9/20/95

CONTRACTOR REPORT

SAND94-2384
Unlimited Release
UC-814

Yucca Mountain Site Characterization Project

Frictional Sliding in Layered Rock Model: Preliminary Experiments

K. E. Perry, Jr., B. J. Buescher, D. Anderson, J. S. Epstein
Fracture Behavior Group
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415-2218

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000

Approved for public release; distribution is unlimited.

Printed September 1995

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

"Prepared by Yucca Mountain Site Characterization Project (YMSCP) participants as part of the Civilian Radioactive Waste Management Program (CRWM). The YMSCP is managed by the Yucca Mountain Project Office of the U.S. Department of Energy, DOE Field Office, Nevada (DOE/NV). YMSCP work is sponsored by the Office of Geologic Repositories (OGR) of the DOE Office of Civilian Radioactive Waste Management (OCRWM)."

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401, FTS 626-8401.

Available to the public from
National Technical Information Service
US Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A03
Microfiche copy: A01

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SAND94-2384
Unlimited Release
Printed September 1995

Distribution
Category UC-814

Frictional Sliding in Layered Rock Model: Preliminary Experiments

K.E. Perry, Jr., B.J. Buescher, D. Anderson and J.S. Epstein
Fracture Behavior Group
Idaho National Engineering Laboratory
P.O. Box 1625, Idaho Falls, Idaho 83415-2218

ABSTRACT

An important aspect of determining the suitability of Yucca Mountain as a possible nuclear waste repository requires understanding the mechanical behavior of jointed rock-masses. To this end we have studied the frictional sliding between simulated rock joints in the laboratory using the technique of phase shifting moiré interferometry. The models were made from stacks of Lexan plates and contained a central hole to induce slip between the plates when the models were loaded in compression. These preliminary results confirm the feasibility of the approach, and show a clear evolution of slip as function of load.

This page was left intentionally blank.

1 Introduction

Frictional sliding between simulated rock joints was studied in the laboratory using the technique of phase shifting moiré interferometry. Models were made from stacks of Lexan plates that had been sand-blasted to provide a uniform frictional interface. Each model contained a central hole bored normal to the plane of the plates, so that slip would be induced between the plates near the hole under compressive loading.

The design of the specimen was guided by preliminary experiments performed by Brown [1]. The most significant departure from the original model used by Brown was to increase the length of the model to eight times the diameter of the hole. This change insured a state of uniform far-field stress around the hole.

Diffraction gratings (300 lines/mm) were replicated on the front surface of the models and interrogated with a phase shifting moiré interferometer. During monotonic loading of the models, fringe patterns representing the in-plane surface displacements were recorded at several loads. The relative slip between the plates was determined from these fringe patterns as a function of position along the interface.

The measurements made using the phase shifting moiré interferometer have a precision on the order of $1.67\text{ }\mu\text{m}$, with a spatial resolution of approximately 0.13 mm (this is based on a viewing width of 60 mm discretized to 512 pixels and 256 gray levels). Because the smoothing provided by phase shifting does not distort the detail near edges and discontinuities, the information right up to the edge of the plates could be used to determine relative slip between plates.

The experimental details concerning the fabrication of the models, the load frame and fixture, and the data acquisition procedures are summarized below. Finally, results for two experiments are presented in the form of color fringe plots and plots of slip versus position along the interfaces around the hole.

The work described in this report is part of the rock mechanics program at Sandia National Laboratories for the Yucca Mountain Site Characterization Program. The laboratory-scale experiments conducted for this work are intended to provide high quality data on the mechanical behavior of jointed structures that can be used to validate complex numerical models for rock-mass behavior. Given the difficulty in obtaining the quality and quantity of data necessary for code validation efforts from field experiments, this work provides essential information for the activities.

2 Experimental Details

2.1 Model Construction

The models were constructed from 12 plates, 2 in. wide by 12 in. long, of 0.25 in. thick Lexan. After cutting and squaring, both sides of all the plates were sand-blasted using a careful procedure to ensure a uniform surface roughness. The plates were then clamped together using threaded round stock inserted through two holes drilled from top to bottom, about 0.5 in. from the sides of the model. The faces of the models were machined flat, and a 1.5 in. diameter hole was bored through the center. The models were then disassembled and finished as follows:

1. The ends of the individual plates were beveled with a grinding wheel to allow them to be secured later with PC-6 epoxy. After grinding, the plates were washed with soap and water to remove grit.
2. The middle plates were temporarily bonded together with silicone to allow an aluminized photoplate diffraction grating to be replicated in epoxy on the resulting surface without epoxy seeping between the Lexan layers by capillary action.
3. After the silicone was cured, the front surfaces of the models were polished flat against a precision granite surface with fine grit sandpaper.
4. After cleaning the front surface with soap and water, a 300 lines/mm grating was replicated onto each model using Photolastic PC-6 epoxy.
5. The plates were then separated so that the silicone could be removed from between them. The edges of the gratings were gently polished with fine sandpaper to remove any "overlap" that would interfere with the sliding of the plates.
6. The models were carefully cleaned and completely reassembled. Finally, the ends of each model were bonded with PC-6 epoxy, which seeped in between the beveled edges to provide a strong yet flexible means to keep the plates aligned properly.

2.2 Load Frame and Fixture

A compact load frame designed for use on an optical table was constructed for this work. Screws and fixtures with a capacity of 500 kN were used to ensure stiffness. Gear boxes were chosen to provide sufficient mechanical advantage to allow the frame to be operated by hand. This avoided potential vibration problems from an electric drive motor. The useful load limit of the frame is determined by the installed load cell, which has a working range of 0–80 kN tension or compression. The load frame design allows a biaxial loading mechanism to be added in the future. The frame is currently being equipped with a linear bearing system to allow translation of the frame (and thus the model) across the field of view of the interferometer.

A custom load fixture for the model was constructed from two 2 in. wide by 12 in. long by 2 in. high steel bars. An additional length of steel bar was used, in conjunction with a pair of dowel pins, to distribute the specimen load evenly. The fixture and the model are shown schematically in Figure 2.

2.3 Material and Interfacial Properties

The wave velocities for Lexan were measured and found to be 2.2 km/sec for compression and 0.92 km/sec for shear. The density of the material is 1.20 g/cm³, resulting in the following elastic properties: Young's modulus, $E = 2.84$ GPa; Shear modulus, $G = 1.02$ GPa; Poisson's ratio, $\nu = 0.39$.

The coefficient of friction between the sand-blasted plates (as measured by tilting the block) was determined to be 0.47. All of these properties agree with values presented in the

report by Brown [1], which contains more information regarding the experimental procedures leading to the determination of this data.

2.4 Phase Shifting Moiré Interferometry

Moiré interferometry [2] is a high-sensitivity method of full-field displacement measurement. The technique directly provides contour maps of the two orthogonal in-plane displacement components, u and v .

Phase shifting [3, 4] is an efficient means for converting the gray-scale fringe pattern information available from moiré interferograms into a digital representation of optical phase. The smoothing provided by the data reduction algorithm is performed in time, not space, so a degree of noise rejection is obtained without loss of spatial detail. This is important when specimens contain edges and discontinuities.

The outputs of the technique are two-dimensional surface maps of in-plane displacement. Strain information can be obtained from the displacement fields via differentiation. The gage length of the strain calculations when using phase shifting is roughly three times the size of a pixel in real data units. Phase shifting moiré interferometry offers an experimental counterpart to the powerful computational methods of solid mechanics, where displacements and strains are also the primary output [5].

2.4.1 Application to the Rock Model Experiment

There were several issues associated with the application of moiré interferometry to this problem that had to be addressed. The first involved how the grating was to be replicated onto each of the plates without introducing large rotations between adjacent pieces of the grating. This technical problem was overcome using the specimen construction method described above.

The second difficulty was a result of each plate having a single isolated grating. Typically, only one continuous diffraction grating is interrogated during a moiré interferometry experiment. In this work, however, the area of interest was covered with multiple diffraction gratings (one per plate), each one slightly rotated relative to the next. The unavoidable slight rotations of the gratings introduced different carrier patterns for each of the plates. Thus, fringe patterns at zero load (null patterns) had to be captured and used as a reference, so that absolute displacement measurements could be made. Fortunately, the video-based phase shifting technique provides an efficient means for accomplishing this.

2.4.2 Description of the Interferometer System

A four beam, fiber optic interferometer was used for this work. This interferometer combines two separate two beam interferometers to provide both u and v (horizontal and vertical) components of displacement. Central to the system is a four-way fiber optic beam splitter assembly that converts a single, uncollimated beam of Argon-ion laser light into four, equal intensity beams channeled through individual fibers. A schematic illustrating the fiber optic assembly Figure 1.

Four 50 mm diameter camera lenses are located at the end of the fibers and are used to collimate the laser light from the individual fiber sources. The four lenses are mounted on

an aluminum bar frame in pairs—two lenses are mounted in a vertical plane, the other two lenses are mounted in a horizontal plane. The entire frame can be rotated to remove any relative rotational misalignment between the interferometer and the specimen.

At any one time, one pair of lenses is capped so that only two lenses project light onto the specimen surface. For example, the vertical pair of lenses can be capped so that the horizontal pair of lenses can be used alone to form fringe patterns representing the in-plane horizontal (u -field) displacements. The angle between the two beams incident on the specimen grating is chosen so that both beams are diffracted into a path normal to the surface of the specimen. This is accomplished by the action of the diffraction grating bonded on the surface of the specimen, and is schematically depicted in Figure 1. When these two beams are recombined using a conventional optical system (lens and camera), they interfere with each other and form a fringe pattern.

Phase shifting is accomplished by stretching one of the selected fibers using a piezoelectric (PZT) transducer. This transducer is under the control of the laboratory personal computer so that the phase shifting can be synchronized with the video image acquisition. This is also illustrated in Figure 1.

Wrapped fringe patterns are obtained by acquiring five images, with 90° phase shifts between the images. These images are then processed using a simple algorithm to produce the wrapped fringe pattern. The wrapped fringe patterns are transferred to a Silicon Graphics workstation and unwrapped using a recursive flood-fill algorithm. A custom software package has been developed for extracting quantitative data from these unwrapped fringe patterns.

3 Experimental Results

Prior to testing, the models were given several cycles of compressive loading to promote uniform frictional properties between the plates. A typical experiment consisted of setting up the model in the load frame, aligning the optics, and taking null patterns at zero load. Load would then be increased gradually, and fringe patterns acquired at predetermined steps.

A typical wrapped fringe pattern obtained during an experiment is shown in Figure 3. These types of images differ from conventional fringe patterns in that the fringes are artificially 'wrapped' every multiple of 2π . This is an artifact of a $\tan^{-1}$ calculation in the data reduction. Before the data in a wrapped fringe pattern can be used, the image must be properly masked and unwrapped. This is accomplished using custom software developed for this purpose.

In addition to unwrapping, it was necessary to subtract the null patterns from the deformed fringe patterns to obtain a measurement of absolute displacements. This leads to what is called a 'nulled' fringe pattern. Once unwrapped and nulled, each pixel in the image provides a measure of the absolute displacement at a given load.

Figures 4 and 5 are color fringe plots of displacement in a Lexan plate model for two levels of compressive load. The colormap used to display these unwrapped images goes from red to yellow to blue (or from black to white in grayscale renderings). The slip between layers can be estimated by noting the difference between the color of the plot above and below an interface. For example, a relatively large amount of slip has occurred near the hole at 0.43 MPa (Figure 4) for interface 1. Figure 5 indicates that at 0.86 MPa, the slip in this

region has increased.

The unwrapped fringe plots are useful in that they provide a quantitative representation of the full-field data, but they are not sufficient for quantitative analysis. For this purpose, detailed line scans must be extracted from the unwrapped fringe patterns and processed to produce slip as a function of position along the interface. This is demonstrated in the next set of experiments, where again, fringe patterns were captured at several loads. The results are shown in Figures 6-8, where slip is plotted as a function of position along each interface for three successive loads. The fringe patterns and line scans for this sequence of loading agree well with the previous experiment.

At 0.14 MPa (Figure 6), the slip between the plates appears to be uniformly distributed around the hole. However, at 0.43 MPa (Figure 7), the slip along the first and second interface from the top has increased dramatically. Finally, at 0.56 MPa (Figure 8), the second interface has become the primary location for slip, while the top interface indicates no slip directly above the hole, and a reduced value of slip far from the hole.

4 Conclusions

These preliminary results confirm the feasibility of using phase shifting moiré interferometry for quantifying slip during laboratory experiments with layered rock models. Results for the Lexan model show a clear evolution of slip as a function of load. The trends apparent in these experiments were reproducible between experiments.

The approach can be applied to models made from actual rock or concrete samples with little difficulty. Models can be fabricated and tested that contain an arbitrary combination of holes and/or vertical cuts. Variations in loading can be obtained by modifying the existing load frame. Such variations may include inclined loading and biaxial compressive loading of the model. A linear bearing system is currently under construction to allow a larger field of view to be interrogated during moiré interferometry data collection.

5 Acknowledgments

This report was prepared under Yucca Mountain Site Characterization Project WBS Number 1.2.4.2.1.2 and SNL contract number AJ-8906. The data in this report were developed subject to QA controls in QAGR S124212, are not qualified, and should not be used for licensing.

References

- [1] Stephen R. Brown. Laboratory measurements of frictional slip on interfaces in a polycarbonate rock mass model. Technical report SAND93-2365, Geomechanics Department, Sandia National Laboratories, 1993. (NNA.940315.0001)

- [2] D. Post, B. Han, and P. Ifju. *High Sensitivity Moiré*. Springer Verlag, 1994.
(MOL.19950329.0263)
- [3] K.E. Perry, Jr. *Calculation of energy release rates for delaminations in composite materials*. PhD thesis, University of Strathclyde, November 1993.
- [4] J.E. Greivenkamp and J.H. Bruning. Phase shifting interferometry. In Daniel Malacara, editor. *Optical Shop Testing*, chapter 14, pages 501-598. John Wiley & Sons, New York, 1986. Series in Pure and Applied Optics. (MOL.19950307.0004)
- [5] D. Post. Moiré interferometry. In A.S. Kobyashi, editor, *Handbook on Experimental Mechanics*, chapter 7, pages 314-383. Prentice-Hall, Inc., 1987. Society of Experimental Mechanics. (MOL.19950414.0432)

Figure 1: Four beam interferometer schematic, showing how two beams are used to form a fringe pattern.

Figure 2: Model and load fixture.

Figure 3: Typical wrapped fringe pattern $\sigma_0 = 0.86$ MPa.

Figure 4: Unwrapped u -displacement field, $\sigma_0 = 0.43$ MPa.

Figure 5: Unwrapped u -displacement field, $\sigma_0 = 0.86$ MPa.

Figure 6: Slip along interfaces at $\sigma_0 = 0.14$ MPa. The position scale is in millimeters, and the slip is in microns.

Figure 7: Slip along interfaces at $\sigma_0 = 0.43$ MPa. The position scale is in millimeters, and the slip is in microns.

Figure 8: Slip along interfaces at $\sigma_0 = 0.56$ MPa. The position scale is in millimeters, and the slip is in microns.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

UC814 - DISTRIBUTION LIST

1	D. A. Dreyfus (RW-1) Director OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	Director Office of Public Affairs DOE Nevada Operations Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518
1	L. H. Barrett (RW-2) Acting Deputy Director OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	8	Technical Information Officer DOE Nevada Operations Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518
1	S. Rousso (RW-40) Office of Storage and Transportation OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	P. K. Fitzsimmons, Technical Advisor Office of Assistant Manager for Environmental Safety and Health DOE Nevada Operations Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518
1	R. A. Milner (RW-30) Office of Program Management and Integration OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	J. A. Blink Deputy Project Leader Lawrence Livermore National Laboratory 101 Convention Center Drive Suite 820, MS 527 Las Vegas, NV 89109
1	D. R. Elle, Director Environmental Protection Division DOE Nevada Field Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518	2	J. A. Canepa Technical Project Officer - YMP N-5, Mail Stop J521 Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87545
1	T. Wood (RW-14) Contract Management Division OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	Repository Licensing & Quality Assurance Project Directorate Division of Waste Management US NRC Washington, DC 20555
4	Victoria F. Reich, Librarian Nuclear Waste Technical Review Board 1100 Wilson Blvd., Suite 910 Arlington, VA 22209	1	Senior Project Manager for Yucca Mountain Repository Project Branch Division of Waste Management US NRC Washington, DC 20555
5	Wesley Barnes, Project Manager Yucca Mountain Site Characterization Office US Department of Energy P.O. Box 98608—MS 523 Las Vegas, NV 89193-8608	1	NRC Document Control Desk Division of Waste Management US NRC Washington, DC 20555

1	Chad Glenn NRC Site Representative 301 E Stewart Avenue, Room 203 Las Vegas, NV 89101	1	L. R. Hayes Technical Project Officer Yucca Mountain Project Branch MS 425 US Geological Survey P.O. Box 25046 Denver, CO 80225
1	E. P. Binnall Field Systems Group Leader Building 50B/4235 Lawrence Berkeley Laboratory Berkeley, CA 94720	1	A. L. Flint US Geological Survey MS 721 P.O. Box 327 Mercury, NV 89023
1	Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road Drawer 28510 San Antonio, TX 78284	1	R. E. Lewis Yucca Mountain Project Branch MS 425 US Geological Survey P.O. Box 25046 Denver, CO 80225
2	W. L. Clarke Technical Project Officer - YMP Attn: YMP/LRC Lawrence Livermore National Laboratory P.O. Box 5514 Livermore, CA 94551	1	D. Zesiger US Geological Survey 101 Convention Center Drive Suite 860, MS 509 Las Vegas, NV 89109
1	V. R. Schneider Asst. Chief Hydrologist -- MS 414 Office of Program Coordination and Technical Support US Geological Survey 12201 Sunrise Valley Drive Reston, VA 22092	2	L. D. Foust Nevada Site Manager TRW Environmental Safety Systems 101 Convention Center Drive Suite P-110, MS 423 Las Vegas, NV 89109
1	J. S. Stuckless, Chief Geologic Studies Program MS 425 Yucca Mountain Project Branch US Geological Survey P.O. Box 25046 Denver, CO 80225	1	C. E. Ezra YMP Support Office Manager EG&G Energy Measurements Inc. MS V-02 P.O. Box 1912 Las Vegas, NV 89125
1	N. Z. Elkins Deputy Technical Project Officer Los Alamos National Laboratory Mail Stop 527 101 Convention Center Drive, #820 Las Vegas, NV 89109	1	E. L. Snow, Program Manager Roy F. Weston, Inc. 955 L'Enfant Plaza SW Washington, DC 20024
2	L. S. Costin, Acting Technical Project Officer - YMP Sandia National Laboratories Organization 6313, MS 1325 P.O. Box 5800 Albuquerque, NM 87185	1	Technical Information Center Roy F. Weston, Inc. 955 L'Enfant Plaza SW Washington, DC 20024
1	Ray Wallace US Geological Survey 106 National Center 12201 Sunrise Valley Drive Reston, VA 22092	1	Technical Project Officer - YMP US Bureau of Reclamation Code D-3790 P.O. Box 25007 Denver, CO 80225

1	B. T. Brady Records Specialist US Geological Survey MS 421 P.O. Box 25046 Denver, CO 80225	1	T. Hay, Executive Assistant Office of the Governor State of Nevada Capitol Complex Carson City, NV 89710
1	M. D. Voegelé Technical Project Officer - YMP M&O/SAIC 101 Convention Center Drive Suite 407 Las Vegas, NV 89109	3	R. R. Loux Executive Director Agency for Nuclear Projects State of Nevada Evergreen Center, Suite 252 1802 N. Carson Street Carson City, NV 89710
1	Paul Eslinger, Manager PASS Program Pacific Northwest Laboratories P.O. Box 999 Richland, WA 99352	1	Brad R. Mettam Inyo County Yucca Mountain Repository Assessment Office P. O. Drawer L Independence, CA 93526
1	A. T. Tamura Science and Technology Division OSTI US Department of Energy P.O. Box 62 Oak Ridge, TN 37831	1	Lander County Board of Commissioners 315 South Humbolt Street Battle Mountain, NV 89820
1	P. J. Weeden, Acting Director Nuclear Radiation Assessment Div. US EPA Environmental Monitoring Sys. Lab P.O. Box 93478 Las Vegas, NV 89193-3478	1	Vernon E. Poe Office of Nuclear Projects Mineral County P.O. Box 1600 Hawthorne, NV 89415
1	ONWI Library Battelle Columbus Laboratory Office of Nuclear Waste Isolation 505 King Avenue Columbus, OH 43201	1	Les W. Bradshaw Program Manager Nye County Nuclear Waste Repository Project Office P.O. Box 1767 Tonopah, NV 89049
1	C. H. Johnson Technical Program Manager Agency for Nuclear Projects State of Nevada Evergreen Center, Suite 252 1802 N. Carson Street Carson City, NV 89710	1	Florindo Mariani White Pine County Coordinator P. O. Box 135 Ely, NV 89301
1	John Fordham, Deputy Director Water Resources Center Desert Research Institute P.O. Box 60220 Reno, NV 89506	1	Judy Foremaster City of Caliente Nuclear Waste Project Office P.O. Box 158 Caliente, NV 89008
1	The Honorable Cyril Schank Chairman Churchill County Board of Commissioners 190 W. First Street Fallon, NV 89406	1	Philip A. Niedzielski-Eichner Nye County Nuclear Waste Repository Project Office P.O. Box 221274 Chantilly, VA 22022-1274

1	Dennis Bechtel, Coordinator Clark County Nuclear Waste Div. 500 S. Grand Central Parkway Suite 3012 Las Vegas, NV 89155-1751	1	G. S. Bodvarsson Head, Nuclear Waste Department Lawrence Berkeley Laboratory 1 Cyclotron Road, MS 50E Berkeley, CA 94720
1	Juanita D. Hoffman Nuclear Waste Repository Oversight Program Esmeralda County P.O. Box 490 Goldfield, NV 89013	1	Michael L. Baughman Intertech Services Corp. P.O. Box 93537 Las Vegas, NV 89193
1	Eureka County Board of Commissioners Yucca Mountain Information Office P.O. Box 714 Eureka, NV 89316	5	B. J. Buescher Fracture Behavior Group Idaho National Engineering Laboratory P.O. Box 1625 Idaho Falls, ID 83415-2218
1	Economic Development Dept. City of Las Vegas 400 E. Stewart Avenue Las Vegas, NV 89101	5	J. S. Epstein Fracture Behavior Group Idaho National Engineering Laboratory P.O. Box 1625 Idaho Falls, ID 83415-2218
1	Community Planning & Development City of North Las Vegas P.O. Box 4086 North Las Vegas, NV 89030	5	D. Anderson Fracture Behavior Group Idaho National Engineering Laboratory P.O. Box 1625 Idaho Falls, ID 83415-2218
1	Community Development & Planning City of Boulder City P.O. Box 61350 Boulder City, NV 89006	5	H. Buck Fracture Behavior Group Idaho National Engineering Laboratory P.O. Box 1625 Idaho Falls, ID 83415-2218
1	Commission of European Communities 200 Rue de la Loi B-1049 Brussels BELGIUM	5	Ken Perry, Jr. Nike Air Lab MJ3 1 Bowerman Dr. Beaverton, OR 97005
2	Librarian YMP Research & Study Center MS 407 P.O. Box 98521 Las Vegas, NV 89193-8521		
1	Amy Anderson Argonne National Laboratory Building 362 9700 S. Cass Avenue Argonne, IL 60439	2	MS 1330 C. B. Michaels, 6352 100/124212/SAND94-2384/QA
		20	1330 WMT Library, 6352
		3	1325 S. R. Sobolik, 6313
		1	1325 R. E. Finley, 6313
		1	1325 N. S. Brodsky, 6313
		1	1325 R. Price, 6313
		1	1325 L. S. Costin, 6302
		1	1145 J. D. Miller, 6514
		1	0437 J. Jung, 1518
1	Glenn Van Roekel Director of Community Development City of Caliente P.O. Box 158 Caliente, NV 89008	1	9018 Central Technical Files, 8523-2
		5	0899 Technical Library, 13414
		1	0619 Print Media, 12615
		2	0100 Document Processing, 7613-2 for DOE/OSTI