerals," in Advances in Materials Sciences, J. Truhan, R. Hopper, and K. Gordon, Eds., Lawrence Livermore National Laboratory, Rept. UCRL-50058-80-3 (1980), p. 23.

We are working to obtain good measurements of atomic diffusion in selected silicate minerals. These data should help us understand a variety of geological processes such as mantle creep and continental drift, diffusion of radionuclides from radioactive waste disposal sites, and ore formation. The Geosciences Division of DOE Office of Basic Energy Sciences is supporting our research on diffusion in silicate materials. We are cooperating with the Earth Sciences Division at LLNL on this project.

We directed our initial studies to olivine, $[(\text{Mg,Fe})_2\text{SiO}_4]$, which is a major constituent in the earth's mantle and has been studied previously at LLNL. Although good measurements of the electrical conductivity, the iron and oxygen bulk diffusion, and creep of olivine have been measured, oxygen diffusion in grain boundaries and dislocations has not.

We are studying the diffusion of 180 into olivine at high temperatures. We monitor the paths of diffusion by bombarding the specimen with 2.8-MeV protons to convert 180 to ^{18}F , which emits positrons and can be quantified

using photographic film. This autoradiographic technique allows us to handle the tracer as if it were radioactive.

During the last two reporting periods, we annealed specimens in ^{130}Si gas at 1350°C and obtained other specimens run in ^{180}Si . Both types of specimens were activated in the LLNL Tandem accelerator and Van de Graaff generator. The activation experiments showed grain-boundary diffusion of oxygen, and although we hope to detect dislocation diffusion, we have been unable to do so yet. We are analyzing our data to obtain a value for the grain-boundary diffusion coefficient, but this preliminary value may be subject to later revision since our activation procedure is not yet perfected and the beam is not sufficiently homogeneous to assure uniform activation.

Piwnskii, A. J., and N. STOUT, "The Enthalpy and Heat Capacity of Molten SiO_2 , CaSiO_3 and $\text{CaMgSi}_2\text{O}_6$ at 0.1MPa to 2600K," Trans. Am. Geophys. Union 61, 407 (1980). [UCRL-84000, Abstract]

We report the results of the first measurements of the enthalpy, $H_T - H_{298}$, and determinations of heat capacity, C_p , of anhydrous melts of SiO_2 , CaSiO_3 , and $\text{CaMgSi}_2\text{O}_6$ made at 0.1MPa to 2600K using a drop calorimeter. Starting materials were glasses prepared by repeated fusions followed by quenching. For molten SiO_2 between 1900 and 2600K, $H_T - H_{298}$ (J/g) = $1.289T - 577.4$ with 1 S.D. = 39 J/g and $X^2 = 5.0$; C_p (J/g.K) = $1.289 + 0.067$. For molten CaSiO_3 between 1850 and 2600K, $H_T - H_{298}$ (J/g) = $1.395T - 672.4$ with 1 S.D. = 13 J/g and $X^2 = 0.57$; C_p (J/g.K) = $1.395 + .021$. For molten $\text{CaMgSi}_2\text{O}_6$ between 1695 and 2600K, $H_T - H_{298}$ (J/g) = $1.499T - 797.9$ with 1.0 S.D. = 19 J/g and $X^2 = 1.499$; C_p (J/g.K) = $1.499 + .024$. As in the case of alkali silicate liquids, the usual assumption of heat content and heat capacity additivity leads to large errors. Using data of Kelley (1960, U.S. Bureau Mines Bull. 584) and JANAF Tables for $\text{SiO}(s)$, $\text{CaO}(s)$, and $\text{MgO}(s)$, the calculated ($H_T - H_{298}$) at 2000K for CaSiO_3 and $\text{CaMgSi}_2\text{O}_6$ is approximately 15% and 11% lower, respectively, using the assumption than that experimentally determined. C_p of CaSiO_3 and $\text{CaMgSi}_2\text{O}_6$ liquids calculated by additivity leads to temperature-dependent functions; $C_p(wo)$ (J/g.K) = $0.902 + 1.74 \times 10^{-4} T - 1.842 \times 10^{-4} T^2$ and $C_p(di)$ (J/g.K) = $0.939 + 1.966 \times 10^{-4} T - 1.966 \times 10^{-4} T^2 - 1.919 \times 10^{-4} T^3$. At 2000K, the calculated C_p for CaSiO_3 and $\text{CaMgSi}_2\text{O}_6$ liquids by additivity relations is approximately 11% lower than the experimentally obtained values.

Piwnskii, A. J., and N. D. STOUT, The Enthalpy ($H_T - H_{298}$) of Anhydrous Silicate Melts from 1520 to 2600 K, Lawrence Livermore National Laboratory, Rept. UCRL-52978 (1980).

As an aid to modeling the behavior of melted rock at high temperatures, we measured the enthalpy, $H_T - H_{298}$, of anhydrous melts of six silicate rock samples and three silicate minerals for values of temperature T from 1520 to 2600 K. The rock samples were basalt, tuff, rhyolite, and desert alluvium from the Department of Energy's Nevada Test Site. The minerals were SiO_2 , CaSiO_3 , and $\text{CaMgSi}_2\text{O}_6$. We observed a slight compositional dependence of enthalpy for the rock melts. Relative values of enthalpy above 1600 K are as follows: enthalpy of basalt > enthalpy of rhyolite > enthalpy of tuff. The measured enthalpies of the molten CaSiO_3 and $\text{CaMgSi}_2\text{O}_6$ are significantly

higher than enthalpies calculated from additivity relations assuming solid oxide components. Since we cannot predict the behavior of high-temperature silicate liquids from the known behavior (at lower temperatures) of their solid components, we need to acquire more high-temperature experimental data on silicate liquids as a basis for realistic modeling of melted rock behavior.

Piwinskii, A. J., M. D. DENNY, and P. W. Rodgers, Initial Siting Study for the Regional Seismic Test Network (U), Lawrence Livermore National Laboratory, Rept. UCID-18778 SNSI (1980).

Piwinskii, A. J., L. PAGE, C. Bazan, G. S. Smith, and S. Wootton, Hydrothermal Investigation of SYNROC Formulations from 150 to 610 C at 100-MPa Water Pressure, Lawrence Livermore National Laboratory, Rept. UCID-18873 (1980).

Piwinskii, A. J., A. DUBA, W. D. Daily, and R. J. Lytle, "A Model for the Electrical Conductivity Distribution During In-Situ Oil Shale Retorting," Trans. Am. Geophys. Union 61, 1130 (1980). [UCRL-85013, Abstract]

Qualheim, B., T. L. STEINBORN, J. L. Wagoner, C. R. Fitts, R. E. Stetkar, and R. W. Turnbull, Recommended New Criteria for the Selection of Nuclear Waste Repository Sites in Columbia River Basalt and U.S. Gulf Coast Domed Salt, Lawrence Livermore National Laboratory, Rept. UCRL-52749 (1980).

Qualheim, B. J., N. W. HOWARD, G. Hage, M. L. Higuera, G. Pawloski, and C. Bell, The LLL Continental Drilling for Scientific Purposes Data Base: DOE-Funded Drill Holes, Lawrence Livermore National Laboratory, Rept. UCRL-52909 (1980).

RABER, E., and R. Stone, Ground-Water Hydrologic Effects Resulting from Underground Coal Gasification Experiments at the Hoe Creek Site Near Gillette, Wyoming, Interim Report October 1979-March 1980, Lawrence Livermore National Laboratory, Rept. UCID-18627 (1980).

This technical note summarizes our activities, to date, on the research project: Ground-Water Hydrologic Effects Resulting from Underground Coal Gasification Experiments (EPA-1AG-79-D-X0795). The gasified coal seam (Felix No. 2 coal) and two overlying aquifers (Felix No. 1 coal and overlying sand) appear to have become interconnected as a result of roof collapse and subsidence at both Hoe Creek Sites II and III near Gillette, Wyoming. To evaluate changes in the ground-water flow regime at the two sites, completion of supplementary wells was necessary to define the distance versus head draw-down relationships in each of the three aquifers. Hydraulic head potentials have been measured at Site III since gasification ended on October 10, 1979. These data are presented in graphic format. Although hydraulic head measurements at Site II seemed to be approaching a steady-state condition 1.5 years after gasification, the subsequent gasification at Site II temporarily altered the ground-water flow patterns. These changes will have a definite effect on contaminant dispersal and will need to be taken into consideration.

RABER, E., and R. E. Thompson, The Processing of High Salinity Brines for Subsurface Injection, Lawrence Livermore National Laboratory, Rept. UCRL-83122, Rev. 2, Preprint (1980).

The objective of this technical note is to present the methodology involved in the treatment and processing of brines for subsurface injection. This subject has become exceedingly important for a variety of industrial fields: (1) as a means of disposal for spent brine effluents from geothermal and/or geopressed resources, (2) as a formation pretreatment for enhanced oil recovery schemes, (3) for the disposal of leached salt dome brines utilized for chemical extractions, (4) as a means of reservoir pressure maintenance, and (5) for clarification of drilling fluid brines for economic reasons. However, it is not only important to measure the clarity of the brine by conventional wastewater schemes, but it is imperative to produce a high quality effluent which is in chemical equilibrium with the injection formation.

Raber, E., R. E. THOMPSON, F. Smith, and V. DuVal, Activated Carbon Adsorption of Ground-Water Contaminants from In-Situ Coal Gasification, Lawrence Livermore National Laboratory, Rept. UCRL-15223 (1980).

Previous work has demonstrated the feasibility of adsorbing organic chemicals from aqueous solutions using activated carbon as the adsorbent. Tests were carried out to evaluate the adsorbability of mixed organic contaminants found in ground waters adjacent to in-situ coal gasification sites. These adsorption tests were performed on original and modified samples of well water from the Hoe Creek III coal gasification site in Wyoming. Information generated from these tests is used to determine the feasibility of testing the regeneration or disposal of spent powdered activated carbon and to design an above ground activated carbon treatment system.

Raber, E., S. W. MEAD, F. T. Wang, D. H. Stuermer, H. C. Ganow, and R. Stone, Implications of Ground-Water Measurements at the Hoe Creek UCG Site in Northeastern Wyoming (6th Ann. Underground Coal Conversion Sympos., Afton, OK, July 13-17, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84083, Preprint (1980).

Underground coal gasification (UCG) promises to become an important source of synthetic fuels. In an effort to provide timely information concerning the environmental implications of the UCG process, we are conducting investigations in conjunction with the UCG experiments carried out in northeastern Wyoming by the Lawrence Livermore National Laboratory. Our ground-water quality measurements have extended over a period of four years and have been supplemented by laboratory studies of contaminant sorption by coal. Cavity roof collapse and aquifer interconnection were also investigated, using surface and subsurface geotechnical instruments, post-burn coring, and hydraulic head measurements. We have found that a broad range of residual gasification products are introduced into the ground-water system. Fortunately, the concentrations of many of these contaminants are substantially reduced by sorption on the surrounding coal. However, some of these materials seem likely to remain in the local ground water, at low concentrations, for

several years. We have attempted to interpret our results in terms of concepts that will assist in the development of effective and practicable control technologies.

E. Raber, and S. W. MEAD, Environmental Controls for Underground Coal Gasification: Ground-Water Effects and Control Technologies (2nd DOE Environmental Control Sympos., Reston, VA, March 17-19, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84075, Preprint (1980).

Underground coal gasification (UCG) promises to provide economic access to an enormous deep-coal resource. It is, therefore, of considerable importance to develop appropriate environmental controls for use in conjunction with the UCG process. The Lawrence Livermore Laboratory has conducted three UCG experiments at its Hoe Creek site in northeastern Wyoming. We are conducting environmental studies in conjunction with these UCG experiments, including an investigation of changes in local ground-water quality and subsidence effects. Ground-water monitoring and geotechnical measurements have helped to clarify the environmental significance of reaction-product contaminants that remain underground following gasification, and the implications of cavity roof collapse and aquifer interconnection. These investigations have led to the development of preliminary plans for a specific method of ground-water quality restoration utilizing activated carbon adsorption. We are also investigating unconventional technologies that may be appropriate for restoring ground water that has been contaminated as a result of UCG operations. These water treatment technologies are being explored as possible supplements to natural controls and process restrictions.

Raber, E., D. ISHERWOOD, D. Coles, and R. Stone, Program Plan: Field Radionuclide Migration Studies in Climax Granite, Lawrence Livermore National Laboratory, Rept. UCID-18838 (1980).

RALEY, J. H., A. K. Burnham, J. H. Campbell, S. B. Libicki, A. G. Cole, J. E. Clarkson, L. L. Ott, and R. L. Ward, Retort Analysis from Fluid Product Data (3rd Briefing Oil Shale Tech. Res. at LLNL, Livermore, CA, Nov. 19-21, 1980), Lawrence Livermore National Laboratory, LLL-Misc. 144 (1980), pp. 87-135.

This paper presents the status of LLNL work on monitoring and evaluating the operation of oil shale retorts from information obtained from the fluid products. Described are methods for obtaining estimates in real time of (a) the fraction of oil formed that is produced and (b) the rates of shale processing and oil production. Offgas data also provide information on participation of steam in the retorting process and identify some of the potential gaseous pollutants.

RALEY, J. H., E. J. Frohwein, L. J. Gregory, and R. L. Ward, Carbon and Sulfur Balances (3rd Briefing Oil Shale Tech. Res. at LLNL, Livermore, CA, Nov. 19-21, 1980), Lawrence Livermore National Laboratory, LLL-Misc. 144 (1980), pp. 136-143.

Carbon and sulfur balances for experiments in both LLNL simulated MIS retorts are presented. These experiments utilized shales of 10-36 gal/ton, sulfur contents of 0.7 to 1.7 w%, and gas feeds of air, air plus steam or oxygen plus steam.

Raley, J. H., J. H. CAMPBELL, F. J. Ackerman, W. A. Sandholtz, and S. B. Libicki, Investigation of Critical Parameters in Modified In-Situ Retorting (13th Oil Shale Sympos., Golden, CO, April 16-18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83739, Preprint (1980).

Recent results from operation of a 6-metric ton simulated, modified in-situ retort show that high (up to 3 m/day) retorting rates can be achieved with high (85%) oil yield and acceptable (<1000°C) maximum temperatures. These results were obtained with a bed of Colorado shale of broad (-30, + 0.001 cm) size range containing a stepped grade change from 75 to 150 g/metric ton. Process control by steam and air injection rates, as stipulated by prerun model calculations, was demonstrated as was continuous estimation of retorting rate and oil yield from off-gas composition.

Raley, J. H., and J. H. CAMPBELL, Underground Oil Shale Retorting, Lawrence Livermore National Laboratory, Rept. UCID-18556 (1980).

The purpose of this manual is to outline the basic principles involved in combustion processing of oil shale. The manual is designed to serve as an introduction to the subject for the support personnel of the LLNL Oil Shale Project. The material is presented in a simple two-page format with one page devoted to a figure or table, and the facing page contains a brief description of that material. Thus, it can serve as a self-study guide.

Following a brief description of oil shale, how it was formed and the extent of the resource, we present an overview of the concepts and major technical problems of Modified In-Situ (MIS) Oil Shale Retorting. Finally, the liquid product, shale oil, is compared with typical petroleum crudes.

Raley, J. H., R. L. BRAUN, J. H. Campbell, D. R. McKenzie, and M. L. Gregg, Proposed Operating Strategy for a Field MIS Oil Shale Retorting Experiment (RBOSC Retort 0), Lawrence Livermore National Laboratory, Rept. UCID-18524 (1980).

Raley, J., F. J. ACKERMAN, W. Sandholtz, J. Carley, L. Tripp, A. Rothman, and J. Campbell, Oil Shale Project Large Retort Run Summary L-3, Lawrence Livermore National Laboratory, Rept. UCID-18595 (1980).

Raley, J., F. J. ACKERMAN, W. Sandholtz, J. Carley, and L. Tripp, Oil Shale Project Run Summary, Small Retort Run S-16, Lawrence Livermore National Laboratory, Rept. UCID-18618 (1980).

Raley, J., W. SANDHOLTZ, F. J. Ackerman, J. Carley, and L. Tripp, LLL Oil Shale Project Small Retort Run Summary, Run S-17, Lawrence Livermore National Laboratory, Rept. UCID-18899 (1980).

Raley, J., F. J. ACKERMAN, W. Sandholtz, L. Tripp, and J. Carley, Oil Shale Project Run Summary, Small Retort Run S-18, Lawrence Livermore National Laboratory, Rept. UCID-18897 (1980).

Raley, J., F. J. ACKERMAN, W. Sandholtz, J. Carley, and L. Tripp, Oil Shale Project Run Summary Small Retort Run S-19, Lawrence Livermore National Laboratory, Rept. UCID-18898 (1980).

Rambo, J., W. SHORT, and R. Fullen, Historical Simulation with the Livermore Economic Modeling System, Lawrence Livermore National Laboratory, Rept. UCRL-15211 (1980).

Lawrence Livermore Laboratory (LLL) has developed an Economic Modeling System (EMS) to forecast future prices and quantities of commodities of interest. This study identifies areas for possible improvement in the EMS parameters and logic through a historical simulation of energy markets between 1950 and 1975. Although this period was not one of uninterrupted free trade, the LLL modeling system proved flexible enough to reproduce historical trends at both the national and regional levels with reasonable accuracy. This report documents the data collected, details the logic problems identified, and suggests parameter values. With the implementation of the changes recommended in the study, the forecasting capability of EMS should be further improved.

RAMIREZ, A. L., and N. Mao, New Developments in Measurement Technology Relevant to the Studies of Deep Geological Repositories in Domed Salt and Basalt, Lawrence Livermore National Laboratory, Rept. UCRL-52747 (1980).

This report briefly describes recent geophysical and geotechnical instrumentation developments relevant to the studies of deep geologic repositories. Special emphasis has been placed on techniques that appear to minimize measurement problems associated with repositories constructed in basalt or domed salt. Included in the listing are existing measurement capabilities and deficiencies that have been identified by a few authors and instrumentation workshops that have assessed the capabilities of existing instrumentation with respect to repository applications. These deficiencies have been compared with the reported advantages and limitations of the new developments described. Based on these comparisons, areas that merit further research and development have been identified. The report is based on a thorough literature review and on discussions with several instrumentation specialists involved in instrumentation development.

Ramirez, A. L., D. W. CARPENTER, K. P. Puchlik, J. L. Wagoner, K. G. Knauss, and P. W. Kasameyer, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume I: Text and Appendices A-E, Lawrence Livermore National Laboratory, Rept. UCRL-53065, Vol. I (1980).

Ramirez, A. L., D. W. CARPENTER, and J. Wagoner, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume II: Appendix F, Lawrence Livermore National Laboratory, Rept. UCRL-53065, Vol. II (1980).

Ramirez, A. L., and N. MAO, New Developments in Measurements Technology Relevant to the Studies of Deep Geological Repositories in Bedded Salt, Lawrence Livermore National Laboratory, Rept. UCID-18687 (1980).

RAMSPOTT, L. D., "Status of LLNL Granite Projects," Proc. ONWI/LBL Workshop Thermomechanical-Hydrochemical Modeling for Hardrock Waste Repository (Berkeley, CA, July 29-31, 1980), 37-44 (1980). [UCRL-84613, Preprint]

The status of LLNL projects dealing with nuclear waste disposal in granitic rocks is reviewed. This review covers work done subsequent to the June 1979 Workshop on Thermomechanical Modeling for a Hardrock Waste Repository and is prepared for the July 1980 Workshop on Thermomechanical-Hydrochemical Modeling for a Hardrock Waste Repository. Topics reviewed include laboratory determination of thermal, mechanical, and transport properties of rocks at conditions simulating a deep geologic repository, and field testing at the Climax granitic stock at the USDOE Nevada Test Site.

RAMSPOTT, L. C., and L. B. Ballou, "Test Storage of Spent Reactor Fuel in the Climax Granite at the Nevada Test Site," The State of Waste Disposal Technology, Mill Tailings, and Risk Analysis Models, Vol. 2 (Waste Management '80, Tucson, AZ, March 10-14, 1980), pp. 515-529. [UCRL-83976, Preprint]

A test of retrievable dry geologic storage of spent fuel assemblies from an operating commercial nuclear reactor is underway at the Nevada Test Site (NTS) of the U.S. Department of Energy (DOE). This generic test is located 420 m below the surface in the Climax granitic stock. Eleven canisters of spent fuel approximately 2.3 years out of reactor core (about 2 kW/canister thermal output) will be emplaced in a storage drift along with six electrical simulator canisters, and their effects will be compared. Two adjacent drifts will contain electrical heaters, which will be operated to simulate within the test array the thermal field of a large repository. The test objectives, technical concepts and rationale, and details of the test are stated and discussed.

RAMSPOTT, L. D., The Spent Fuel Test Project, Climax Granitic Stock, Nevada Test Site (Int. Sympos. Environ. Protection, Low Cost Storage & Energy Savings--Rockstore '80, Stockholm, Sweden, June 23-27, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85078, Preprint (1980).

The Spent Fuel Test-Climax (SFT-C) is a test of dry geologic storage of spent nuclear reactor fuel. The SFT-C is located at a depth of 420 m in the Climax granitic stock at the Nevada Test Site of the U.S. Department of

Energy. Eleven canisters of spent commercial PWR fuel assemblies are to be stored for 3 to 5 years. Additional heat is supplied by electrical heaters, and more than 800 channels of technical information are being recorded. The measurements include rock temperature, rock displacement and stress, joint motion, and monitoring of the ventilation air volume, temperature, and dewpoint.

RAMSPOTT, L. D., Climax Granite Test Results, Lawrence Livermore National Laboratory, Rept. UCID-18502 (1980).

The Lawrence Livermore National Laboratory (LLNL), as part of the Nevada Nuclear Waste Storage Investigations (NNWSI) program, is carrying out in-situ rock mechanics testing in the Climax granitic stock at the Nevada Test Site (NTS). Although LLNL is heavily involved in planning and execution for a test storage of spent reactor fuel in the Climax granite and in the planning and design for a Rock Mechanics Test Facility, this summary will address only those field data taken to date that address thermomechanical modeling for a hardrock repository. The results to be discussed include thermal measurements in a heater test that was conducted from October 1977 through July 1978, and stress and displacement measurements made during and after excavation of the canister storage drift for the Spent Fuel Test (SFT) in the Climax granite. Associated laboratory and field measurements will be summarized.

RARD, J. A., and D. G. Miller, "Mutual Diffusion Coefficients of $\text{BaCl}_2\text{-H}_2\text{O}$ and $\text{KCl-H}_2\text{O}$ at 25°C from Rayleigh Interferometry," J. Chem. & Eng. Data **25**, 211-215 (1980). [UCRL-83065, Preprint]

The volume-fixed mutual diffusion coefficients of $\text{BaCl}_2\text{-H}_2\text{O}$ and $\text{KCl-H}_2\text{O}$ have been measured to an accuracy of 0.1-0.2%, from dilute solutions to near saturation, using free-diffusion Rayleigh interferometry. These diffusion coefficients are compared to other available diffusion data for these systems, measured by the conductometric and optical methods. The new data extend previously available optical results to higher and lower concentrations and confirm that the diffusion coefficients of $\text{BaCl}_2\text{-H}_2\text{O}$ are unusually low, relative to the other alkaline earth chlorides, at moderate and high concentrations. The effect of cation hydration on the diffusion coefficients of alkali and alkaline earth chloride solutions is briefly discussed.

RARD, J. A., and D. G. Miller, Isopiestic Determination of the Osmotic and Activity Coefficients of Aqueous MgCl_2 Solutions at 25°C , Lawrence Livermore National Laboratory, Rept. UCRL-84462, Preprint (1980).

The osmotic coefficients of aqueous MgCl_2 solutions have been measured at 25°C by the isopiestic method. These and other available accurate data were represented by a least-squares equation, and this equation was used to calculate water activities and mean molal activity coefficients. Osmotic coefficients from some previous studies are lower than the present results, while other data are in agreement. Some lower osmotic coefficients reported by other workers may be due to alkali contamination of their MgCl_2 solutions.

The isopiestic standards NaCl, KCl, CaCl₂, and H₂SO₄ have been intercompared in this study, and these data can be used to refine the standards' osmotic coefficients. Several different MgCl₂, CaCl₂, and NaCl solutions were used to determine the reproducibility of isopiestic measurements. It is concluded that independent isopiestic measurements should agree to 0.1-0.2% in most cases, relative to the same isopiestic standard. The solubilities of NaCl and MgCl₂ · 6H₂O have also been determined at 25°C.

RARD, J. A., and D. G. Miller, Isopiestic Determination of the Osmotic Coefficients of Aqueous Na₂SO₄, MgSO₄, and Na₂SO₄-MgSO₄ at 25 C, Lawrence Livermore National Laboratory, Rept. UCRL-84238, Preprint (1980).

The osmotic coefficients of aqueous Na₂SO₄, MgSO₄, and an equimolar mixture of these salts have been measured by the isopiestic method at 25°C. The solubilities of KCl, Na₂SO₄ · 10H₂O, and MgSO₄ · 7H₂O have also been determined. The results are compared to other available activity and solubility data for these salts. Least-squares equations were used to represent these data and to calculate activity coefficients of Na₂SO₄ and MgSO₄. Discrepancies between isopiestic and freezing-point-depression measurements for most 2-2 electrolytes may be due to the neglect of the temperature dependence of the heat capacities.

Rard, J. A., D. G. MILLER, L. B. Eppstein, and R. A. Robinson, "Mutual Diffusion Coefficients, Electrical Conductances, Osmotic Coefficients, and Ionic Transport Coefficients l_{ij} for Aqueous CuSO₄ at 25°C," J. Solu. Chem. 9, 467-496 (1980). [UCRL-83465, Preprint]

Reichlin, R., N. STOUT, F. J. Ryerson, and J. Akella, "Crystal-Liquid Fractionation in a Trace Element Rich Magma," Trans. Am. Geophys. Union 61, 1142 (1980). [UCRL-84889, Abstract]

A tholeiitic basalt (USGS standard) has been doped with ZrO₂, SrO, Cs₂O, Ce₂O₃, Nd₂O₃, U₂O₃, and MoO₂ in the range 0.5-3 wt%. Runs were conducted under equilibrium and dynamic crystallization conditions at one atmosphere with oxygen fugacities corresponding to the I-W buffer. Under equilibrium conditions, olivine is the first phase to appear on the liquidus at 1195°C. Clinopyroxene, plagioclase and Mo-metal reach saturation simultaneously at ~1140°C. At 1120°C, Ol, CPX and Pl are joined on the liquidus by a REE-rich Ca-Ti silicate tentatively identified as sphene. Preliminary analyses indicate that the REE's enter this phase by coupled substitution REE⁺³ + Al⁺³ = Ca⁺² + Ti⁺⁴. It is presumed that the high REE content of these liquids tends to stabilize sphene on the liquidus surface. The ratios of incompatible elements Ce/Nd, U/Nd remain essentially constant with increasing absolute abundance during Ol, CPX, Pl fractionation. Cs₂O abundances increase (despite some volatilization), and the CsO/SrO ratio increases presumably due to the buffering of SrO content by plagioclase fractionation. At the onset of sphene fractionation, the abundances of Ce, Nd, and U decrease. The Nd/U ratio of the liquids decreases when sphene is on the

liquidus. Our data suggest that sphene may act as a sink for highly charged incompatible elements, and may effectively fractionate lanthanides from actinides in natural geological processes and also from nuclear waste.

RODEAN, H. C., Further Study of ISC Events from 1964 to 1976 at and Very Near the Nuclear Testing Ground in Eastern Kazakhstan (U), Lawrence Livermore National Laboratory, Rept. UCRL-52937 S-FRD (1980).

(Abstract unclassified) In an earlier study [ISC Events from 1964 to 1976 at and Near the Nuclear Testing Ground in Eastern Kazakhstan (U)], I considered seismic events from 1964 to 1976 at and near the Nuclear Testing Ground in eastern Kazakhstan, using data published by the International Seismological Centre in the United Kingdom. In this study, I consider seismic events during the same period and in the same area, using another source of seismic data. I compare both data sets with respect to event detection, apparent origin time, and location. I also examine the reasons for differences between the two data sets.

RODEAN, H. C., Inelastic Processes in Seismic Wave Generation by Underground Explosions (NATO Adv. Study Inst., Ident. Seis. Sources--Earthquake or Underground Explosion, Oslo, Norway, Sept. 8-18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84515, Preprint (1980).

There are similarities and differences between chemical and nuclear explosions underground. Most of the differences are in the early stages of the explosions. The later stages are similar with respect to seismic wave generation. Three sources of seismic waves from explosions are coincident in space and time, or nearly so: the explosion itself, explosion-induced tectonic strain release, and (probably) spall-closure following explosion-produced spall. Cavity collapse and explosion-induced aftershocks are two sources of delayed seismic signals. Theories, computer calculations, and measurements of spherical stress waves from explosions are described and compared, with emphasis on the transition from inelastic to almost-elastic relations between stress and strain. Two aspects of nonspherical explosion geometry are considered: tectonic strain release and surface spall. Tectonic strain release affects the generation of surface waves; spall closure may also. The forward problem in seismology can, in principle, be solved by calculations beginning with explosive detonation and ending with the synthetic seismogram. The inverse problem can also, in principle, be solved by inverting observed seismic data to obtain an "equivalent elastic source," but the solution cannot extend backward in space and time into the nonlinear inelastic processes of the explosion. The reduced-displacement potential is a common solution (the "equivalent elastic source") of the forward and inverse problems, assuming a spherical source. Measured reduced-displacement potentials are compared with potentials calculated as solutions of the direct and inverse problems; there are significant differences between the results of the two types of calculations and between calculations and measurements. The simple spherical model of an explosion is not sufficient to account for observations of explosions over wide ranges of depth and yield. The explosion environment can have a large effect on explosion detection and yield estimation. The best sets of seismic observations for use in developing

discrimination techniques are for high-magnitude high-yield explosions; the identification problem is most difficult for low-magnitude low-yield explosions. Most of the presently available explosion data (time, medium, depth, yield, etc.) are for explosions in a few media at the Nevada Test Site; some key questions concerning magnitude vs yield and m_b vs M_s relations can be answered only by data for explosions in other media at other locations.

Rodgers, P. W., M. D. DENNY, and A. J. Piwinski, Initial Siting Study for the Regional Seismic Test Network (U), Lawrence Livermore National Laboratory, Rept. UCID-18778 SNSI (1980).

Rogers, L. L., R. STONE, J. L. Wagoner, K. P. Puchlich, and W. B. McKinnis, "Selection and Characterization of a Potential Underground Coal-Gasification Site in Washington," in LLNL In Situ Coal Gasification Project Quarterly Progress Report, April Through June 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50026-80-2 (1980), pp. 9-20.

Rohrer, R. F., J. M. MILLS, JR., and F. E. Followill, Locations and Mechanisms for Aftershocks of the January, 1980, Livermore, California, Earthquake Sequence (Am. Geophys. Union, Toronto, Ontario, May 21, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85306, Abstract (1980).

ROTHMAN, A., Ed., LLL Oil Shale Project Quarterly Report, Lawrence Livermore National Laboratory, Rept. UCID-16986-80-1 (1980).

ROTHMAN, A., Ed., LLL Oil Shale Project Quarterly Report, Lawrence Livermore National Laboratory, Rept. UCID-16986-80-2 (1980).

ROTHMAN, A., Ed., LLL Oil Shale Project Quarterly Report, Lawrence Livermore National Laboratory, Rept. UCID-16986-80-3 (1980).

ROTHMAN, A., Ed., LLL Oil Shale Project Quarterly Report, Lawrence Livermore National Laboratory, Rept. UCID-16986-80-4 (1980).

Rothman, A., F. J. ACKERMAN, W. Sandholtz, J. Raley, J. Carley, L. Tripp, and J. Campbell, Oil Shale Project Large Retort Run Summary L-3, Lawrence Livermore National Laboratory, Rept. UCID-18595 (1980).

Ryerson, F. J., N. STOUT, R. Reichlin, and J. Akella, "Crystal-Liquid Fractionation in the Trace Element Rich Magma," Trans. Am. Geophys. Union 61, 1142 (1980). [UCRL-84889, Abstract]

SANDHOLTZ, W. A., Some Relationships of Thermal Effects to Rubble Bed Structure and Gas Flow Patterns in Oil Shale Retorts (13th Oil Shale

Sympos., Golden, CO, April 16-18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83740, Preprint (1980).

Conventional tracer measurements in packed beds rely on detection of specific molecular species to characterize bed structure and measure fluid dispersion under varied flow conditions. The work reported here demonstrates the use of temperature sensors such as thermocouples to develop similar kinds of information from thermal data.

In oil shale retorts (that is, packed beds in which the process is driven by heat transfer from a flowing medium to the rubble) much can be inferred about bed and void structure and flow patterns from the time/temperature relationships among thermocouple arrays placed in the bed. The use of temperature data as a bed diagnostic tool in oil shale retorting experiments is shown. The close relationships in combustion retorting between the thermal effects produced by condensing steam and those produced by retorting are illustrated. This thermal logging technique has proved useful in understanding laboratory retorting experiments and predicting retort performance.

SANDHOLTZ, W., F. J. Ackerman, J. Raley, J. Carley, and L. Tripp, LLL Oil Shale Project Run Summary, Small Retort Run S-16, Lawrence Livermore National Laboratory, Rept. UCID-18899 (1980).

Sandholtz, W., F. J. ACKERMAN, J. Raley, J. Carley, L. Tripp, A. Rothman, and J. Campbell, Oil Shale Project Large Retort Run Summary L-3, Lawrence Livermore National Laboratory, Rept. UCID-18595 (1980).

Sandholtz, W., F. J. ACKERMAN, J. Carley, J. Raley, and L. Tripp, Oil Shale Project Run Summary, Small Retort Run S-16, Lawrence Livermore National Laboratory, Rept. UCID-18618 (1980).

Sandholtz, W., F. J. ACKERMAN, J. Raley, L. Tripp, and J. Carley, Oil Shale Project Run Summary, Small Retort Run S-18, Lawrence Livermore National Laboratory, Rept. UCID-18897 (1980).

Sandholtz, W., F. J. ACKERMAN, J. Raley, J. Carley, and L. Tripp, Oil Shale Project Run Summary Small Retort Run S-19, Lawrence Livermore National Laboratory, Rept. UCID-18898 (1980).

Sandholtz, W. A., J. H. CAMPBELL, J. H. Raley, F. J. Ackerman, and S. B. Libicki, Investigation of Critical Parameters in Modified In-Situ Retorting (13th Oil Shale Sympos., Golden, CO, April 16-18, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83739, Preprint (1980).

SCHAFFER, E. S., and H. J. Patton, Surface-Wave Study of Secondary Sources of Yucca Valley Underground Explosions (Am. Geophys. Union, San Francisco,

CA, Dec. 8-12, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84939, Abstract (1980).

Spectra of surface waves recorded on a broad-band digital network at regional distances from NTS are used to test models of tectonic strain release and other secondary sources of underground nuclear explosions. Observations of amplitude and source phase spectra of Rayleigh and Love waves from 0.05 to 0.16 Hz are presented for explosions detonated in Yucca Valley. These observations show two interesting features: (1) enriched Love-wave amplitudes at high frequencies and (2) azimuthal asymmetry of the Rayleigh-wave amplitudes and initial phase. The model of Toksoz and Kehler (tectonic strain release on a vertical strike-slip fault) fits all of the observations of one explosion except the Love-wave amplitudes at high frequencies and gives results consistent with the trend of Yucca fault and regional stress. However, for the majority of explosions, this model fails to match the features described above. In particular, the Love-wave amplitudes cannot be matched by a secondary source with step-function time dependence. The Rayleigh wave asymmetry cannot be matched by secondary sources with azimuthal symmetry such as strike-slip faulting or spall closure.

SCHOCK, R. N., M. E. Hanson, R. P. Swift, and O. R. Walton, "In Situ Fracture Related to Energy and Resource Recovery," in High Pressure Science and Technology, B. Vodar and P. Marteau, Eds. (Pergamon Press, Oxford, 1980), pp. 902-912. [UCRL-82731, Preprint]

Many resources require fracturing of rock before recovery. This is often accomplished by energy deposition under in situ conditions. The mechanical properties of the medium, confining pressure, pore fluid pressure, temperature, and energy deposition rate are among the important factors leading to an understanding and prediction of fracture production. Recent experimental and modeling studies have improved understanding of the effects of confining pressure on explosive-induced fracturing in small-scale blocks, effect of timing of multiple explosives, rate of pressurization on hydraulic fracture production, changing material properties on hydraulic pressure-produced fracture initiation and orientation, and material properties on rubble behavior after fracturing.

SCHOCK, R. N., A. Duba, and R. L. Stocker, Defect Production and Electrical Conductivity in Olivine (Lunar & Plan. Sci. Conf., Houston, TX, March 17-21, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83879, Preprint (1980).

The electrical conductivity of olivine single crystals from the Red Sea (Fog₁) and San Carlos (Fog₂) has been measured as a function of oxygen fugacity at 1200°C for all three major crystallographic directions in San Carlos olivine and the [010] direction in Red Sea olivine.

San Carlos olivine varies between no f_{O_2} dependence and a positive or p-type dependence with increasing f_{O_2} . The slopes reach values of between 1/10 and 1/8. The Red Sea peridot, on the other hand, shows entirely a negative or n-type dependence on f_{O_2} with a slope of about -1/20. The Red Sea peridot is also less conducting by almost an order of magnitude. Thus, we are observing the behavior of two different olivines.

When the data on these olivines are plotted as a function of temperature, they yield activation energies of about 2 eV at these temperatures. The optical band gap, on the other hand, has been measured at about 8 eV. Therefore, we may conclude that the conductivity data do not represent intrinsic electronic conduction, and that either impurity controlled electronic conduction or ionic conduction is the most likely possibility.

Simple thermodynamic considerations allow us to determine the variation of point defect concentrations as a function of fO_2 . We would like to be able to interpret the data in terms of the mobility of possible charge carriers. However, we have controlled only three of the state variables (P , T , fO_2) and, therefore, we cannot interpret the data unambiguously because the precise thermodynamic state has not been determined. We can narrow the possible interpretations considerably if we combine (1) the knowledge that the system is closed and therefore the ion concentration ratios are fixed and (2) plausible arguments.

Since olivine conductivity is known to increase with dissolved SiO_2 , we may conclude from the data that the San Carlos olivine contains more SiO_2 than the Red Sea peridot. Thus, we expect the Red Sea peridot to be more stoichiometric (i.e., to have a higher Mg/Si ratio) and the San Carlos olivine to contain more silica because it equilibrated at a higher temperature in contact with a more siliceous phase.

Schock, R. N., J. AKELLA, and Q. Johnson, "Phase Transformations in Americium at High Pressure: Relation to Rare Earth Elements," J. Geophys. Res. **85**, 7056-7058 (1980). [UCRL-83539, Rev. 1, Preprint]

Schock, R. N., A. S. KUSUBOV, W. B. Durham, J. F. Schatz, and T. J. Ahrens, "Explosive-Induced Damage in Porous Sandstone," in High Pressure Science and Technology, Vol. 2, B. Vodar and Ph. Marteau, Eds. (Pergamon Press, Oxford, England, 1980), pp. 917-923. [UCRL-83448, Preprint]

Schwartz, L. L., and A. L. HENRY, Earth Sciences Division Collected Abstracts--1979, Lawrence Livermore National Laboratory, Rept. UCRL-52906 (1980).

SHAFFER, R. J., "A Finite Element Model for Transient Fracturing," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), p. 45.

A dynamic two-dimensional, finite-element model is applied to several transient fracture problems which include shear fracturing with frictional effects, tensile fracturing, and pressurized fracturing near interfaces. These problems arise in geophysics with the analyses of earthquakes and hydrofractures near interfaces. Interfaces and layers or lenses are trivial to handle with a finite-element formulation, although they do wreak havoc with the regularity of the stiffness matrix. Dynamic fractures are modeled in the finite element mesh by breaking along the center line of an element. The breaking is accomplished by applying a stress boundary condition to the faces of the crack. In the shear case, friction is activated by modifying the time-dependent stress boundary condition. At each time step, nodal

accelerations are obtained by relaxing the distributed mass matrix (sometimes called the consistent mass matrix) and simple differencing yields the displacements. The use of the mass matrix smoothes most of the numerical oscillations except in the analysis of tensile fracturing. Here the oscillations are tolerated or an artificial damping is used.

Shaffer, R. J., M. E. HANSON, G. D. Anderson, and L. D. Thorson, Some Effects of Stress, Friction, and Fluid Flow on Hydraulic Fracturing, Lawrence Livermore National Laboratory, Rept. UCRL-85003, Abstract (1980).

Shaffer, R. J., M. E. HANSON, G. D. Anderson, D. F. Towse, W. Lin, L. D. Thorson, and M. P. Cleary, LLL Gas Stimulation Program Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, Rept. UCRL-50036-79-4 (1980).

Shaffer, R. J., M. E. HANSON, G. D. Anderson, D. F. Towse, W. Lin, M. P. Cleary, D. R. Peterson, S. K. Wong, and B. C. Haimson, LLNL Gas Stimulation Program Quarterly Progress Report, January Through March 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50036-80-1 (1980).

Shaffer, R. J., M. E. HANSON, and G. D. Anderson, "Theoretical and Experimental Research on Hydraulic Fracturing," J. Energy Resources Tech. 102, 92-98 (1980). [UCRL-80558, Preprint]

Shaffer, R. J., M. E. HANSON, and G. D. Anderson, "Effects of Various Parameters on Hydraulic Fracture Geometry," Rept. SPE/DOE 8942, Proc. 1st Sympos. Unconventional Gas Recovery (Pittsburgh, PA, May 18-20, 1980), pp. 163-172. [UCRL-83784, Preprint]

Shaffer, R. J., and M. E. HANSON, "Some Results from Continuum Mechanics Analyses of the Hydraulic Fracturing Process," Soc. Pet. Eng. J. 20, 86-94 (1980). [UCRL-81707, Preprint]

STONE, R., and R. W. Hill, Underground Coal Gasification Site Selection and Characterization in Washington State and Gasification Test Designs, Lawrence Livermore National Laboratory, Rept. UCRL-53052 (1980).

A program of investigation has been carried out to identify and characterize a site in Washington State suitable for underground coal gasification (UCG) experiments and possible commercial development. A site in the Tono Basin of the Centralia-Chehalis district containing an estimated 5×10^{10} kg of subbituminous coal in two deeply buried seams (the Lower Thompson and the Big Dirty) was found that may be suitable for underground coal gasification (UCG) experiments and possible commercial development.

Eight exploratory boreholes and two test wells were drilled to provide the primary subsurface geologic and hydrologic information about the site. The clastic rock sequence, which includes the Lower Thompson and Big Dirty, is a

sandstone-siltstone-claystone assemblage that is generally only slightly indurated. The Big Dirty, the coal seam of primary interest, is apparently an aquitard with permeability less than $0.025 \text{ (}\mu\text{m)}^2$. The associated clastic rock units are generally of low permeability with the possible exception of the sandstone units. The hydraulic characteristics of the thick sandstone unit between the Lower Thompson and the Big Dirty seams should be evaluated before a final judgment on site suitability is made. The major structural feature of the proposed UCG experimental site is a normal fault which can be avoided by proper placement of the UCG experiments.

A series of surface gasification tests using large blocks of coal cut free of the Big Dirty seam in mine exposures will be conducted to establish a preliminary set of in situ operational parameters--air injection pressures, flow rates, and coal consumption rates. If the site is found suitable, the surface gasification tests will be followed by two deep underground gasification experiments--one employing borehole linking and the other reverse combustion-linking.

The proposed large coal block surface gasification tests and the UCG experiments will provide a basis for decisions concerning the nature of future gasification efforts in the Tono Basin.

STONE, R., L. L. Rogers, J. L. Wagoner, K. P. Puchlich, and W. B. McKinnis, "Selection and Characterization of a Potential Underground Coal-Gasification Site in Washington," in LLNL In Situ Coal Gasification Project Quarterly Progress Report, April Through June 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50026-80-2 (1980), pp. 9-20.

We have completed our search for a site suitable for UCG testing and possible commercial development in Washington. Our preliminary investigation of the site selected suggests it may be suitable for UCG. However, additional geohydrologic investigation of the site is needed.

STONE, R., K. P. Puchlik, J. L. Wagoner, and R. D. McArthur, "Investigation of Potential UCG Sites in Wyoming," in LLL In Situ Coal Gasification Project Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, UCRL-50026-79-4 (1980), pp. 23-32.

Exploratory wells were drilled at two sites in the Powder River Basin near Gillette, Wyoming. Some hydraulic characteristics of the coal seam of interest were evaluated at one site. The first work was at the Hoe Creek site where the Roland coal at about 130 m (422 ft) depth was the seam of interest. The second site explored is the Wildcat Creek lead, located in Section 21, T52N, R73W, about 26 km (16 mi) northwest of Gillette. The Canyon coal at about 180 m (590 ft) depth is the seam of interest at the Wildcat Creek lead. The seams of interest at both sites are contained in the Paleocene Ft. Union Formation.

Stone, R., and E. RABER, Ground-Water Hydrologic Effects Resulting from Underground Coal Gasification Experiments at the Hoe Creek Site Near Gillette, Wyoming, Interim Report October 1979-March 1980, Lawrence Livermore National Laboratory, Rept. UCID-18627 (1980).

Stone, R., S. W. MEAD, F. T. Wang, D. H. Stuermer, E. Raber, and H. C. Ganow, Implications of Ground-Water Measurements at the Hoe Creek UCG Site in Northeastern Wyoming (6th Ann. Underground Coal Conversion Sympos., Afton, OK, July 13-17, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84083, Preprint (1980).

Stone, R., D. ISHERWOOD, E. Raber, and D. Coles, Program Plan: Field Radionuclide Migration Studies in Climax Granite, Lawrence Livermore National Laboratory, Rept. UCID-18838 (1980).

STOUT, R. B., "Note on Strain Rate, Dislocation Density, Dislocation Motion, and Dislocation Constitutive Equations," Crystal Lattice Defects 9, 47-61 (1980).

The model of a propagating dislocation as a surface discontinuity leads to a definition of stochastic strain rate. It is defined as a functional of a probabilistic density function (pdf) for the number of dislocation segments per unit volume per unit type. The unit type is a hyperspace over the set of possible Burger's vectors, tangent vectors, and velocity vectors of a dislocation segment. A balance statement for the pdf of dislocation segments results in a dislocation transport equation analogous to the Boltzmann equation in statistical mechanics. A solution is obtained to illustrate concepts of the theoretical developments.

STOUT, R. B., and L. Thigpen, Modelling Microcrack Kinetics in Rocks, Lawrence Livermore National Laboratory, Rept. UCRL-83994, Preprint (1980).

Mathematical concepts of statistical mechanics are used to formulate the stochastic problem of microcrack kinetics. The approach defines a stochastic microcrack density function on a limited hyperspace of idealized microcrack species. A particular idealized microcrack species is characterized by the effective parameters of area, orientation, opening displacement, and opening displacement rate. The formalism of statistical mechanics results in a Boltzmann type of evolutionary equation for the microcrack density function. This equation has several functional degrees of freedom for purposes of modelling microcrack kinetics. By imposing a shear stress history dependent functional to describe the production rate of microcracks and ignoring microcrack interaction kinetics, a most simple and limited model for dilatancy and failure rock responses can be developed. This model is developed to illustrate some concepts of the microcrack kinetic approach.

STOUT, R. B., L. Thigpen, and J. Peterson, "Stochastic Microcrack Modelling in Rock Material," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), pp. 45-46.

A stochastic model for microcrack kinetics in rock material has been formulated by using some concepts from statistical mechanics. The model defines a stochastic or probabilistic density function for the number of microcracks per unit volume per unit species type. For the present model, the

species type is a hyperspace over measures for the microcrack area A , the microcrack orientation Ω , the microcrack displacement opening U , and the microcrack displacement opening rate $\dot{U}$. A balance or accounting statement for each species of microcrack results in an integral-differential equation for the stochastic microcrack density function. This equation is a microcrack transport equation analogous to the Boltzmann equation in classical statistical mechanics.

Based on the above formalism, a simple failure model for rock material has been completed to illustrate concepts of the theoretical development. Through recent extensions, a deformation functional, which depends on the microcrack function space, has been obtained. This leads to approximations for the kinematic measures of strain and strain rate that also depend on the microcrack density function.

STOUT, R. B., Note on Modelling the Deformations and Thermodynamics for Materials Involving a Dislocation Kinetics, Lawrence Livermore National Laboratory, Rept. UCRL-84435, Preprint (1980).

An idealized model of the discrete discontinuous deformation due to dislocation motion and dislocation creation kinetics is developed. The total deformation is modeled as a continuum deformation of a crystalline lattice structure plus the discontinuous deformation due to dislocation kinetics. It is shown that a differential strain measure does not exist when dislocation kinetics occurs, only an approximation is possible. In the thermodynamics, the entropy, the continuum lattice strain, and the scalar dislocation density are used as thermodynamic variables. The continuum lattice strain is termed the reversible strain and its conjugate variable is the thermodynamic stress. The conjugate variable to the scalar dislocation density is the chemical potential. Thus, the thermodynamics of dislocation kinetics, as modelled here, contains a chemical potential for each species of dislocation, somewhat analogous to Gibbs' treatment of chemical potential for various mass species. From this, the phenomenological concept for the plastic yield condition becomes equivalent to the thermodynamic criteria of a stress-lattice work term becoming equal to (or greater than for irreversible thermodynamics) the chemical potential of a dislocation species. The actual dislocation motion is strictly irreversible and is a local entropy production term. The irreversible thermodynamics shows that entropy production also occurs for processes where the applied mechanical stress is not equal to the thermodynamic stress during strain rate processes and when the stress-lattice work is not equal to the chemical potential of the dislocation during dislocation creation rate processes. This suggests, in terms of Onsager's relationships, a form for the models to be used for the irreversible thermodynamic processes.

SWIFT, R. P., and A. S. Kusubov, "Technique for Studying Multiple Fractures Produced at Intermediate Loading Rates," The State of the Art in Rock Mechanics, Proc. 21st U.S. Sympos. Rock Mechanics (Rolla, MO, May 28-30, 1980), pp. 682-690. [UCRL-83653, Preprint]

A laboratory experimental technique has been developed to study the effects of pressurizing the borehole of rock samples with tailored pulses at

intermediate loading rates. The technique provides a way to identify loading conditions needed to initiate and sustain multiple fracture growth from a borehole. Controlled loading conditions are achieved by compressing fluid in a borehole with a piston engaged by a profiled cam mounted on a rotating shaft. The experimental apparatus provides sample confinement to 50 MPa pressure, borehole pressures up to 200 MPa with loading rates from 0.01 to 100 MPa/ms, and pulse durations on the order of 1 to 50 ms. Observations from tests on a dense quartz sandstone under ambient confinement of 0.1 MPa are as follows: for static loading with oil, the breakdown pressure is about 21 MPa and two fractures oriented at 180 degrees are produced. For loadings with water at rates of about 10 MPa/ms, the breakdown pressure increases to about 30 MPa and multiple fractures are created. For loading rates between 50 to 90 MPa/ms, the breakdown pressure increases to 35 MPa and there is an increase in the number of initiated fractures. The dependence of breakdown pressure on the loading rate is attributed to the transient water-intrusion effects around the borehole.

SWIFT, R. P., and D. E. Burton, "Calculations Illustrating Stemming Closure and Containment Phenomenology for a Low Yield Nuclear Event," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), p. 49.

Two TENSOR (an explicit finite difference code) calculations were performed for a low yield nuclear event with a horizontal line-of-sight (HLOS) tunnel in order to study stemming plug formation induced by ground shock and to assess the subsequent integrity of the stemming plug during and after the development of a residual stress cage. One calculation, Case A, employed an axisymmetric configuration to represent the grout-lined tunnel embedded in tuff rock. Three different rock matching grouts formed the tunnel walls with the stronger grouts located closer to the source. The other calculation, Case B, modeled the influence of three concrete baffles keyed into the grout and tuff at different ranges along the HLOS tunnel.

Both calculations were carried out to 80 ms at which time equilibrium was firmly established. They showed the following phenomenology: (1) a high velocity (jet-type) flow of grout that could be extremely hazardous to experiments in the HLOS test section developed early in collapse process along the axis of the tunnel. Baffles did not influence jetting because the ground shock had yet to interact with the first baffle by the time jetting ceased at 3.2 ms. (2) One effect of the baffles was to inhibit the stemming closure process, causing the stemming plug thickness to be reduced from $2.23 R_c$ (cavity radius) to $1.27 R_c$. (3) The baffles failed in tension opening fractures that could act as permeable ducts to the unstemmed portion of the tunnel. (4) A good residual stress cage of about $3.6 R_c$ thick was formed in the tuff around the cavity for both cases, but was thinner in the stemming region for Case A, $1.5 R_c$, and further degraded in Case B by the presence of baffles to $0.7 R_c$. The integrity of the containment region for Case B is quite suspect because of a strong possibility for the thin stemming plug to fail by hydrofracture.

SWIFT, R. P., D. E. Burton, and L. R. Moreno, Calculations of the Stemming and Containment Phenomenology for the Hybla Fair Event (U), Lawrence Livermore National Laboratory, Rept. UCRL-52998 CFRD (1980).

(Unclassified abstract) Two TENSOR (an explicit, finite-difference code) calculations were performed to address the phenomenon of ground shock-induced closure of the stemming column and to assess the effect of this closure on late-time containment for the low-yield horizontal line-of-sight (HLOS) event, HYBLA FAIR. Both calculations employed an axially symmetric configuration to represent the stemming region, which in actuality was highly asymmetric. One calculation, case A, modeled the three semi-block concrete baffles keyed into the grout stemming and tuff rock as donuts located at their appropriate ranges along the stemming column. In the other calculation, case B, the baffles were removed so as to ascertain their influence on the closure process.

Both calculations were carried out to 80 ms, at which time equilibrium was firmly established. They showed the following phenomenology: (1) a high velocity (jet-type) flow of grout that could be extremely hazardous to experiments in the HLOS test section developed early in collapse process along the axis of the tunnel. Baffles did not influence jetting because the ground shock had yet to interact with the first baffle by the time jetting ceased at 3.2 ms. (2) One effect of the baffles was to inhibit the stemming closure process, causing the stemming plug thickness to be reduced from $2.23 R_C$ (cavity radius) to $1.27 R_C$. (3) The baffles failed in tension opening fractures that could act as permeable ducts to the unstemmed portion of the tunnel. (4) A good residual stress case of about $3.6 R_C$ thick was formed in the tuff around the cavity for both cases, but was thinner in the stemming region for case B, $1.5 R_C$, and further degraded in case A by the presence of baffles to $0.7 R_C$. The integrity of the containment region for case A is quite suspect because of a strong possibility for the thin stemming plug to fail by hydrofracture.

SWIFT, R. P., and D. E. Burton, Stemming and Containment Phenomenology for the Hybla Fair Event, Lawrence Livermore National Laboratory, Rept. UCID-18628 (1980).

Two TENSOR code calculations were performed to address the phenomenon of ground shock-induced closure of the stemming column and to assess the effect of this closure on late time containment for the low yield HLOS event, Hybla Fair. Both calculations employed an axisymmetric configuration to represent the stemming which in actuality was non-axisymmetric. In the highly non-axisymmetric baffle regions, one calculation conserved the mass of the baffles by representing them as donuts enclosing the corresponding conserved masses of grout stemming material. In order to ascertain the influence of the donut baffles on the closure process, another calculation was performed with the baffles removed. The boundary condition for both calculations was a pressure profile applied at the interface between the tunnel bed tuff and sands that surrounded the work point. This boundary condition was derived from a SOC calculation using the iron gas source model. Differences in the two TENSOR calculations are localized to the stemming region and attributed to the concrete baffles. The closure rate and closure thickness are somewhat perturbed by the presence of the baffles, and the containment lock-up stresses in the stemming region are highly dependent on material strengths and boundary interaction effects.

Swift, R. P., and A. S. KUSUBOV, "Rock Fracture at Intermediate Loading Rates," Trans. Am. Geophys. Union 61, 373 (1980). [UCRL-84033, Abstract]

Swift, R. P., R. N. SCHOCK, M. E. Hanson, and O. R. Walton, "In Situ Fracture Related to Energy and Resource Recovery," in High Pressure Science and Technology, B. Vodar and P. Marteau, Eds. (Pergamon Press, Oxford, 1980), pp. 902-912. [UCRL-82731, Preprint]

TAYLOR, S. R., and M. N. Toksoz, "Measurement of Interstation Phase and Group Velocities and Q Using Wiener Filtering," Trans. Am. Geophys. Union 61, 1043 (1980).

A method for calculating interstation phase and group velocities and relative attenuation coefficients using a Wiener (least squares) filtering technique is presented. The interstation transfer (or Green's) function is estimated from two stations lying along the same great circle path. The estimate is obtained from a Wiener filter constructed to predict the signal at the station further from the source from the signal recorded at the nearer station.

The interstation group velocity is obtained by applying the multiple filtering technique to the transfer function, and the interstation phase velocity from the phase of the transfer function. The amplitude spectrum of the transfer function is used to calculate relative attenuation between the two stations. The Q values calculated from the transfer function appear to be more stable than those obtained by taking spectral ratios.

The method is particularly useful for paths involving short station separations and is applied to a surface wave path crossing the Iranian Plateau. Shear velocity structure is then derived by a simultaneous inversion of Rayleigh wave phase and group velocities using a maximum-likelihood technique.

TERHUNE, R. W., M. E. Hanson, and C. R. McKee, Explosion Phenomenology and Permeability Enhancement in Earth Media, Lawrence Livermore National Laboratory, Rept. UCRL-84784, Abstract (1980).

Detonation of tamped explosives in a borehole results in a shock wave with a peak stress of about 100 kbar propagating into the rock. The effects of high intensity stress waves on the rock have been deduced from numerical computer calculations which simulate the physics associated with the process and verified by comparison with experimental measurements. The shock wave attenuates as it propagates away from the borehole by fracturing and compacting the rock until at some distance from the borehole the peak stress is below the elastic limit of the earth media and the wave propagates quasi-elastically. Near the borehole the rock is pulverized with exceptionally high fracture frequency, but the explosion-produced fracture density decreases rapidly with distance until reduced to a few short isolated tensile fractures. The porosity is severely reduced near the borehole, but increases to near or slightly above preshot value in the tensile fracture region. The rebound of the elastic media creates a compressive hoop stress in the fractured media around the explosive cavity which tends to temporarily close those fractures oriented radially from the borehole.

Relationships describing permeability enhancement using explosives fired in boreholes have been derived and compared with existing field measurements.

The theory predicts that explosive permeability enhancement behaves according to a power law relationship. The degree to which permeability can be enhanced with high explosives depends on material properties and initial fracture density. Porosity distribution from the explosive is the dominant parameter in permeability enhancement. Permeability as a function of radius has been measured from the American Hardhat nuclear shot, the French nuclear events in North African Hoggar granite, and a chemical explosive shot in coal near Kemmerer, Wyoming. Significant correlation of permeability between theory and field measurements has been established. Some comparisons of explosive stimulation with variants of hydraulic fracturing have been made with Devonian shale wells. It was seen that in terms of open flow potential, foam fracturing provides the greatest indicated permeability enhancement.

Terhune, R. W., H. D. GLENN, J. B. Bryan, and L. R. Moreno, Destruction of the Peninsula Device (U), Lawrence Livermore National Laboratory, Rept. UCID-18511 CFRD (1980).

Tewhey, J. D., L. W. YOUNKER, and P. W. Kasameyer, Geological, Geophysical, and Thermal Characteristics of the Salton Sea Geothermal Field, California, Lawrence Livermore National Laboratory, Rept. UCRL-84230, Preprint (1980).

Tewhey, J. D., D. G. COLES, and H. C. Weed, Geochemical Studies of Sorption and Transport of Radionuclides in Rock Media, Annual Report, FY 1979, Lawrence Livermore National Laboratory, Rept. UCRL-52929, Rev. 1 (1980).

THIGPEN, L., Seismic Waves in a Horizontally Stratified Half-Space, Lawrence Livermore National Laboratory, Rept. UCRL-53072 (1980).

The reflectivity method for computing synthetic seismograms as developed by Fuchs and Muller and extended by Kennett is modified to include both body and surface waves from a buried source in a layered half-space. Some details of the general method are presented. The vertical components of the displacement are computed for various structures at different source locations to elucidate numerical difficulties encountered with the reflectivity method. Portions of the seismograms are interpreted in terms of reflected, refracted and surface waves.

THIGPEN, L., and R. C. Y. Chin, On Constitutive Models for Compressive Loading of Geologic Materials, Lawrence Livermore National Laboratory, Rept. UCRL-53073 (1980).

This paper addresses some aspects of the theory of plastic straining which unify the constitutive equations for geologic materials under compressive loading. Effort is devoted to generalizing of existing models with particular emphasis on ascertaining the minimum number of phenomenological coefficients to adequately represent these models. Results show both single-mode and multiple-mode plasticity models may be generalized to the same form. Five

phenomenological coefficients are adequate to describe the response of strain hardening materials to compressive loading.

Thigpen, L., G. W. HEDSTROM, and R. C. Y. Chin, A Quadrature Method for Synthetic Seismograms, Lawrence Livermore National Laboratory, Rept. UCRL-84012, Abstract (1980).

The reflectivity method requires the evaluation of integrals of the form

$$\int_0^{\infty} J_n(kr) R(k) \exp \{ \Sigma i h_j v_j(k) \} dk.$$

This integral has two sources of numerical difficulty: the poles of $R(k)$ and the oscillations of the Bessel function and exponential. We remove the oscillations by writing J_n in terms of Hankel functions,

$$J_n = (H_n(1) + H_n(2))/2,$$

and by deforming the path of integration so that it is a path through a saddle point for

$$H_n(m)(kr) \exp \{ \Sigma i h_j v_j(k) \}.$$

We handle the poles by finding them and calculating their residues. The resulting algorithm is reliable and efficient, and the error can be estimated.

Thigpen, L., R. C. Y. CHIN, and G. W. Hedstrom, Matrix Methods in Synthetic Seismograms, Lawrence Livermore National Laboratory, Rept. UCRL-84005, Abstract (1980).

The Haskell-Thomson formalism and Kennett's recursive algorithm in computing synthetic seismograms can be unified by considering the formulation of the inherent linear algebraic problem. In the Haskell-Thomson formalism, the linear system is cast in a block bi-diagonal form. In this form it is well known that numerical error propagation is severe. We rearrange the equations and variables to obtain a block tri-diagonal linear system. We decompose the coefficient matrix using a discrete invariant imbedding algorithm to obtain Kennett's recursive method involving the generalized reflection coefficients. Equivalently, the block tri-diagonal coefficient matrix may be decomposed into upper and lower block bi-diagonal matrices. Here, the upper and lower bi-diagonal matrices do not have immediate physical interpretation. The block tri-diagonal structure is also obtained in finite-element or finite-difference solutions of the transformed governing equations of elastodynamics. Richard's full-wave theory can also be cast in this form.

Thigpen, L., and R. B. STOUT, Modelling Microcrack Kinetics in Rocks, Lawrence Livermore National Laboratory, Rept. UCRL-83994, Preprint (1980).

Thigpen, L., R. B. STOUT, and J. Peterson, "Stochastic Microcrack Modelling in Rock Material," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), pp. 45-46.

Thorson, L. D., M. E. HANSON, G. D. Anderson, R. J. Shaffer, D. F. Towse, L. Lin, and M. P. Cleary, LLL Gas Stimulation Program Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, Rept. UCRL-50036-79-4 (1980).

Thorson, L. D., M. E. HANSON, G. D. Anderson, and R. J. Shaffer, Some Effects of Stress, Friction, and Fluid Flow on Hydraulic Fracturing, Lawrence Livermore National Laboratory, Rept. UCRL-85003, Abstract (1980).

TOWSE, D., A Review of the Mechanics and Occurrence of Natural Fractures in Rock as Applied to the Development of the Tight Western Gas Sands, Lawrence Livermore National Laboratory, Rept. UCRL-52908 (1980).

Data on natural rock fractures and measurement or estimates of stress show promise as an aid in predicting the orientation and continuity of both natural and artificial fractures in natural gas reservoirs. Overbey and Rough, for instance, have shown that one set of surface joints in the Bradford field in Pennsylvania nearly parallels the direction of artificial hydraulic fractures in the reservoir.

The "tight gas sands" in the Rocky Mountains are thin, discontinuous, and have low permeability. They are found in gently folded rocks and often have abnormally high pore pressure.

In a relaxed tectonic setting, one principal stress is most often nearly vertical and the other two horizontal. Natural fractures usually approximate the same orientation to stresses as those produced experimentally. Increased pore pressure extends the depth to which extensional fractures can occur; these tend to form perpendicular to the direction of the least principal stress.

Local stresses that control small features such as joints may be different from, although compatible with, regional stress. In folded rocks, sliding and bending forces appear to be most important in forming the smaller structures, such as joints. Fractures can be formed by flexing during downwarp and uplift; more intense folding or faulting is not necessary.

Fractures are controlled by the physical environment, the stresses, and the nature of the rock. Changes in stress due to burial and uplift are also important. Jointing frequency is greater in weak and thinly bedded rocks and is directly related to intensity of folding.

Two sets of both shear and extensional fractures may develop: one oriented parallel, the other normal, to axes of folding or downwarp. These relations may be used to extrapolate fracture patterns laterally or into the subsurface.

TOWSE, D., Geologic Factors Affecting the Development of the Tight Western Gas Sands (2nd Chem. Cong. N. Am. Continent, San Francisco, CA, Aug. 25-28, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84630, Abstract (1980).

Synthesis of geologic information, well log data, and material properties from core analyses provides some important boundary conditions required for analysis and production of the western gas sands.

Their mechanical and hydraulic properties and the stress regime are the product of a variable history of mechanical and thermal stress acting on the original reservoir material. The mechanical and thermal history is determined directly from the rock's mineralogy and fabric and indirectly from geologic evidence on the amount and rate of deposition, burial, and tectonic distortion.

These data are used to calculate maximum and minimum regional strain; with laboratory-measured mechanical properties, the corresponding stresses are calculated. These change in time with alternating burial, uplift, and erosion. Minimum distortion required for fracturing to occur can be calculated. Data indicate that this minimum has generally been exceeded. Preliminary information indicates that artificial fractures generally lie parallel to the natural ones.

Changes in the chemistry and pressure of the formation fluids, pore shapes and sizes and surface mineralogy are responses to burial, uplift, and structural deformation. Rapid burial of tight reservoirs has developed abnormally high pressures in the deeper basins. Present reservoir configurations and properties are the results of different geologic histories on similar original sediments, as is shown by comparison of "tight" sands in the Denver, Green River, and the Uinta basins.

TOWSE, D. F., "Evolution and Stress History of Low-Permeability Upper Cretaceous Gas Reservoirs, Rock Mountains," AAPG Bull. 64, 794 (1980).
[UCRL-83514, Abstract]

The physical properties of the Mesaverde gas reservoirs in Wyoming, Utah, Colorado, and New Mexico are the result of stress-induced changes that modified the sediment's original properties. Consideration of the stress history aids in interpretation of well log data and in understanding the reservoir performance that is controlled by natural or artificial fractures.

The poorly sorted and discontinuous reservoir sands were formed in a shifting nearshore environment in a region of nascent tectonic compression. Rapid sedimentation induced compaction and diagenesis, and later Tertiary burial continued compression and promoted some thermal stress. Laramide wrench-faulting could cause early shear fractures; a later uplift-reburial-uplift sequence, together with episodes of extensional tectonics, could promote tensional fracturing and a reorientation of fractures and other structures in the well-indurated sediments.

Reservoir style is a result of several aspects of basin history, e.g., the depth of Tertiary burial in the Green River versus the San Juan basin. The regions considered are now generally inactive seismically, and there has been very little igneous activity since Cretaceous time, as contrasted to most nearby areas in the Rocky Mountains.

Towse, D. F. M. E. HANSON, G. D. Anderson, R. J. Shaffer, L. Lin, L. D. Thorson, and M. P. Cleary, LLL Gas Stimulation Program Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, Rept. UCRL-50036-79-4 (1980).

Towse, D. F., M. E. HANSON, G. D. Anderson, R. J. Shaffer, W. Lin, M. P. Cleary, D. R. Peterson, S. K. Wong, and B. C. Haimson, LLNL Gas

Stimulation Program Quarterly Progress Report, January Through March 1980,
Lawrence Livermore National Laboratory, Rept. UCRL-50036-80-1 (1980).

TRIMMER, D., B. Bonner, H. C. Heard, and A. Duba, "Effect of Pressure and Stress on Water Transport in Intact and Fractured Gabbro and Granite," J. Geophys. Res. 85, 7059-7071 (1980). [UCRL-83932, Preprint]

New laboratory data are reported on the effect of confining pressure, pore-water pressure, and stress difference on permeability of intact and fractured White Lake gneissic granite, Westerly granite, and Creighton gabbro. Permeabilities as low as 10^{-24} m² (10^{-12} Darcy) have been measured using a transient technique. Fracture displacement, electrical conductance, compressional velocity, and pulse amplitude are determined simultaneously. The loads applied to the 0.15-m diameter by 0.28-m length test sample are controlled automatically, and most data are taken by microcomputer.

Tests on the intact gneissic granite indicated permeabilities of 10^{-22} to 10^{-24} m² that appeared to be unaffected either by effective pressure or by stress. The granite yielded permeabilities of 4×10^{-20} m² that decreased by a factor of two as effective pressure increased to 25 MPa and varied by a factor of two with stress. Permeability of the gabbro linearly decreased from 2×10^{-22} to 8×10^{-24} m² with pressure to 25 MPa. Loading of the gabbro up to 0.88 of the fracture stress increased permeability by a factor of seven. The introduction of a throughgoing fracture increased the apparent permeability by 10^6 to 10^{10} over the intact values in both granite and gabbro.

TRIMMER, D., C. Boro, E. Arnold, and K. Keller, An Apparatus for Measuring Ultra-low Permeabilities at Pressure and Temperature, Lawrence Livermore National Laboratory, Rept. UCRL-84995, Abstract (1980).

A hydraulic fracturing process is often used to enhance natural gas recovery. Pore pressure effects and changes in pore pressure due to invasion of fluid from the fracture may play an important role in determining the geometry of the created fracture, especially in the lenticular Western reservoirs. Evaluation of fracture length from a pressure test and production data requires an accurate knowledge of in-situ fluid transport. Therefore, the measurement of reservoir and source rock permeabilities at in-situ conditions is important to understanding the fracturing process as well as evaluating the created fractures.

We report here a new apparatus capable of measuring gas or water permeabilities of representative rocks at in-situ pressures and temperatures. Permeabilities of 10^{-16} to 10^{-24} m² (10^{-4} to 10^{-12} darcy) can be measured for multiple samples (44-mm diameter by 76 mm long) at confining pressures to 100 MPa, pore pressures to 50 MPa, and temperatures to 350°C. These conditions correspond to those found in the deepest production zones (10,000 m). Permeability data at pressure and temperature for several representative rocks are reported.

TRIMMER, D., and H. C. Heard, "Compaction and Permeability of Oil Shale Aggregates at High Temperatures," Soc. Petrol. Eng. J. 20, 95-104 (1980). [UCRL-80104, Preprint]

We have measured the change in bulk volume and permeability of an oil-shale aggregate subjected to high temperatures and pressures in a one-dimensional strain loading configuration. At stresses of 0.69 to 6.2 MPa and temperatures as high as 700°C, the 6-liter sample may compact by as much as one-third, and permeability may decrease by factors of 10 to 100. There is no simple relationship between strain or porosity and permeability. Attempts to analyze the data in terms of a Kozeny-type equation were unsuccessful.

Trimmer, D. A., W. B. DURHAM, and A. E. Abey, Thermal Conductivity, Diffusivity and Expansion of Avery Island Salt at Pressure and Temperature (ITCC and ITES Conf., Chicago, IL, Nov. 7-9, 1979), Lawrence Livermore National Laboratory, Rept. UCRL-83789, Preprint (1980).

Trimmer, D., H. C. HEARD, W. B. Durham, and A. Abey, "Thermal, Thermal-Elastic, and Water Transport Behavior of Generic High-Level Waste Repository Rocks," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 444 (1980). [UCRL-84404, Abstract]

Tripp, L., F. J. ACKERMAN, W. Sandholtz, J. Raley, J. Carley, A. Rothman, and J. Campbell, Oil Shale Project Large Retort Run Summary L-3, Lawrence Livermore National Laboratory, Rept. UCID-18595 (1980).

Tripp, L., F. J. ACKERMAN, W. Sandholtz, J. Carley, and J. Raley, Oil Shale Project Run Summary, Small Retort Run S-16, Lawrence Livermore National Laboratory, Rept. UCID-18618 (1980).

Tripp, L., W. SANDHOLTZ, F. J. Ackerman, J. Raley, and J. Carley, LLL Oil Project Small Retort Run Summary, Run S-17, Lawrence Livermore National Laboratory, Rept. UCID-18899 (1980).

Tripp, L., F. J. ACKERMAN, W. Sandholtz, J. Raley, and J. Carley, Oil Shale Project Run Summary, Small Retort Run S-18, Lawrence Livermore National Laboratory, Rept. UCID-18897 (1980).

Tripp, L., F. J. ACKERMAN, W. Sandholtz, J. Raley, and J. Carley, Oil Shale Project Run Summary Small Retort Run S-19, Lawrence Livermore National Laboratory, Rept. UCID-18898 (1980).

WAGONER, J. L., "Grain-Size Distribution Analysis of Nonmarine Sandstone, Imperial Valley, California," Geol. Soc. Am. Abst. with Prog. 12, 158 (1980).

Grain-size distribution analyses were performed on 61 sandstone samples from the Pleistocene Brawley and Borrego Formations of the Imperial Valley,

California. Three depositional environments are identified: fluvial-deltaic, nearshore shallow lacustrine, and quiet water lacustrine deposition. The depositional environments are differentiated by linear discriminant analysis, bivariate plots, and sedimentary textures. Statistical grain-size parameters most useful in differentiating the depositional environments are mean and standard deviation. Bivariate plots of standard deviation vs. skewness, standard deviation vs. mean, and 1st percentile vs. median best identify the depositional environments. Fluvial-deltaic sand has a mean grain-size of 1.3 ϕ (medium sand) and standard deviation of 1.13 (poorly-sorted). Large-scale planar and trough cross-bedding and channeling are characteristic of these sediments. Shallow lacustrine sand has a mean grain-size of 2.7 ϕ (fine sand) and standard deviation of 0.64 (moderately well-sorted). Ripple-drift cross-lamination and small-scale cross-bedding are common. Quiet water lacustrine sand has a mean grain-size of 3.6 ϕ (very fine sand) and average standard deviation of 1.0 (moderate to poor sorting). These sandstones are generally interbedded with thick mudstone-siltstone sequences and have ripple-drift cross-lamination and thinly laminated planar bedding. Sandstones deposited in the three depositional environments occur throughout the stratigraphic sections and are not restricted to specific parts of the basin. This suggests that changes in the sandstone were a function of changes in energy conditions, due to periodic transgression and regression of the ancient lake system.

WAGONER, J. L., Use of Fourier Grain Shape Analysis to Differentiate Source Terrains in the Owens Valley, East-Central California (Geol. Soc. Am., Atlanta, GA, Nov. 17, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-84837, Abstract (1980).

Fourier grain shape analysis was used to identify three basic source terrains in the Owens Valley, California: Precambrian marine clastics, Quaternary tuffaceous volcanics, and Mesozoic granitics. The Fourier analysis uses normalized frequency distributions of shape components (harmonic amplitudes) of quartz grains to distinguish sources of sediment. Sediment samples were collected from alluvial fans which received detritus from the various rock types. For each sample, 200 quartz grains in the very fine to fine sand class (106-150 μ) were analyzed using a manual digitizing system. The three rock types are best identified by plotting mean harmonic amplitude vs. harmonic number. In general, granitic source sediments have the highest mean harmonic amplitudes, volcanic source samples have intermediate amplitudes, and clastic source samples have the lowest. Chi-square statistical tests show significant differences between different sources at several harmonics and few differences between similar lithologic types. The greatest difference exists between the granitic and clastic sources, where 14 of 20 harmonics show differences at the 0.05 significance level. Histograms of harmonic amplitudes were useful to define the nature of significant differences between sources. A mixed sample from both granitic and volcanic sources has mean amplitudes intermediate between the granitics and volcanics, indicating probable contributions from both sources.

Wagoner, J. L., T. L. STEINBORN, B. Qualheim, C. R. Fitts, R. E. Stetkar, and R. W. Turnbull, Recommended New Criteria for the Selection of Nuclear

Waste Repository Sites in Columbia River Basalt and U.S. Gulf Coast Domed Salt, Lawrence Livermore National Laboratory, Rept. UCRL-52749 (1980).

Screening criteria and specifications are recommended to aid in the evaluation of sites proposed for nuclear waste disposal in basalt and domed salt. The recommended new criteria proposed in this report are intended to supplement existing repository-related criteria for nuclear waste disposal. The existing criteria are contained in 10 CFR 60 sections which define siting criteria of the Nuclear Regulatory Commission (NRC), and ONWI 33(2) which defines siting criteria of the Office of Nuclear Waste Isolation (ONWI) for the Department of Energy. The specifications are conditions or parameter values that the authors recommend be applied in site acceptance evaluations. The siting concerns covered in this report include repository depth, host rock extent, seismic setting, structural and tectonic conditions, groundwater and rock geochemistry, volcanism, surface and subsurface hydrology, and socioeconomic issues, such as natural resources, land use and population distribution.

Wagoner, J. L., R. STONE, K. P. Puchlik, and R. D. McArthur, "Investigation of Potential UCG Sites in Wyoming," in LLL In Situ Coal Gasification Project Quarterly Progress Report, October Through December 1979, Lawrence Livermore National Laboratory, UCRL-50026-79-4 (1980).

Wagoner, J. L., R. STONE, L. L. Rogers, K. P. Puchlich, and W. B. McKinnis, "Selection and Characterization of a Potential Underground Coal-Gasification Site in Washington," in LLNL In Situ Coal Gasification Project Quarterly Progress Report, April Through June 1980, Lawrence Livermore National Laboratory, Rept. UCRL-50026-80-2 (1980), pp. 9-20.

Wagoner, J. L., D. W. CARPENTER, K. P. Puchlik, A. L. Ramirez, K. G. Knauss, and P. W. Kasameyer, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume I: Text and Appendices A-E, Lawrence Livermore National Laboratory, Rept. UCRL-53065, Vol. I (1980).

Wagoner, J. L., D. W. CARPENTER, and A. L. Ramirez, Status Report on the Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, Volume II: Appendix F, Lawrence Livermore National Laboratory, Rept. UCRL-53065, Vol. II (1980).

WALTON, O. R., Particle-Dynamics Modeling of Geological Materials, Lawrence Livermore National Laboratory, Rept. UCRL-52915 (1980).

A technique to calculate the motion of large numbers of arbitrarily shaped two-dimensional polygonal blocks interacting with elastic and viscous normal forces of tangential surface friction has been developed. The functional form of the interaction forces between the polygons is chosen to model the forces acting between macroscopic blocks and/or grains typical of geologic media. A

point-side contact force similar to that originally used by Cundall (1974) is used in the first version of the model. A second version incorporates a contact force proportional to the area of overlap between two polygons. The numerical techniques and data structures used to efficiently model each of these force laws are described. Comparison with analytic solutions for simple systems has verified the model's ability to calculate collision dynamics, rotational motion, surface friction and gravitationally driven failure of multi-block configurations. Direct comparison with physical experiments has verified the model's ability to predict the motion of real materials. Careful determination of the physical properties of the modeled material was found to be necessary for successful computer simulation of the motion. The calculated motion of discrete systems was often found to be strongly dependent on the manner in which the motion was initialized, and on the energy dissipation parameters used in the calculation. The computer program can produce color movies and trajectory traces of the simulated motion. Examples of the graphical output are shown. Possible applications and future extensions of the model are discussed.

WALTON, O. R., "Discrete Particle Modeling of the Motion of Fractured Material," in Abstracts 4th Biennial Cube Sympos. (Livermore, CA, Oct. 22-24, 1980), p. 29.

A technique to calculate the motion of large numbers of arbitrarily shaped two-dimensional polygonal blocks interacting with elastic and viscous normal forces and tangential surface friction is described. Several simplifying assumptions are made in this computer model in order to explicitly treat the complex flow behavior of fractured or rubblized materials. Comparisons with analytic solutions for simple configurations have been used to verify the model. Also, direct comparisons with physical experiments have been used to verify the model's ability to predict the motion of real materials. Potential geologic applications include calculations of oil-shale rubble movement, roof stability over coal-gasification beds and chimney formation during cavity collapse following an underground nuclear event. Computer-generated movie sequences showing the simulated motion will be shown along with high-speed movie sequences from physical tests of particle systems.

WALTON, O. R., W. Patrick, J. Carley, and J. Peterson, DIBS Solid Flow Model (3rd Briefing on Oil Shale Tech. Res., Livermore, CA, Nov. 19-21, 1980), Lawrence Livermore National Laboratory, Misc. Pub.-144 (1980), pp. 608-621.

Uninterrupted flow of oil shale rubble through a continuous feed surface retort is not always easy to achieve. During the retorting process, the preheating of raw shale as it approaches the retorting region and the condensing oil and water vapors carried by the counter current gas flow combine to significantly change the compressibility, surface friction, and interparticulate cohesion in the moving rubble. These changed properties can result in unexpected interruption in the solid material flow as arches, bridges, or other blockages occur. Empirical studies of material flow in bins and hoppers indicate that even weak cohesion between particles (such as that due to surface wetting) can give rise to cohesive arches across significant distances. One part of a study of the flow properties of oil shale rubble at

various loading and temperature conditions will be computer modeling of discrete particulate motion.

The Discrete Interacting Block System (DIBS) model calculates the motion of arbitrary polygonal particles interacting with contact forces, surface friction, and initial cohesion. Gravity and applied loads drive the motion. This model will be used to study the effects particle shape, surface friction, and interparticulate cohesion have on the flow properties of systems of particles. Past calculations with the model have verified its ability to calculate the motion of small sets of particles in rocking, sliding, and toppling configurations. (Movie sequences of these calculations and corresponding experiments will be shown.)

The macroscopic effects of changing various surface properties can be studied directly with the DIBS model. In a study starting this year, both the DIBS Model and continuum models will be used to model shear tests on oil shale rubble under various conditions. Using the values of the input parameters that give the best agreement with laboratory shear tests, these same models will then be applied to various surface retort flow geometries and temperature histories. Our plan is to develop a model of surface retort flow that can be effectively used to aid in the design of retorts without solid flow interruptions.

Walton, O. R., R. N. SCHOCK, M. E. Hanson, and R. P. Swift, "In Situ Fracture Related to Energy and Resource Recovery," in High Pressure Science and Technology, B. Vodar and P. Marteau, Eds. (Pergamon Press, Oxford, 1980), pp. 902-912. [UCRL-82731, Preprint]

WEED, H. C., F. Bazan, J. H. Rego, J. S. Schweiger, and J. E. Fontanilla, Sorption of Radionuclides from Water and Brine on St. Peter Sandstone (Sympos. Sorption from Aqueous Solu., Am. Chem. Soc., Houston, TX, Mar. 23-28, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-83589, Preprint (1980).

Migration rates and retardation factors have been measured for ^{85}Sr , ^{95}mTc , and ^3H in St. Peter sandstone cores, using sandstone-equilibrated water or a synthetic brine ($\sim 4\text{M}$ in NaCl) as the transporting fluid. Cores are 26-mm diameter x 25-mm length. During the measurement, steady flow is first established along the core. Then a short pulse of mixed radionuclide solution is injected at the inlet face, transported along the core, and collected in the effluent as a function of time. Migration rates are obtained from the effluent activity vs. time curves since less than 1.5% of the injected radionuclides remain in the core. Retardation factors (R) and sorption ratios (K_d) are calculated from the migration rates assuming local equilibrium between radionuclide solution and rock, linear sorption isotherms for ^{85}Sr and ^{95}mTc , and $R = 1$ for ^3H as tritiated water. From experiments lasting up to 5 days, $R = 1$ and $K_d = 0$ for ^{95}mTc in both sandstone- H_2O solution and the synthetic brine. In sandstone- H_2O solution, $R = 13$ and $K_d = 0.81 \text{ cm}^3/\text{g}$ for ^{85}Sr . In the synthetic brine, $R = 1.78$ and $K_d = 0.05 \text{ cm}^3/\text{g}$ for ^{85}Sr ; there is good agreement between this result and one from static K_d measurements.

Weed, H. C., D. G. COLES, and J. D. Tewhey, Geochemical Studies of Sorption and Transport of Radionuclides in Rock Media, Annual Report, FY 1979, Lawrence Livermore National Laboratory, Rept. UCRL-52929, Rev. 1 (1980).

Four studies, which supported the goals of the WISAP Program at Battelle PNL, were undertaken by the Lawrence Livermore Laboratory during FY 1979. These were (1) batch K_d experiments, (2) dynamic sorption experiments on rock cores, (3) feasibility study for an in situ tracer test at the Climax Stock, NTS, and (4) geochemical equilibrium code development. Only the equilibrium code development was not funded by the WISAP during FY 1979.

The emphasis for the batch K_d studies was on various (15) sandstones in brine using ^{75}Se , ^{85}Sr , ^{125}Sb , ^{137}Cs , ^{141}Ce , and ^{237}Pu tracers. These sandstone samples were well-characterized for their physical and mineralogical nature. Complex K_d behavior was observed for the radionuclides studied, but ^{85}Sr showed K_d values near zero for all samples. Both ^{141}Ce and ^{239}Pu K_d values ranged from 20 to upper limits of $\geq 17,000$.

Dynamic sorption studies were done on NTS tuff and St. Peter sandstone cores using ^3H , ^{85}Sr , and ^{95}mTc . These radionuclides were injected as a short pulse into the rock-equilibrated water that was flowing through the core. Tracer-free water was then continually flowed through the core until elution curves for the mobile radionuclides were established. Tritium and ^{95}mTc both traveled through the cores at the same rate, indicating no sorption for the mobile fraction of ^{95}mTc ($^{95}\text{TcO}_4^-$). Strontium-85 did not exit the tuff cores but did exit the sandstone core although the elution curves showed definite retardation relative to the movement of ^3H and ^{95}mTc . Post-elution sectioning of the cores indicated that a fraction of the ^{95}mTc remained in the cores and was evenly distributed through the tuff cores. Strontium-85 showed a generally decreasing distribution from the inlet side to the outlet side of the tuff cores.

Weed, H. C., and A. J. PIWINSKII, "Dynamic Viscosity of Some Silicate Melts to 1688°C Under Atmospheric Pressure," Thermochimica Acta 37, 189-195 (1980). [UCRL-83126, Preprint]

WILDER, D. G., and W. C. Patrick, Geotechnical Status Report for Test Storage of Spent Reactor Fuel in Climax Granite, Nevada Test Site (Sympos. Geol. Disposal of High-Level Radioactive Wastes, AEG Mtg., Oct. 20, 1980), Lawrence Livermore National Laboratory, Rept. UCRL-85096, Abstract (1980).

Currently storage and retrieval of spent nuclear reactor fuel assemblies in granite are being tested 420 m (1400 ft) underground at the U.S. Department of Energy's Nevada Test Site. Eleven Westinghouse PWR spent fuel assemblies from Turkey Point Unit No. 3 (Florida) have been interspersed with six electrical heaters to compare the effects caused by heat alone with those of heat and radiation. Two parallel side drifts, which contain electrical heaters, allow a simulation within the central drift of the thermal field of a large single-level nuclear-waste repository. Instrumentation involved in this Spent Fuel Test includes multi-point rod extensometers, thermocouples, extensometers, three-axis fracture monitoring systems and Irad stress gauges. With emplacement complete, data on nuclear radiation, air and rock

temperature, humidity, rock stress, and displacements are being collected on a continuous basis by a computerized data acquisition system. Preliminary analysis indicates that geotechnical instruments are functioning except for Irad stress gauges located near the spent fuel canisters and rod extensometers in the canister drift. Stick-slip responses, possibly due to friction within the instruments, have been observed in all displacement instruments. While detailed interpretations for the data are premature, initial indications point to the tendency for deformations and stresses to increase more rapidly where there are shear zones.

Wilder, D. G., R. C. CARLSON, W. C. Patrick, W. G. Brough, D. N. Montan, P. Harben, L. B. Ballou, and H. C. Heard, Spent Fuel Test-Climax: Technical Measurements Interim Report FY 1980, Lawrence Livermore National Laboratory, Rept. UCRL-53064 (1980).

WOLERY, T. J., "Modelling Seawater-Basalt Interactions in a Flow-Through System with a Temperature Gradient," Proc. 3rd Int. Sympos. Water-Rock Interaction (Edmonton, Canada, July 14-21, 1980), p. 81. [UCRL-83940, Abstract (1980).

Circulation of seawater through the crust at mid-ocean ridges is a major process in cooling newly formed oceanic lithosphere. This paper introduces a new simple theoretical model for seawater-basalt interaction in a flow-through system with a temperature gradient. This is an extension of the closed system theoretical models presented by Wolery (1978), which were in at least qualitative agreement with laboratory experiments reported by Seyfried (1976), Seyfried and Mottl (1977), and Seyfried and Bischoff (1979).

WOLERY, T. J., Chemical Modeling of Geologic Disposal of Nuclear Waste: Progress Report and a Perspective, Lawrence Livermore National Laboratory, Rept. UCRL-52748 (1980).

Chemical interactions among nuclear waste, groundwater, waste packaging, and rock are complex but critical factors in determining the consequences of geologic waste disposal. This report presents a perspective on the development of a theoretically based chemical modeling capability for application to nuclear waste geochemistry. It also presents some progress made in developing this capability.

The starting point in this study is the thermodynamic-arbitrary kinetics modeling developed by geochemists to study rock-water interactions. A number of other materials, including crystalline waste forms, packaging, buffers, and backfills, can be brought into this model by supplying appropriate thermodynamic data. In addition, other phenomena can, in principle, also be included in the model. These phenomena include realistic (nonarbitrary) kinetics, sorption, and radiolysis. Recent progress in the understanding both of mineral dissolution kinetics and of ionic substitutions in solid solution reported in the geochemical literature may strongly impact the state-of-the-art of modeling waste form, packaging, and chemical buffer performance in the geologic disposal of nuclear waste.

The performance of the EQ3/EQ6 software package for geochemical modeling has been improved, and its thermodynamic data base has been expanded to

represent uranium and some other elements significant to waste disposal. Model calculations of UO_2 dissolution in granitic groundwaters confirm the importance of dissolved oxygen and of carbonate complexing of the uranyl ion in accounting for the magnitude of dissolved uranium in the temperature range 25 to 200°C. The maximum transient levels of dissolved uranium decrease with increasing temperature in this temperature range in response to the decreasing relative stabilities of the uranyl carbonate complexes. Simulations of UO_2 dissolution at 300°C based on thermodynamic extrapolations show higher levels of dissolved uranium. Speciation in these simulations is dominated by the complexes UO_2SO_4 and $\text{UO}_2(\text{SO}_4)_2^{2-}$.

Applications to waste-container-groundwater interactions are illustrated by simulations of the codissolution of UO_2 and Cu metal in an oxidizing granitic groundwater at 100 and 300°C. Copper may partially protect UO_2 (in a chemical sense) by consuming dissolved oxygen. It is an attractive packaging component because it and groundwater may reach a state of thermodynamic equilibrium.

YOUNKER, L. W., P. W. Kasameyer, and J. D. Tewhey, Geological, Geophysical, and Thermal Characteristics of the Salton Sea Geothermal Field, California, Lawrence Livermore National Laboratory, Rept. UCRL-84230, Preprint (1980).

The Salton Sea Geothermal Field is the largest water-dominated geothermal field in the Salton Trough in Southern California. The sequence of sedimentary rocks in the trough is approximately 6000 m thick and composed largely of detritus from the Colorado River. In the Salton Sea field, the sediments are relatively undeformed and can be divided into three categories as a function of depth: (1) low-permeability cap rock, (2) unaltered reservoir rocks consisting of sandstones, siltstones, and shales, and (3) hydrothermally altered reservoir rocks. The effect of thermally induced alteration in reservoir rocks has been that intergranular porosity and permeability are reduced with depth. The permeability in the field is enhanced by renewable fractures, i.e., fractures that can be reactivated by natural seismicity subsequent to being sealed by mineral deposition.

The Salton Trough is a northwest-trending rift valley that represents the landward extension of the Gulf of California into North America. The tectonic setting of the geothermal field is in an offset region between the San Andreas and Brawley faults. Despite the presence of a thick sequence of low-density detrital sediments, there is a regional gravity anomaly that is broad, positive, and associated with the trough. The anomaly has been attributed to: (1) crustal thinning resulting from extension and (2) emplacement of high density material beneath the axis of the trough. A local gravity high, probably resulting from hydrothermal alteration of the sediments, is associated with the field. In addition, magnetic surveys yield evidence of intrusive rocks beneath the geothermal field. Resistivity surveys indicate a large volume of brine-saturated rock between the surface and a depth of 2 km, and seismic refraction surveys indicate anomalously high velocities at shallow depths.

The Salton Sea field is characterized by temperatures of 300°C or higher at depths of 2 km. Temperature gradients are typically high near the surface and lower below 700 m. Surface gradients are fairly constant (0.36°C/m) and define a thermal cap not necessarily corresponding to the lithologic cap. At

the margin of the field, temperature gradients are low at the surface and increase with depth. The heat transfer mechanisms in the field can be modeled as a function of depth. The upper portion of the reservoir is impermeable to fluid flow and has a high temperature gradient consistent with conduction. The next layer is below the cap rock, but within the thermal cap, and is characterized by a lower temperature gradient produced by highly conductive sand units. The deep portions of the reservoir are characterized by low temperature gradients from convective flow of pore fluids. Geophysical and geochemical evidence suggests that vertical convective motion in the reservoir is confined to small units and that small-scale convection is superimposed on large-scale lateral flow of pore fluid.

YOUNKER, L., P. Kasameyer, and J. Hanson, "Application of Hydrothermal Modeling to the Selection of Deep Drilling Sites in the Salton Sea Geothermal Field," Trans. Am. Geophys. Union 61, 1149 (1980). [UCRL-84961, Abstract]

The development of quantitative convective flow models can be an important step in assessing sites for the Continental Scientific Drilling Program. These models can increase our understanding of the thermal system as well as highlight critical areas where additional data are needed. They can therefore help define scientific objectives and guide the selection of drilling sites.

To illustrate, we have modeled the convective system associated with the Salton Sea Geothermal Field. A simple lateral flow model adequately explains many of its shallow features. Heat is transferred from an inferred area of intrusion by horizontal spreading of hot water in a reservoir beneath an impermeable cap rock. An analytic model encompassing this transfer mechanism matches the observed temperature field and has been used to estimate flow rates, heat input, and the age of the presently observed system.

Observations of temperature, fluid composition, mineral assemblages, and permeability in a 5-km hole could place additional constraints on the hydrothermal model and thereby reduce uncertainties in these estimates. In particular, these data could establish the thickness of the reservoir and test alternative fluid recharge patterns.

Development of a refined heat transfer model would allow extrapolation of temperature data to find and characterize the heat source and to determine the optimum location for a deeper (10-km) hole. Interpretations of data from that hole could (1) establish heat and mass transfer mechanisms between the magmatic heat source and the hydrothermal system; (2) test fundamental aspects of the leaky transform model by establishing the source of the magma, intrusion mechanisms, and type of underlying crust; and (3) calibrate deep geophysical measurements throughout the Salton Trough.

Yunker, L. W., P. W. KASAMEYER, and J. M. Hanson, "Age of the Salton Sea Geothermal System as Inferred from the Thermal Data," Geol. Soc. Am. Abst. with Prog. (Atlanta, GA, Nov. 17-20, 1980) 12, 458 (1980). [UCRL-85117, Abstract]

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