evaluation for the Rocky Flats, Colorado nuclear arsenal performed by Risk Engineering, Inc. Dr. Campbell has also estimated ground motions for the IPEEE at the Palo Verde nuclear power plant in Arizona and at California's San Onofre Nuclear Generating Station and Diablo Canyon Nuclear Power Plant. He testified on his work at San Onofre at a hearing conducted by the Atomic Safety Licensing Board. Using regional strong motion data bases, Dr. Campbell has developed attenuation relationships appropriate for specific regions including Utah in the Basin and Range province and the source region for the 1989 Loma Prieta, California earthquake, among others. He is a recognized expert in this field and has developed near-source relationships for use in specifying seismic design criteria for critical and noncritical facilities. He has published widely on his attenuation studies in various scientific journals and presented his work at professional and technical conferences.

Dr. Arthur F. McGarr, geophysicist, is currently Chief of the Earthquake Geology and Geophysics Section, Earthquake Hazards Team, USGS, Menlo Park, California. His undergraduate degree was earned in physics followed by a M.S. in geophysics from the California Institute of Technology. He received his Ph.D. degree in geology from Columbia University in 1968, having specialized in seismology there. In late 1968, Dr. McGarr accepted the position of Senior Research Officer at the Bernard Price Institute of Geophysics, University of the Witwatersrand, Johannesburg, South Africa. During the next 9 years, he led a team of technical support staff and graduate students in numerous investigations of earthquakes induced by the deep-level gold mining operations of the Witwatersrand. Most of these studies entailed running underground networks of seismic and strain monitoring instrumentation. Broad-band, wide-dynamic range acceleration recorded in boreholes within several hundred meters of the hypocenters of mining-induced earthquakes yielded novel insights about the source processes that give rise to the strong ground motion as well as the response of the nearby mine excavations, at typical depths of 3 kilometers, to these vibrations. In 1978, Dr. McGarr accepted a research position at the USGS in Menlo Park where his primary efforts have included the analysis of strong ground motion in the western U.S., the state of stress in the lithosphere, and further studies of induced and triggered earthquakes. In 1990, for example, he determined the design seismic ground motion for the Sudbury Neutrino Observatory, Ontario, Canada, due to nearby mining-induced earthquakes. Of particular interest here, Dr. McGarr demonstrated how the state of crustal stress and focal depth influence ground motion parameters. In this latter study, a result of key interest for the

Yucca Mountain project is the finding that earthquakes in extensional tectonic regimes yield lower levels of ground motion than their counterparts in compressional regimes, for similar recording circumstances. Dr. McGarr's personal experience with the Yucca Mountain project includes participation in the study that led to the development of the ground motion attenuation model SEA 96 for earthquakes in extensional tectonic regimes, one of the empirical proponent models utilized by the Expert Panel.

Dr. Walter J. Silva is President and Senior Seismologist at Pacific Engineering and Analysis. He holds a B.A. degree in geophysics, an M.A. in geophysics, and a Ph.D. in geophysics all from the University of California, Berkeley. He has over 20 years of experience in seismology with particular emphasis on strong ground motion estimation using both numerical modeling and empirical approaches. He has developed and thoroughly validated a numerical modeling methodology that accurately models strong ground motions at any distance (0-500 km) from small or large magnitude earthquakes. In addition to source modeling, Dr. Silva also specializes in quantifying the effects of site conditions on strong ground motions using empirical and 1- and 2-dimensional modeling techniques. In this context, he has evaluated a number of nonlinear approaches as well as the widely used equivalent-linear methodology in applications to recorded motions. To augment his finite fault modeling to accommodate nonlinear site response in an accurate and computationally attractive manner, he developed and validated a frequency domain random vibration theory equivalent-linear formulation. Dr. Silva has provided ground motion evaluations on a number of both large and small projects on a worldwide basis. He has provided site response predictions for over 30 nuclear power plants and numerous small projects. He has applied strong motion modeling techniques at four DOE facilities and at the Exploratory Studies Facility for the proposed high-level nuclear repository at Yucca Mountain, Nevada. Similar projects include numerous USBR dams. He has developed region-specific attenuation relations for eastern and central North America, Colorado, Idaho, New Mexico, and Spain using the stochastic ground motion model. He has been a state-of-the-art speaker on site effects and continues to do applied research on source modeling and site effects for such agencies as National Earthquake Hazards Reduction Program and DOE.

Dr. Paul G. Somerville received his doctoral degree in geophysics from the University of British Columbia in 1976. He spent 2 years as a Visiting Research Fellow at the Earthquake

Research Institute, Tokyo University, during 1977 and 1978, and since then has participated in post-earthquake reconnaissance activities in Japan, most recently in the 1996 Kobe earthquake. He has 18 years of experience as an engineering seismologist with Woodward-Clyde and is manager of the Pasadena office. He is a member of the National Research Council's Seismology Committee and is a member of the Earthquake Engineering Research Institute and an affiliate member of the Structural Engineers Association of California. Dr. Somerville has participated in earthquake hazard evaluations for a large number and variety of engineering projects in many parts of the world. During the past 10 years, he has developed and applied seismological methods for estimating ground motions for the seismic design of engineered structures, including the use of strong motion simulation procedures to generate realistic ground motion time histories close to large earthquakes, which include near-fault effects such as those due to rupture directivity. These procedures have been used to simulate ground motion time histories for structures such as the California Department of Transportation bridges in Northern and Southern California, and the Metropolitan Water District's Domenigoni Valley Reservoir in Southern California. Dr. Somerville is currently participating with the FEMA/SAC Steel Project by providing ground motion time histories to represent the ground motions experienced by steel moment frame buildings during the Northridge earthquake as well as other possible events. Multiyear projects that Dr. Somerville has directed include a program of numerical ground motion studies for the Long Term Seismic Program for PG&E's Diablo Canyon Power Plant, evaluation of earthquake source and ground motion characteristics in eastern North America for EPRI and NRC, estimation of strong ground motions in the Pacific Northwest from large subduction earthquakes on the Cascadia subduction zone for the USGS, analysis of the characteristics of near-fault ground motions for the USGS, and analysis of the ground motion characteristics of the 1989 Loma Prieta and 1994 Northridge earthquakes for the NSF.

Dr. Marianne C. Walck has been evaluating local-to-near-regional recordings of NTS underground nuclear explosions (UNEs) since 1984. She obtained her A.B. degree in geology-physics from Hope College, Michigan, and both an M.S. and Ph.D. in geophysics from California Institute of Technology, Pasadena, California. Currently the Manager of the Geophysics Department at Sandia National Laboratories, Dr. Walck is a seismologist whose career has focused on seismic array analysis of the structure of the upper mantle. She has used seismic array data to model attenuation parameters and acceleration anomalies using ray

tracing and synthetic seismograms. She has sited acceleration stations on Jackass Flats, analyzed the resulting data for travel times and relative amplitude patterns, and modeled the shallow crustal structure at NTS using both 2-D ray tracing and finite difference synthetic seismogram techniques. Her involvement with the Yucca Mountain project began in 1988 with a study of 2-D crustal structure for three paths at NTS between nuclear testing areas and Yucca Mountain. Using UNE source, she successfully reproduced absolute travel time, relative amplitude, and waveshape data for the three paths, documenting significant crustal structure differences at shallow depths near Yucca Mountain. She has recently been employing propagator matrix techniques to model the very shallow structure at Yucca Mountain using UNE records from four borehole/surface pairs in order to develop a predictive capability at depth near the site of the potential repository. She has also conducted and published research using recordings of nuclear explosion sources at teleseismic and regional distances. The latter used NTS explosions recorded at high-frequency stations in Nevada and California; the former used Soviet Explosions recorded at NORESS to deduce path attenuation. She has published her work on spectral estimates of P-wave attenuation (teleseismic recordings), path attenuation (northern Europe, regional recordings), and attenuation of Asian explosions (teleseismic recordings) in refereed journals and conference proceedings.

APPENDIX B

DATA PACKAGES DISTRIBUTED TO EXPERTS

SEISMIC SOURCE AND FAULT DISPLACEMENT CHARACTERIZATION DATA PACKAGES DISTRIBUTED TO EXPERTS

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Miscellaneous:

Aerial photograph of the Yucca Mountain area.

Index to orthophotos, Yucca Mountain area.

GROUND MOTION CHARACTERIZATION DATA PACKAGES

Vol. 1 Reference material for proponent models

Vol. 1B Additional reference material for proponent models

Vol. 2 Spectral plots of proponent models

Vol. 3 Individual plots of proponent models and expert estimates
Horizontal component, Rev 1

Vol. 4 Individual plots of proponent models and expert estimates
Vertical component, Rev 1

Vol. 5 Spectral plots of expert point estimates, Rev 1

Vol. 6A* Regression model fits to experts point estimates, Rev 1
Anderson, Boore, Campbell

Vol. 6B* Regression model fits to experts point estimates, Rev 1
McGarr, Silva, Somerville, Walck

Vol. 7 Individual plots of proponent models and expert estimates
Horizontal component, Rev 2

Vol. 8 Individual plots of proponent models and expert estimates
Vertical component, Rev 2

Vol. 9 Spectral plots of expert point estimates, Rev 2

Vol. 10A Regression model fits to experts point estimates
Expert: Anderson, Rev 2

Vol. 10B Regression model fits to experts point estimates
Expert: Boore, Rev 2

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Vol. 10D Regression model fits to experts point estimates
Expert: McGarr, Rev 2

Vol. 10E Regression model fits to experts point estimates
Expert: Silva, Rev 2

Vol. 10F Regression model fits to experts point estimates
Expert: Somerville, Rev 2

Vol. 10G Regression model fits to experts point estimates
Expert: Walck, Rev 2

Vol. 11A Regression model fits to experts point estimates
Expert: Anderson, Rev 3

Vol. 11B Regression model fits to experts point estimates
Expert: Boore, Rev 3

Vol. 11C Regression model fits to experts point estimates
Expert: Campbell, Rev 3

Vol. 11D Regression model fits to experts point estimates
Expert: McGarr, Rev 3

Vol. 11E Regression model fits to experts point estimates
Expert: Silva, Rev 3

Vol. 11F Regression model fits to experts point estimates
Expert: Somerville, Rev 3

Vol. 11G Regression model fits to experts point estimates
Expert: Walck, Rev 3

Vol. 12 Spectral plots of expert point estimates, Rev 3

* The full set was not sent to the experts. Each expert only received plots for his/her own model.

** No Volume 10C.

APPENDIX C

SUMMARIES OF SEISMIC SOURCE AND FAULT DISPLACEMENT CHARACTERIZATION WORKSHOPS

SUMMARIES OF SSFDC WORKSHOPS

Note: Workshop summaries were prepared after each workshop and then distributed to workshop participants. See the project files for all figures and attachments referred to in these summaries, including agendas and copies of information distributed to workshop participants both during and after the workshops.

WBS: 1.2.3.2.8.3.6
QA: L

Civilian Radioactive Waste Management System
Management & Operating Contractor

Summary of Data Needs Workshop on Seismic Source Characterization at Yucca Mountain

SSC Workshop 1

Salt Lake City, UT
April 17-19,1995

May 25,1995

Prepared for:

U.S. Geological Survey
Box 25046, MS-425
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I. INTRODUCTION

The United States Geological Survey (USGS) is carrying out a probabilistic seismic hazards analysis (PSHA) for Yucca Mountain, Nevada as part of the Department of Energy's (DOE) project to characterize this site as a potential geologic repository for high-level radioactive waste. The aim of this study is to provide the annual probability with which various levels of vibratory ground motion and fault displacement will be exceeded at the site. These results will be used as a basis for developing seismic design inputs and in assessing the performance of the site.

The PSHA process involves development by two panels of experts of input interpretations and assessments of uncertainties required by the hazards calculations. One panel addresses characterization of seismic sources and fault displacement, while the other deals with vibratory ground motion. Development of interpretations is being facilitated through a series of structured workshops to evaluate available data, to explore the range of interpretations allowed by the data, to examine critically the interpretations proposed by the experts, and to provide feedback on the implications of various interpretations for the seismic hazard at the site. The goal of this process is to have differences in experts' interpretations be the results of true differences in judgment and not differences in access to data, differences in definition, or differences resulting from a lack of understanding each others' interpretations. This report summarizes the first in the series of structured workshops for characterization of seismic sources and fault displacement: the Data Needs Workshop.

The primary goal of the workshop was to discuss and develop a specification of the data required to characterize seismic sources for vibratory ground motion and fault displacement hazards at Yucca Mountain. This includes both data that are presently available and data that are not yet available. A secondary goal was to provide information to participants, particularly the Expert Panel, on the overall study, the products to be developed, the project schedule, the roles of various participants, basic approaches to probabilistic analyses and expressing uncertainties, and ground-rules regarding communication and interaction throughout the study.

To accomplish these goals, the workshop included a series of presentations and discussion sessions, which are summarized chronologically below. Copies of overhead transparencies shown by presenters were distributed to participants during the workshop and are included with this summary as Attachment 3. The basic approach of the workshop was to: 1) identify technical issues of most significance to seismic hazards at Yucca Mountain; 2) link these issues with the data that are most important to addressing the issues; 3) specify the available relevant data for the Yucca mountain region; and 4) identify the data that are required by the Expert Panel to characterize seismic sources for the PSHA.

MONDAY, APRIL 17, 1995

A welcome and introductory presentations were given by: 1) the Project Representative for DOE, Tim Sullivan; 2) the Project Director, J. Carl Stepp of Woodward-Clyde Federal Services; and 3) the Team Leader of the Seismic Source Characterization and Fault Displacement Facilitation Team (SSC-FT), Kevin J. Coppersmith of Geomatrix Consultants. Table 1 shows the list of workshop attendees.

Because the DOE has the responsibility of evaluating Yucca Mountain as a potential repository site for the permanent disposal of spent nuclear fuel and high-level radioactive waste, Mr. Sullivan provided an overview of the overall Yucca Mountain Project. His overview included a brief description of proposed facilities and background on the DOE's program approach and general objectives for the PSHA. He emphasized that although the DOE's position was that the database was adequate to begin assessment, data would continue to be gathered, and that this PSHA will provide seismic design parameters for the preclosure period (100 years). The project will also provide seismic hazard estimates that have potential application in evaluating the performance of the repository system during the postclosure period. Dr. Stepp more specifically defined PSHA project objectives and outlined the project plan. including the basic approach, organization, and schedule for the project.

Dr. Coppersmith introduced members of the Expert Panel and SSC-FT, further explained their roles and responsibilities, and specified the guidelines used for selecting experts. He defined ground rules for experts and emphasized their role as informed "evaluators" of various interpretations, rather than "proponents" of a single model, in an intensely interactive but nonhostile process whereby a common understanding of the issues and available data is achieved. He also discussed forthcoming workshops and the project deliverables, including milestones and the final report. Four workshops are scheduled through January 1996, followed by the elicitation process through March, a workshop to provide feedback, final assessments by experts in June, and a final report delivered in September 1996. In addition to the workshops, two field trips were tentatively planned for November.

Dr. Coppersmith also provided background on multiple-expert probabilistic hazard assessments, including an ongoing study of volcanic hazards at Yucca Mountain. He highlighted important aspects of this PSHA, such as: 1) results of the source characterization component of the project will be used to evaluate the probabilities of exceeding both certain levels of vibratory ground motions and certain amounts of fault displacement through the proposed repository; 2) ground motions will be used for design purposes and fault displacements will be used for performance assessment; 3) this project is a hazard rather than risk analysis, although results could become an integral part of a risk analysis; 4) resulting probability distributions should incorporate various types of uncertainties (including expert-to-expert diversity of interpretation, modeling uncertainties, parameter uncertainties, aleatory and epistemic uncertainties); 5) probabilistic treatment should allow for full consideration of alternative models and parameters that reflect true differences of interpretation and

uncertainties rather than perceptions of conservatism, as conservatism will subsequently be more explicitly adopted by others in choices of acceptable risk; and 6) conducting the PSHA does not indicate that all applicable data have been collected, but it is vital that the present level of knowledge and uncertainty is adequately captured in the analysis. Dr. Coppersmith also answered questions from the Expert Panel, clarifying that the experts will be grouped into six teams of three, and each team will be asked to reach consensus on probability distributions for the source characterization.

Peter A. Morris of Applied Decision Analysis, Inc., initiated the second session of the day with a presentation on the treatment of uncertainties and the expert elicitation process. He compared aleatory and epistemic uncertainties and emphasized focusing on those most significant to seismic hazards at Yucca Mountain. Dr. Morris highlighted advantages and potential pitfalls of the elicitation process. He specified responsibilities of the SSC-FT, emphasizing their role in promoting interaction among experts to identify areas of unintended disagreement. He described the different "hats" experts will wear during the course of the study, including proponent, evaluator, and technical facilitator, but ultimately they must act as experts during the elicitation process. The intent in the process is not to develop one "best" model and achieve consensus but rather to preserve true diversity in the outcome and only remove unintended outcomes that result from lack of understanding.

Walter J. Arabasz of the University of Utah then gave the first of three presentations on technical issues significant to evaluating seismic hazards at Yucca Mountain. He focused on the role of historical and instrumental seismicity analysis, covering basic concepts, highlighting general and specific issues significant to characterizing seismic sources in the Yucca Mountain region, and interjecting insights on lessons learned from previous multiple-expert PSHAs. He emphasized the importance of rates in the analysis and encouraged experts to give them appropriate consideration during the investigation. He identified many of the subtle but significant caveats in compiling, processing, and analyzing the earthquake catalog for use in hazard analysis.

The first day of the workshop closed with questions and statements from observers. Dr. Stepp clarified that the focus of the project is on tectonic events and not mining-induced, or thermally induced seismicity, which are beyond the scope of this project. Bakr Ibrahim of the U.S. Nuclear Regulatory Commission (NRC) asked whether the group might be reconvened if results were found during the ongoing site characterization that impacted the PSHA, and Mr. Sullivan answered yes, if the findings would significantly impact the results of the PSHA.

TUESDAY, APRIL 18, 1995

Frank (Bert) H. Swan of Geomatrix Consultants started the morning session with a presentation on technical issues significant to characterizing fault sources at Yucca Mountain. He covered basic concepts and provided insights into both general and site-specific issues for

Yucca Mountain, particularly in regard to distributive and secondary faulting that is important to characterizing fault displacements. He also highlighted caveats in using the present geologic database, such as likely subsurface differences and complexities in geometry, absence of Quaternary cover, the incomplete paleoseismic record, and differences between average net slip and observed displacements.

Next, one of the Deputy Directors of the project, Ivan G. Wong of Woodward-Clyde Federal Services, presented technical issues found to be most significant during the preliminary PSHA done for the Exploratory Studies Facility (ESF) at Yucca Mountain. For their preliminary study of vibratory ground motions only and not fault displacement, they considered 24 faults and one background seismic source zone. They found that the background source was the most significant contributor to seismic hazard at the ESF for return periods up to 100,000 years. This finding underscores the importance of how the earthquake catalog is processed and analyzed for use in characterizing background sources at Yucca Mountain. They also found that three local faults, the Paintbrush Canyon, Solitario Canyon, and Fatigue Wash faults, became significant contributors to the peak acceleration hazard at return periods greater than 20,000 years. When asked whether this project should just focus on local faults, Mr. Wong emphasized the limitations of his study, which was not comprehensive and used simple tectonic and fault segmentation models. He cautioned the experts to use the preliminary findings from the ESF study only as guidelines for prioritizing time spent on characterizing sources.

The morning session concluded with a discussion of the significant technical issues highlighted by Drs. Arabasz, Swan, and Mr. Wong, which are shown in Table 2. Also shown in Table 2 are the data identified by project participants as being particularly important to addressing each issue. Dr. Coppersmith facilitated the discussion and Dr. Arabasz served as scribe. Many members of the Expert Panel, Oversight Panel and Project Management Team actively contributed to the discussion.

Mary-Margaret Coates of the USGS began the afternoon session with a brief explanation of the introductory data package sent out to experts prior to the workshop (Table 3) and the data that are scheduled to be forthcoming from the USGS during this, and the next, fiscal years. She described the role of the Data Management Team as a resource to the experts with the objective of providing a consistent database to all experts in a timely fashion that is as comprehensive and up-to-date as reasonably possible. In regard to timeliness, many experts expressed an interest in electronic access to digital data files, such as placing earthquake catalogs on a home page on the World-Wide Web or providing access to Silvio K. Pezzopane's (USGS) digital compilation of focal mechanism data.

Presentations on available data sets for the Yucca Mountain region began with a joint presentation on seismicity data by Kenneth D. Smith and James N. Brune of University of Nevada at Reno (UNR). Dr. Smith identified the various seismic networks operating in the region at different time periods, including monitoring networks of NTS blasts and the Non-

Proliferation Experiment. He also identified corresponding earthquake catalogs and specialized data sets available, including a forthcoming study of the 1992 Little Skull Mountain earthquake sequence. Six catalogs of historical earthquakes in the region were compiled into a comprehensive report by Gross and Jaume at UNR. In contrast, although numerous other compilations and reports exist for the instrumental record, this data set has not yet been compiled and processed into a single comprehensive and consistent catalog. Dr. Brune elaborated on some of the caveats in using the present database, such as inconsistencies and systematic errors among assigned magnitudes, some catalogs contain numerous sonic events, and it may be difficult to distinguish induced events.

The next presentation on available data for regional faults within 100 km of Yucca Mountains (except studies conducted by the State of Nevada) was primarily given by Larry W. Anderson of the USBR and supplemented by R. Ernst (Ernie) Anderson of the USGS. Mr. L. Anderson identified three types of studies: 1) general geologic; 2) regional compilations of suspected Quaternary faults; and 3) fault-specific paleoseismic studies. He also listed available data sources for each type of study and emphasized the number of fault-specific paleoseismic studies was limited; however, existing studies do help provide a Quaternary tectonic framework. He also summarized a compilation by Dr. Pezzopane showing magnitude and distance relations for known and suspected Quaternary faults in the Yucca Mountain region. Dr. R. Anderson summarized data being collected for ongoing studies of regional faults by the USGS, which are scheduled to be available before the end of this fiscal year.

John W. Bell of the Nevada Bureau of Mines and Geology (NBMG) gave the final presentation of the day, providing a summary of data from geologic studies for Yucca Mountain conducted by NBMG and UNR. Regional studies by NBMG have provided extensive data on fault zones with historical surface ruptures in the Basin and Range, particularly in the Central Nevada seismic belt and Walker Lane regions. In particular, distributive faulting of the 1932 Cedar Mountain earthquake was studied in detail by Craig M. dePolo and others to provide possible analog data for Yucca Mountain. Regional NBMG studies also include analog investigations of historical aseismic and seismic cracks in eastern Nevada to better understand the nature of prehistoric cracks found extensively in trenches at Yucca Mountain. Regional studies by UNR include a variety of data for the surrounding region, such as mapping, trenching and geochronological data that have been used to develop tectonic models. Local fault studies by NBMG have included detailed mapping using low-sun-angle photography, chronostratigraphic studies (which include soils, rock varnish, and series data), and some trenching. The day concluded with the opportunity for questions and comments from observers.

WEDNESDAY, APRIL 19,1995

The Project Chief, John W. Whitney of the USGS, opened the last day of the workshop with a presentation on available data for local Quaternary faults at Yucca Mountain. He

summarized data on geometry, kinematics, and paleoseismic behavior for the seven to eight faults closest to the proposed repository block. He focused on mapping and trenching data and emphasized the closely-spaced, complex trace geometry and the long, but incomplete, paleoseismic record preserved for most of the faults. He also identified data that are scheduled to be available this and next fiscal year, including cooperative studies with the State of Nevada being conducted by Alan R. Ramelli of NBMG and Dr. Brune of UNR.

James B. Paces of the USGS gave the next presentation on available and forthcoming geochronological data for Yucca Mountain. He gave an overview of the multiple-purpose, extensive scope, general problems, and integrated approach for the geochronology program at Yucca Mountain. Although a variety of methods have been applied, including cosmogenic, radiocarbon, tephrochronology, U-series, and thermoluminescence, the effort has been most concentrated toward applying the latter two methods. Dr. Paces then identified new developments in U-series dating that are expanding application opportunities at Yucca Mountain. He also identified extensive problems with U-trend methods such that U-trend ages are no longer deemed reliable by most geochronologists. Finally, he stated that the USGS plans to have a trench-by-trench summary of geochronology data for Yucca Mountain that will be available to the Expert Panel by this autumn.

Christopher J. Potter of the USGS summarized available and forthcoming data from structural geology studies of the proposed repository block. He summarized previous and ongoing work involving geologic mapping, paleomagnetic studies, borehole investigations, fracture studies and 3-D modeling. Fracture studies include 2-D and 3-D mapping of surface fracture networks in cleared pavements, outcrop studies of general orientations and crosscutting relations, and stratigraphic studies of vertical continuity of fractures. Many experts expressed an interest in obtaining map data of the ESF and the ongoing 3-D modeling study, which integrates stratigraphic and structural data and uses a surface handling method. Dr. Potter also highlighted some of the issues surrounding the Sundance fault and ongoing studies to address these issues.

Victoria E. Langenheim of the USGS gave the final presentation on available and forthcoming geophysical databases for Yucca Mountain. She specified available data from numerous potential field, seismic, electrical, borehole, heat flow, geodetic, and hydrofracture studies. Potential field studies included gravity and magnetic data, and seismic studies included reflection, refraction, and tomography data. Dr. Lamgenheim also highlighted good overview and summary references for geophysical data.

Dr. Coppersmith facilitated a final wrap-up discussion. No other data were identified that had not been previously discussed in the workshop. It was decided that the SSC-FT would develop a list of needed data specified during the workshop. This list will be distributed to the Expert Panel for them to specify which data they would like sent to them. A Working Group to develop criteria for a project earthquake catalog will be formed including seismologists on the Expert Panel, Mr. Wong, and Dr. Brune. A Working Group on surface

displacement methodology, including Drs. Swan, Pezzopane, and David P. Schwartz (USGS), will complete their deliberations before the next workshop and will keep the Project Management informed as to their progress. Working Groups on empirical rupture dimensions and deep structures will also be considered. Drs. Pezzopane, Whitney, and Chris J. Fridrich (USGS), will develop a preliminary itinerary for the field trip scheduled for this autumn.

The discussion was followed by a training session on Quality Assurance procedures for the project given by Martha Mustard of the USGS. After statements and questions by observers, Dr. Coppersmith adjourned the workshop.

TABLE 1
SEISMIC SOURCE CHARACTERIZATION AND FAULT DISPLACEMENT WORKSHOP

17-19 APRIL 1995
Attendance List

Name	Affiliation
Norm Abrahamson	Consultant
Jon Ake	U.S. Bureau of Reclamation
Ernie Anderson	U.S. Geological Survey
Larry Anderson	U.S. Bureau of Reclamation
Walter Arabasz	University of Utah
Ann Becker	Woodward-Clyde Federal Services
John Bell	University of Nevada at Reno
Ron Bruhn	University of Utah
Jim Brune	University of Nevada at Reno
Bob Budnitz	Future Resources Associates Inc.
Tom Chaney	U.S. Geological Survey
Mary-Margaret Coates	U.S. Geological Survey
Kevin Coppersmith	Geomatrix Consultants
Allin Cornell	Consultant
Tony Crone	U.S. Geological Survey
Craig dePolo	University of Nevada at Reno
Diane Doser	University of Texas at El Paso
Chris Fridrich	U.S. Geological Survey
Tom Hanks	U.S. Geological Survey
Robert Harpster	SAIC
Bakr Ibrahim	U.S. Nuclear Regulatory Commission
Dick Keefer	U.S. Geological Survey
Jerry King	SAIC
Vicky Langenheim	U.S. Geological Survey
Martha Mustard	U.S. Geological Survey
Jim McCalpin	GEO-HAZ Consulting
Steve McDuffie	U.S. Nuclear Regulatory Commission
Robin McGuire	Risk Engineering

TABLE 1 (Continued)

Name	Affiliation
Chris Menges	U.S. Geological Survey
Peter Morris	Applied Decision Analysis
Susan Olig	Woodward-Clyde Federal Services
Jim Paces	U.S. Geological Survey
Sue Penn	Woodward-Clyde Federal Services
Roseanne Perman	Geomatrix Consultants
Silvio Pezzopane	U.S. Geological Survey
Paul Pomeroy	Advisory Committee on Nuclear Waste
Chris Potter	U.S. Geological Survey
Rich Quittmeyer	Woodward-Clyde Federal Services
Alan Ramelli	University of Nevada at Reno
A1 Rogers	U.S. Geological Survey
Jean Savy	Lawrence Livermore National Laboratory
John Schneider	Woodward-Clyde Federal Services
David Schwartz	U.S. Geological Survey
Burt Slemmons	Woodward-Clyde Federal Services
Robert Smith	University of Utah
Ken Smith	University of Nevada at Reno
Carl Stepp	Woodward-Clyde Federal Services
Bill Sublette	SAIC
Tim Sullivan	U.S. Department of Energy
Bert Swan	Geomatrix Consultants
David Elllson	Nevada Agency for Nuclear Projects
Gabriel Toro	Risk Engineering
Engelbrecht von Tiesenhausen	Clark County Nuclear Waste Division
John Whitney	U.S. Geological Survey
Ivan Wong	Woodward-Clyde Federal Services
Bob Youngs	Geomatrix Consultants
lim Yount	U.S. Geological Survey
Mary Lou Zoback	U.S. Geological Survey

TABLE 2
SIGNIFICANT TECHNICAL ISSUES AND ASSOCIATED DATA NEEDS FOR CHARACTERIZING SEISMIC SOURCES IN THE YUCCA MOUNTAIN REGION

Note: This list of issues was not intended to be exhaustive. Rather, it was developed to focus discussion and thought on the types of data that could be used to address several key SSC issues.

Issue 1. What are the candidate seismic sources for the background earthquake and what is the relative importance of volcanic earthquakes.

Data Needed:

- Spatial and temporal relation of volcanic-related events and background seismicity
- Suzette Jackson's compilation of volcanic-related seismicity (analog information)
- Heat flow data
- Comparison of the temporal and spatial patterns of paleoseismic events and volcanic-related events
- Stress field and relation to volcanic features, such as dike injection
- Recurrence information on volcanism near Yucca Mountain

Issue 2. What is size of maximum background earthquake?

Data Needed:

- Compilation by Craig dePolo of minimum magnitudes for surface-faulting earthquakes
- Other evidence of deformation besides surface faulting
- Stability of rupture dimensions with magnitude
- Maximum magnitude of non-surface-faulting earthquakes in other extensional tectonic environments (analog information)

Issue 3. Are rates of earthquake occurrence significantly affected by remotely triggered and "encouraged" mainshocks or are the effects insignificant when averaged over long periods?

Data Needed:

- UNR's data on decay of aftershocks and triggered events
- Information on blasting induced earthquakes, including depths
- Catalog of focal mechanisms
- Dislocation modeling of "encouraged" mainshocks

Issue 4. Relative weighting of exponential versus characteristic versus maximum magnitude earthquake recurrence models for fault-specific sources.

Data Needed:

- Distribution of displacements in paleoseismic data base
- Worldwide analogs on displacement per event
- Information on scaling relations of displacement versus fracture dimension (e.g., UK conference)
- Patience Cowie's Ph.D. dissertation (Lamont) and oil company information relating length and displacement

Issue 5. Developing fault segmentation models that define likely rupture segments

Data Needed:

- Paleoseismic data including timing, displacements, rupture lengths
- Analog earthquakes

Subsurface geometry (see below)

Issue 6. Characterizing fault geometry and kinematics.

Data Needed:

- Mapping
- Subsurface data including drill hole, seismic reflection and refraction, and gravity
- Cross-sections
- Focal mechanisms, focal depths, and aftershock patterns
- Kinematic indicators (distinguish those in bedrock from those in Quaternary deposits)
- Aftershocks of normal-faulting earthquakes worldwide (analog information)

Issue 7. Characterizing distributive faulting.

Data Needed:

- Literature on hangingwall versus footwall deformation
- Analogs of normal-faulting earthquakes and their aftershocks and focal mechanisms
- Historical faulting in the Basin and Range Province
- Mapping of tunnel for superconducting supercollider in Texas
- Oil industry data on normal faults in subsurface
- Geoff King's 3-D boundary element model of Yucca Mountain
- Ron Bruhn's preprint on splay faulting and evolution of normal faults
- Mining industry data to calibrate models

Issue 8. Non-stationary and possible temporal clustering of large earthquakes

Data Needed:

(Data Needs added by SSC-FT after workshop)

- Paleoseismic data on timing and recurrence of events

- Jim McCalpin's compilation and analysis on variation of slip rates in the Basin and Range (analog information)

TABLE 3

CONTENTS OF THIS PACKAGE

BACKGROUND INFORMATION ON YUCCA MOUNTAIN SEISMIC SOURCES AND FAULT DISPLACEMENT

FIRST MAILING TO EXPERTS / APRIL 7, 1995

Cover letter from John Whitney and Mary-Margaret Coates

Preliminary table of contents: Tectonic characterization studies of Yucca Mountain, Nevada--A potential geologic repository for high-level nuclear waste, U.S. Geological Survey Circular (based on talks presented at a workshop in January 1994)

Summaries, reports, bibliographies, and other material as listed below, by topic. Note that the enclosed U.S. Geological Survey Bulletin 1790 contains several referenced papers.

Faults and Seismic Sources

Summary: Faults and seismic sources

Bibliographies: Detachment faulting
Faulting at Yucca Mountain
Quaternary faulting
Surface faulting

Carr, M.D., and Yount, J.C., eds., 1988, Geologic and hydrologic investigations of a potential nuclear waste disposal site at Yucca Mountain, southern Nevada: U.S. Geological Survey Bulletin 1790, 152 p.

Menges, C.M., Wesling, J.R., Whitney, J.W., Swan, F.H., Coe, J.A., Thomas, A.P., and Oswald, J.A., 1994, Preliminary results of paleoseismic investigations of Quaternary faults on eastern Yucca Mountain, Nye County, Nevada, *in* Proceedings, 5th International Conference, High-Level Radioactive Waste Management, v. 4, p. 2373-2390.

Pezzopane, S.K., Menges C.M., and Whitney, J.W., 1994, Quaternary paleoseismology and Neogene tectonics at Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 94-568, p. 149-151.

Piety, L.A., 1995, Appendices 2, 3, 4, and 5 of Compilation of known or suspected Quaternary faults within 100 km of Yucca Mountain; Nevada and California: U.S. Geological Survey Open-File Report 94-112, text to accompany map, 331 p. (in press).

Simonds, W.F., Whitney, J.W., Fox, K.F., Ramelli, A., Yount, J., Carr, M.D., Menges, C.M., Dickerson, R., and Scott, R.B., 1995, Map of fault activity of the Yucca Mountain area, Nye County, Nevada: text to accompany map, 30 p. (in press).

Geochronology of Surficial Stratigraphy

Summary: Geochronology of Quaternary stratigraphy

Bibliography: Geochronology of Quaternary stratigraphy

Lundstrom, Scott, 1994, Map unit descriptions for the preliminary surficial deposits of the southern half of the Topopah Spring quadrangle and northern half of the Busted Butte quadrangle, Nye County, Nevada: Prepared by EG&G, scale 1:12,000.

Paces, J.B., Menges, C.M., Widmann, B., Wesling, J.R., Bush, C.A., Futa, K., Millard, N.T., Matt, P.B., and Whitney, J.W., 1994, U-Series disequilibrium and thermoluminescense ages of paleosols associated with Quaternary faults, east side of Yucca Mountain: Proceedings, International Topical Meeting, High Level Nuclear Waste Management: American Nuclear Society, Inc., Las Vegas, Nevada, p. 2391-2401.

Geodetic Leveling

Summary: Geodetic leveling

Bibliography: Geodetic leveling

Savage, J.C., Lisowski, M., Gross, W.K., King, N.E., and Svarc, J.L., 1994, Strain accumulation near Yucca Mountain, Nevada, 1983-1993: Journal of Geophysical Research, v. 99, p. 18,103-18,107.

Geologic Mapping

Summary: Geologic mapping

Bibliography: Geologic maps

Index to orthophotos, Yucca Mountain area

Viewgraph of the Yucca Mountain Area

Frizzell, V.A., Jr., and Shulters, J., 1990, Geologic map of the Nevada Test Site, southern Nevada: U.S. Geological Survey Miscellaneous Investigations Map I-2046, scale 1:100,000.

Scott, R.B., and Bonk, J., 1984, Preliminary geologic map of Yucca Mountain, Nye County, Nevada with geologic sections: U.S. Geological Survey Open-File Report 84-494, scale 1:12,000, 9 p.

Geophysical Data

Summary: Geophysical data

Bibliographies: Gravity
Magnetic
Seismic reflection and refraction

Carr, M.D., and Yount, J.C., eds., 1988, Geologic and hydrologic investigations of a potential nuclear waste disposal site at Yucca Mountain, southern Nevada: U.S. Geological Survey Bulletin 1790, p. 3-21. Several articles.

Hildenbrand, T.G., Rogers, A.M., Oliver, H.W., Harmsen, S.C., Nakata, J.K., Aitken, D.S., Harris, R.N., and Carr, M.D., 1988, Regional geologic and geophysical maps of the southern Great Basin, *in* Carr, M.D., and Yount, J.C., eds., Geologic and hydrologic investigations of a potential nuclear waste disposal site at Yucca Mountain, southern Nevada: U.S. Geological Survey Bulletin 1790, p. 3-21.

Oliver, H.W., Ponce, D.A., and Hunter, W.C., 1995, Major results of geophysical investigations at Yucca Mountain and vicinity, southern Nevada: U.S. Geological Survey Open-File Report 95-74, 235 p., (in press).

Heat Flow

Summary: Heat flow

Bibliography: Heat flow

Sass, J.H., Dudley, W.W., Jr., and Lachenbruchm, A.H., Regional thermal setting, 1995, *in* Oliver, H.W., Ponce, D.A., and Hunter, W.C., eds, Major results of regional geophysical investigations of Yucca Mountain and vicinity, Nevada: U.S. Geological Survey Open-File Report 95-74, 235 p. (in press).

Seismicity

Summary: Historical and current seismicity

Bibliography: Seismicity

Harmsen, S.C., 1994, The Little Skull Mountain, Nevada, earthquake of 29 June 1992--Aftershock focal mechanisms and tectonic stress field implications: Bulletin Seismological Society America, v. 84, p. 1484-1505

Rogers, A.M., and Harmsen, S.C., 1991, The seismicity of Nevada and some adjacent parts of the Great Basin, *in* The Geology of North America, Decade Map: Volume 1, p 153-184

Stress Analysis

Summary: Stress analysis

Bibliography: Stress analysis

Harmsen, S.C., and Rodgers, A.M., 1986, Inferences about the local stress field from focal mechanisms--Applications to earthquakes in the southern Great Basin of Nevada: Bulletin of the Seismological Society of America, v. 76, p. 1560-1572.

Stock, J.M., and Healy, J.H., 1988, Stress field at Yucca Mountain, Nevada, *in* Carr, M.D., and Yount, J.C., eds., Geologic and hydrologic investigations of a potential nuclear waste disposal site at Yucca Mountain, southern Nevada: U.S. Geological Survey Bulletin 1790, p. 87-93.

Tectonic Models

Summary: Tectonic models

Bibliography: Tectonic models

Carr, W.J., 1990, Styles of extension in the Nevada Test Site region, southern Walker Lane Belt; an integration of volcano-tectonic and detachment fault models, *in* Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Geological Society of America Memoir 176, p. 283-303.

Crowe, B., Perry, F., Geissman, J., McFadden, L., Wells, S., Murrell, M., Poths, J., Valentine, G.A., Bowker, L., and Finnegan, K., 1995, Status of volcanism studies for the Yucca Mountain site characterization project: Los Alamos National Laboratory Report LA-12908-MS.

Scott, R.B., 1990, Tectonic setting of Yucca Mountain, southwest Nevada, *in* Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Geological Society of America Memoir 176, p. 251-282.

Spengler, R.W., and Fox, K.F., 1989, Stratigraphic and structural framework of Yucca Mountain, Nevada, *in* Radioactive Waste Management and the Nuclear Fuel Cycle: v. 13, p 21-36.

Civilian Radioactive Waste Management System
Management & Operating Contractor

Summary of Seismic Source Characterization Hazard Methodologies Workshop

SSC Workshop 2

Salt Lake City, UT
October 16-18, 1996

Prepared for:

U.S. Geological Survey
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November 11, 1996

1. INTRODUCTION

The United States Geological Survey (USGS) is carrying out a probabilistic seismic hazards analysis (PSHA) for Yucca Mountain, Nevada as part of the Department of Energy's (DOE) project to characterize this site as a potential geologic repository for high-level radioactive waste. This study was initiated in April 1995 and resumed in June 1996. The aim of the analysis is to provide the annual probability with which various levels of vibratory ground motion and fault displacement will be exceeded at the site. These results will be used as a basis for developing design inputs and in assessing the performance of the site.

The PSHA process involves development by two panels of experts of input interpretations and assessments of uncertainties required by the hazards calculations. One panel addresses characterization of seismic sources and fault displacement (SSFD), while the other deals with vibratory ground motion. Development of interpretations is being facilitated through a series of structured workshops to evaluate available data, to explore the range of interpretations allowed by the data, to examine critically the interpretations proposed by the experts, and to provide feedback on the implications of various interpretations for the seismic hazard at the site. The goal of this process is to have differences in experts' interpretations be the results of true differences in judgment and not differences in access to data, differences in definitions, or differences resulting from a lack of understanding each others' interpretations. This report summarizes the second in the series of structured workshops for characterization of seismic sources and fault displacement: the Hazard Methodologies Workshop.

The workshop had two principal goals: to review the newly available data for the Yucca Mountain region, and to identify available methodologies for characterizing seismic sources for the Yucca Mountain seismic hazard analysis. The first goal is a follow-on to the first SSFD workshop held in April of 1995, because additional data have become available and/or synthesized in summary reports since that time. The workshop also served as a second kick-off meeting for restarting the project, and participants were advised on revisions to the project plan and schedule.

To accomplish the above goals, the workshop included a series of presentations and discussion sessions, which are summarized chronologically below. Copies of overhead transparencies shown by presenters were distributed to participants during the workshop and are included with this summary as Attachment 1. Also included in Attachment 1 are copies of manuscripts distributed during the workshop. Table 1 is a bibliography of all of the reference material distributed, including oversize maps and cross-sections.

The basic approach of the workshop was to divide seismic source characterization (SSC) into two parts: SSC related to vibratory ground motion hazard analysis and related to fault

displacement hazard analysis. SSC is then divided into three components: seismic source location and geometry, maximum earthquake magnitude, and earthquake recurrence assessment. Each of these topics is first introduced by overview presentations that focus on the *methods and approaches* that are available to characterize them. These talks are then followed by a series of talks that describe the available *data bases and data interpretations* that relate to these topics. Although the presentations will undoubtedly entail some interpretations, the next workshop (Workshop #3 Alternative Models and Interpretations) will provide a forum for debating alternative interpretations of the available data.

WEDNESDAY, OCTOBER 16, 1996

Introductory presentations were given by: 1) the Project Representative for DOE, Tim Sullivan; 2) the Project Director, J. Carl Stepp; and, 3) the Team Leader of the SSFD Facilitation Team, Kevin J. Coppersmith. Table 2 shows the list of workshop attendees and their affiliations.

Mr. Sullivan provided an update and overview of developments in the Yucca Mountain program since April 1995. He emphasized that the objectives for the PSHA to provide seismic design parameters for the 1998 Viability Assessment remained the same, and that the viability assessment is a interim step to site recommendation in 2001. He also pointed out that the DOE Topical Report "Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain" has been accepted by the U.S. Nuclear Regulatory Commission (NRC) pending review of the final results of the PSHA.

Dr. Stepp reviewed changes in the PSHA schedule and project plan. The plan remains mainly the same with one difference being in the change of the Oversight Panel to a Peer Review Panel. This panel will consist of four members, reviewing different project areas according to expertise, and the process will be structured as a participatory peer review.

Dr. Coppersmith outlined the goals and approach of the workshop. He also discussed ground rules for the workshops, roles of project participants, major milestones and key aspects for the SSC component of the project, guidelines used in selecting experts, ground rules for experts and expert teams, and the goal of having a defensible basis for combining team assessments into the final analysis with equal weights. With the aid of hats as props, he emphasized that although the experts are encouraged to play the role of proponent occasionally during the process, their overall role and the role they must ultimately play when they develop their assessment is that of an evaluator.

Following the introductory session, the rest of the day consisted of presentations focusing on seismic source characterization for assessing vibratory ground motions. Dr. Walter Arabasz started out with an overview, pointing out key issues and personal insights from past experiences, including examples dealing with the processing of earthquake catalogues. A question was raised about defining the size of the area for detailed characterization, resulting in discussion about the need to be comprehensive but not to waste limited resources. Therefore, some guidance will be sought on this issue from the ground motion expert panel.

Dr. Ronald Bruhn next discussed methods for assessing the location and geometry of fault seismic sources. He pointed out significant issues regarding fault segmentation, inferring down-dip geometry from limited subsurface data, and long-term vs. short-term fault behavior. He highlighted many approaches and tools that are available for assessing the geometry and kinematics of fault systems such as: standard map and cross-section techniques, fault scaling relations, models of hanging and footwall rotation and flexure, thermal and rheologic constraints, implications from fracture mechanics and lab experiments, and kinematic and dynamic analyses to assess fault interactions and fault segmentation. He cited many examples from the February/March 1996 issue of the Journal of Structural Geology.

Following the lunchbreak, Dr. Christopher Menges summarized Quaternary fault studies in the immediate vicinity of Yucca Mountain, emphasizing results from trenching and mapping studies on fault location and geometry. Quaternary faults show a complex, anastomosing, intersecting pattern that can be separated into two fault systems: an east and west side that may possibly interconnect. Fault traces are relatively short (< 12 km), discontinuous, and densely spaced (< 1 to 5 km). Slip is dominantly normal oblique (left-lateral) on faults that dominantly strike N to NE and dip steeply to the W. These faults show small to moderate bedrock displacements and very small Quaternary displacements.

Presentations on newly available data for regional Quaternary faults were given by Mr. Larry Anderson and Dr. R. Ernst (Ernie) Anderson. Mr. L. Anderson discussed studies of the Bare Mountain, Death Valley and Furnace Creek fault zones. He emphasized information on slip rates, recurrence, and fault segmentation, particularly differences with previous and ongoing studies. Dr. E. Anderson presented results from reconnaissance mapping and scarp profiling studies of 15 different faults in the region. Theses studies focused on using fault scarp morphology to assess age of most recent activity and fault length.

Next Dr. Thomas Brocher presented newly available results from a deep seismic reflection study conducted by the U.S. Geological Survey. He also distributed preprints of manuscripts in review or in press. The two new lines extend from the Amargosa Desert to Jackass Flats, overlapping at Yucca Mountain. Dr. Brocher also presented gravity and aeromagnetic data that were used to help constrain interpretations of the seismic lines. These interpretations

suggest a series of east-dipping faults buried in Crater Flat, west of Yucca Mountain and a series of west-dipping faults that are chiefly east of and include the Solitario Canyon fault. All of those faults show relatively minor total offsets and are in the hanging wall of the larger Bare Mountain fault. Beds in the hanging wall overall step down to the west, forming a slight rollover and suggesting a listric geometry for the Bare Mountain fault. However, the Bare Mountain fault appears planar to 6-7 km depth and dips roughly 65° to the east in the seismic lines. Dr. Brocher also emphasized the large uncertainties in the data and models.

Dr. Kenneth Smith presented results from recent studies of seismicity in the vicinity of Yucca Mountain, focusing on location, depth, focal mechanisms, and spatial distributions of sequences. He discussed the 1992 Little Skull Mountain earthquake sequence, the 1993 Rock Valley earthquake sequence, and other small events in the region including the 1995 M 4.2 Timber Mountain earthquake and a sequence of small events south of Lathrop cones. He also discussed 15 very small earthquakes ($M < 1$) detected by the new network at Yucca Mountain that occurred since May 1995, and moment-magnitude scaling relations for the region.

Dr. Coppersmith then wrapped-up the day by asking for questions and comments from observers. Dr. Clarence Allen commented on the increased importance of the PSHA and the SCC due to changes in canister design and emplacement. Dr. Phil Justus presented a list of issues including points of clarification, and themes that needed further consideration, and important aspects of the SCC from the NRC's perspective.

THURSDAY, OCTOBER 17, 1996

Topics on SSC for evaluating ground motions continued to be the focus for Thursday's presentations. Dr. Coppersmith started the day with a presentation on methods for assessing maximum magnitudes, focusing on using fault rupture dimensions to estimate maximum magnitude. He pointed out some of the common pitfalls in determining maximum magnitudes and introduced methods for incorporating uncertainties using logic trees and continuous distributions.

Dr. Silvio Pezzopane gave the next presentation on data (fault length and displacement per event) for determining maximum magnitudes on Yucca Mountain faults. This included using paleoseismic data to assess fault segmentation and fault interdependence so that rupture scenarios could be developed. Surface-faulting earthquake parameters for these rupture scenarios can then be used to estimate maximum magnitudes. These rupture scenarios are discussed in more detail in the seismotectonic synthesis report by the U.S. Geologic Survey.

After the break, Dr. John Anderson discussed a new empirical relation that also incorporates fault slip rate to estimate maximum magnitude in addition to the typical fault parameters. He distributed reprints of his recent paper on this relation, which yields relatively higher magnitudes for lower slip rate faults. He also discussed possible reasons for why magnitude may be slip rate dependent.

Next, Dr. James McCalpin discussed methods for assessing earthquake recurrence on faults, emphasizing uncertainties, pitfalls, and the limitations and interdependence of paleoseismic data sets. He stressed the use of different types of probability distributions (e.g., Gaussian versus Weibull) is significant in terms of interpreting lower- and upper-bound values.

Dr. John Whitney followed with a presentation on slip rate and recurrence data for Yucca Mountain faults, summarizing information that is discussed in more detail in the seismotectonic synthesis report by the U.S. Geological Survey. Slip rates and the left-lateral component of slip generally increase to the south. However, all slip rates are relatively low (< 0.027 mm/yr) and generally have decreased through time. Depending on the recurrence model assumed, average recurrence intervals vary from about 5,000 (for < 150 ka) to 54,000 (for < 500 ka) years, with the uncertainties primarily due to ambiguities in correlating events between trench sites, ambiguities in interpreting the origin of cracking events, and uncertainties in the dating of deposits.

Mr. Alan Ramelli presented recent results from paleoseismic studies at four trench sites along the Solitaro Canyon fault. These results show variable displacements and rates of activity through time (temporal clustering) and a possible temporal association of faulting with basaltic volcanism.

Next, Dr. John Stamatakos presented results from studies of the Crater Flat area and the Bare Mountain fault that were conducted by the Center for Nuclear Waste Regulatory Analyses (CNWRA). These studies used a variety of data including: paleomagnetic, gravity, magnetic, geodetic, structural, geomorphic, and geochronologic. Based on geological and geophysical studies, they infer a possible spatial association between volcanism and faulting. They also interpret slip rates on the Bare Mountain fault to increase to the south and to be much higher than the rates of < 0.01 mm/yr reported by Mr. L. Anderson based on paleoseismic trenching studies. Dr. Stamatakos reported long-term uplift rates for the Bare Mountain fault of 0.19 mm/yr and short-term uplift rates as high as 5.0 ± 3.5 mm/yr based on geodetic data.

After the break, Dr. Thomas Channey distributed copies of the Quality Management Procedure for scientific expert elicitation (YMP-USGS-QMP-3.16, RO) to each of the experts, and Facilitation and Management Team members

Following Dr. Stamatakos, Dr. Pezzopane discussed results from geodetic studies conducted by the U.S. Geological Survey. He emphasized the questionable data quality of the earlier leveling surveys, particularly the 1907 survey. He pointed out that in contrast to the CNWRA's results, Savage *et al.* (1994 JGR) found no detectable deformation above the error limits of the network except for a negative elevation change ($\approx$ 2 cm at the surface) associated with the 1992 Little Skull Mountain earthquake.

Mr. Ivan Wong presented results on development of the historical earthquake catalogue for the Yucca Mountain PSHA. He discussed the data sources and statistics of the catalogue and highlighted significant issues related to its use. Dr. Pezzopane then gave a short unscheduled presentation on his analysis of relevant fault sources for Yucca Mountain that is summarized in Chapter 11 of the seismotectonic synthesis report, and follows guidance given by NRC in their report NUREG-1451. Mr. Wong also provided input on faults found to be most significant during their preliminary PSHA for the ESF.

Dr. Coppersmith then announced the SSC teams. Teams were selected by a random process that would ensure that each team contains a seismologist, a regional geologist, and a local geologist/paleoseismologist.

Dr. Coppersmith then closed the day with statements from observers. Dr. Allen commented on the change of the location and shape of the proposed repository block (it now lies entirely west of the ESF and the Ghost Dance fault). Dr. Jerry King commented on his role as providing regulatory oversight to ensure that the needs of the NRC are met. He discussed seismic design parameters of interest from his perspective, including dual design basis earthquakes (with return periods of 1,000 and 10,000 years) and periods of interest (up to 1 second) for the types of facilities being designed. Leon Reiter asked a question regarding the time frame in considering maximum magnitudes and Dr. Coppersmith clarified that these are independent of time with respect to the current tectonic regime. Dr. Stamatakos commented that the CNWRA's report on Type I faults will be available soon.

FRIDAY, OCTOBER 18, 1996

Dr. Robert Youngs gave the first presentation on SSC for fault displacement analysis. He discussed methods for assessing the fault displacement hazard, pointing out differences with assessments for ground motions and differences between fault hazard analysis for design purposes and performance assessments. He outlined the necessary components and various approaches to determining input for characterizing fault displacement. He emphasized characterizing uncertainty in rupture distributions and gave examples of specific applications.

Next, Dr. Warren Day presented results from detailed surface mapping of the bedrock geology at Yucca Mountain. He distributed copies of a manuscript, including maps and cross-sections, and several abstracts. He compared new results with earlier mapping , discussed accuracies, highlighted new results, and concluded by summarizing the characteristics of the principal types of bedrock faults at Yucca Mountain: block-bounding, intrablock, and northwest-striking faults (the latter including both intrablock and bridging faults). He also suggested a possible fault classification scheme based on offsets observed over certain along-strike distances.

After the break, Dr. Robert Lung presented preliminary results of detailed subsurface mapping of fractures and faults in the ESF. At the time of his report, roughly 6,600 m of the tunnel had been drilled, 6,400 m had been mapped, and 5,400 m of mapping had been cleared through quality assurance. He described the type and format of data available from their studies. He highlighted "notable" structural features observed in the ESF to date and discussed some differences and similarities between subsurface and surface mapping.

Dr. Mark Feighner then presented results from geophysical studies of Yucca Mountain conducted by Lawrence Berkeley National Laboratory. These studies involved collection of seismic, gravity, magnetic, and magnetotelluric data. He presented first order preliminary interpretations for many of these studies. He also highlighted differences between their models and those developed by the U.S. Geological Survey (previously presented by Dr. Brocher), emphasizing the assumptions made and the uncertainties in their data and models.

Dr. Whitney gave the next presentation on paleoseismic displacement data for the Ghost Dance fault. He summarized data from both geomorphic studies, which included cosmogenic dating of surfaces along Whaleback and Antler Ridges, and trenching studies. He highlighted issues related to interpreting the genesis and significance of cracking events.

After lunch Dr. Burt Slemmons discussed the advantages and disadvantages of using average and maximum fault displacements compared to using surface rupture lengths to estimate maximum magnitudes. Using examples from historic earthquakes, he highlighted issues related to assessing magnitude for complex rupture patterns, such as uncertainties in fault segmentation and distributive fault ruptures.

Dr. Pezzopane gave the final presentation of the workshop on displacement data from historic surface-rupturing earthquakes in the Basin and Range. The purpose of his study was to help characterize secondary displacement by analyzing along-strike and across-strike fault displacement distributions. He described the data set, including its uncertainties and limitations. He discussed large variations in the shape of along-strike slip distributions, variations in the width of surface ruptures, the relation between lengths of primary and secondary components of surface-rupturing events, the relation between displacements on

primary and secondary faults, and the relation between secondary rupture lengths and secondary displacements.

Dr. Coppersmith wrapped up the workshop by discussing plans for the next workshop and field trip. He then opened up the meeting to comments from observers. Dr. Allen commented on the observations of fracturing in the ESF opening up more issues. Dr. Daniel Soeder clarified the status of availability for certain data sets. Dr. Reiter commented on the difficulty of characterizing fault displacement without a more specific minimum threshold, and he encouraged design engineers to give as much guidance as possible to the SSC experts to help focus their efforts. The workshop was adjourned at about 3:00 pm.

TABLE 1
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* Includes material distributed to SSC Experts in a November 1996 mailing following Workshop #2.

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TABLE 2
YUCCA MOUNTAIN SEISMIC SOURCE CHARACTERIZATION WORKSHOP #2 - HAZARD METHODOLOGIES

Attendance List
OCTOBER 16-18, 1996

Name	Affiliation
1. Ake, Jon	U.S. Bureau of Reclamation (USBR)
2. Allen, Clarence	Nuclear Waste Technical Review Board (NWTRB)
3. Anderson, Ernie	U.S. Geological Survey (USGS)
4. Anderson, John	University of Nevada at Reno (UNR)
5. Anderson, Larry	USBR
6. Arabasz, Walter	University of Utah (UU)
7. Bell, John	UNR
8. Brocher, Tom	USGS
9. Bruhn, Ron	UU
10. Brune, James	UNR
11. Chaney, Tom	USGS
12. Coppersmith, Kevin	Geomatrix
13. Cornell, Allin	Consultant
14. Day, Warren	USGS
15. dePolo, Craig	UNR
16. Doser, Diane	University of Texas, El Paso
17. Feighner, Mark	Lawrence Berkeley National Laboratory
18. Fridrich, Chris	USGS
19. Hanks, Tom	USGS
20. Justus, Phil	U.S. Nuclear Regulatory Commission (NRC)
21. Kimball, Jeff	U.S. Department of Energy (DOE)
22. King, Jerry	M&O/SAIC
23. Knuepfer, Peter	State University of New York at Binghamton
24. Lui, Christiana	NRC
25. Lung, Rob	USBR
26. McCalpin, Jim	GEO-HAZ Consulting, Inc.
27. McGuire, Robin	Risk Engineering
28. Menges, Chris	USGS
29. O'Leary, Dennis	USGS
30. Olig, Susan	Woodward-Clyde Federal Services (WCFS)

TABLE 2 (Cont.)
YUCCA MOUNTAIN SEISMIC SOURCE CHARACTERIZATION
WORKSHOP #2 - HAZARD METHODOLOGIES

Attendance List
OCTOBER 16-18, 1996

Name	Affiliation
31. Perman, Roseanne	Geomatrix
32. Pezzopane, Silvio	USGS
33. Pomeroy, Paul	Advisory Committee on Nuclear Waste
34. Potter, Chris	USGS
35. Quittmeyer, Richard	WCFS
36. Ramelli, Alan	UNR
37. Reiter, Leon	NWTRB
38. Robert Smith	UU
39. Rogers, Al	EQE International
40. Savy, Jean	Lawrence Livermore National Laboratory
41. Schwartz, David	USGS
42. Slemmons, Burt	WCFS
43. Smith, Ken	UNR
44. Soeder, Daniel	USGS
45. Stamatakos, John	CNWRA
46. Stepp, Carl	WCFS
47. Sullivan, Tim	DOE
48. Swan, Bert	Geomatrix
49. Tillson, David	Nevada Agency for Nuclear Projects
50. Toro, Gabe	Risk Engineering
51. Whitney, John	USGS
52. Wong, Ivan	WCFS
53. Youngs, Robert	Geomatrix
54. Yount, Jim	UNR

Civilian Radioactive Waste Management System
Management & Operating Contractor

Summary of Seismic Source Characterization Field Trip and Workshop on Alternative Models and Interpretations

SSC Workshop 3

Amargosa Valley, NV
November 18-21, 1996

Prepared for:

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December 18, 1996

1. INTRODUCTION

The U.S. Geological Survey (USGS) is carrying out a probabilistic seismic hazards analysis (PSHA) for Yucca Mountain, Nevada as part of the Department of Energy's (DOE) project to characterize this site as a potential geologic repository for high-level radioactive waste. This study was initiated in April 1995 and resumed in June 1996. The aim of the analysis is to provide the annual probability with which various levels of vibratory ground motion and fault displacement will be exceeded at the site. These results will be used as a basis for developing seismic design inputs and in assessing the performance of the site.

The PSHA process involves development by two panels of experts of input interpretations and assessments of uncertainties required by the hazards calculations. One panel addresses characterization of seismic sources and fault displacement, while the other deals with vibratory ground motion. Development of interpretations is being facilitated through a series of structured workshops to evaluate available data, to explore the range of interpretations allowed by the data, to examine critically the interpretations proposed by the experts, and to provide feedback on the implications of various interpretations for the seismic hazard at the site. This report summarizes the third in the series of structured workshops for characterization of seismic sources and fault displacement: the Field Trip and Workshop on Alternative Models and Interpretations.

The primary goal of the field trip and workshop was to discuss alternative models, hypotheses, and interpretations that are important to the characterization of seismic sources for vibratory ground motion hazard and fault displacement hazard. The discussions allowed for all of the members of the panel to gain a better understanding of the technical bases for each model, to hear the pros and cons of the alternatives, and to better understand the uncertainties associated with each model. In addition, the field trip allowed experts to observe both surface and subsurface exposures at many key sites, providing first-hand insights into the limits on resolution and uncertainties associated with the field data and interpretations.

To accomplish the above goals, the approach taken was to provide a forum, both in a meeting setting and a field-trip setting, for structured debate of the alternative models and interpretations of importance to the seismic source characterization (SSC). Various individuals, including some members of the expert panel, played the role of "proponents" in presenting arguments in favor of a particular model or interpretation. The experts on the panel, as "evaluators", were encouraged to probe and technically challenge the proponent positions in an effort to better understand the positions, the available supporting data for each

position, and the associated uncertainties. The field trip included 2½ days of field review and discussion focusing on: 1) the behavior of faults in the Yucca Mountain vicinity; 2) the nature of faulting in the potential repository block; and 3) the behavior of the Bare Mountain fault. The workshop discussions entailed presentations and discussions centered around five key issues of importance to the ground motion and fault displacement hazard: tectonic models, three-dimensional geometry of faults, definition and synchroneity of faulting events, characterization of faulting in the repository, and maximum background earthquakes.

The agenda is included as Attachment 1 and it contains a map showing general locations of most field trip stops. Copies of overhead transparencies shown by presenters and additional material distributed during the workshop are included as Attachment 2. Table 1 is a list of participants and their affiliations.

MONDAY, NOVEMBER 18, 1996

The first day of the field trip covered faults on the west side of Yucca Mountain in Crater Flat. The first stop was at Steve's Pass at the southern end of Crater Flat. Dr. John Whitney, the field trip coordinator, gave a brief introduction and outline of the trip. The itinerary was constructed to highlight major issues in interpreting field data and provide a representative sampling of the range and variability of the data. At all of the sites with trench or natural exposures, excavations were still accessible and participants were given the opportunity to observe exposures first hand throughout the trip. Next, Dr. Christopher Fridrich provided a brief overview of the geology of Yucca Mountain, Crater Flat, Bare Mountain, and Black Marble Hill, including eruption of the nearby Timber Mountain and Silent Canyon calderas.

The second stop was at a trench site along the southern Crater Flat fault. Dr. Emily Taylor presented results from Trenches SCFF1 and SCFF1a, including evidence for three surface-faulting events that caused 24 to 65 cm of total vertical slip during the past 250,000 years. Dr. Taylor pointed out uncertainties and alternative interpretations, particularly for Trench SCFF1. Dr. Whitney pointed out possible structural relationships and coseismic rupture between the southern Crater Flat and Windy Wash faults. He also pointed out that deposits associated with the penultimate event on the southern Crater Flat fault contain basaltic ash and this fault may have ruptured with other faults at Yucca Mountain in addition to the Windy Wash fault, as outlined for Scenario U of the rupture scenarios presented in Chapter 5 of the Seismotectonic Synthesis Report.

The third stop was at the Windy Wash fault where Dr. Whitney discussed long-term net slip rates (with 5:1 vertical to horizontal slip ratios) of 0.027 mm/yr derived from offset of a 3.7 Ma basalt flow. He compared these to shorter-term vertical slip rates determined at trench site CF2, to the north, for the past 300 ka that are 0.011 mm/yr. The differences imply that either rates of activity have decreased through time, or perhaps the Windy Wash fault merges

down-dip with the Fatigue Wash and Solitario Canyon faults and extension on the Windy Wash fault to the south is accommodated by all three faults to the north. He also pointed out the coincidence of renewed extension with basaltic volcanism in Crater Flat.

The fourth stop was at trenches CF2 and CF3 on the Windy Wash fault. Dr. Whitney discussed evidence for 7 to 10 faulting events during the past 400,000 years. He clarified that offsets measured were vertical separations and not net slip values. However, geomorphic relations suggest any component of late Quaternary horizontal slip is small. Regardless, he believes the slip rates to be fairly robust and the greatest uncertainties in the paleoseismic record at this site to be in possibly missing small events and the ages of events, particularly older events.

Next, an unscheduled stop was made where the road crossed a fault scarp of the Fatigue Wash fault, so that the SSC experts could observe the relatively subtle geomorphic expression of most faults at Yucca Mountain. Dr. Daniel Soeder provided a brief overview of the stratigraphy of the Paintbrush Canyon Tuff visible in a nearby ridge.

After lunch, at the sixth stop, Mr. Alan Ramelli presented results from Trench T3 on the Solitario Canyon fault. Two large fissure fills provide evidence for two surface-faulting events in the past 700,000 to 900,000 years, with a very long hiatus in activity for about 500,000 years. The younger fissure fill contains a thick section of basaltic ash and Mr. Ramelli emphasized the possibility that the Solitario Canyon fault may have ruptured with the Windy Wash and Southern Crater Flat faults during this "ash event", as discussed previously by Dr. Whitney.

The seventh stop was at Trench T8, north of Trench T3, on the Solitario Canyon fault. Participants split into two groups. Dr. James Brune led one group to the top of a nearby ridge to observe a precariously balanced rock in the footwall, and very close to the trace, of the Solitario Canyon fault. Precariously balanced rocks along the fault suggest that although there is equivocal evidence for Holocene events on the Solitario Canyon fault, if these events occurred, they must have been fairly small. Mr. Ramelli presented his results for Trench T8 to the other group. The paleoseismic record at Trench T8 is similar to that at Trench T3, with suggestive evidence for two possible additional events at T8.

The next stop was an unscheduled stop at a precariously balanced rock north of Trench T8. Dr. Brune discussed results from his studies that suggest that north-south directed horizontal ground accelerations in the area have not exceeded 0.2 g during the past 10,000 to 20,000 years, based on ^{14}C-dating of rock varnish on rock pedestals and measurements of the force required to topple balanced rocks.

The last stop of the day was at Trench T4 on the Solitario Canyon fault. Mr. Ramelli first discussed the trench exposure. Of the two fault traces at this site, only the westernmost trace shows evidence for Quaternary activity, with two fissure fills that are similar to, but smaller than those in Trench T8, indicating that displacement is dying out to the north. Drs. Christopher Potter and Warren Day discussed some of the results of their bedrock mapping along the Solitario Canyon fault. They discussed deformation patterns of block-bounding, intrablock and bridging faults.

After dinner, an evening workshop session on tectonic models and their implications was convened. Dr. Christopher Fridrich presented his data and interpretations on the Late Cenozoic tectonic evolution of the Crater Flat basin. He distributed preprints of two related papers. He defined structural domains in the region and described chronologically the tectonic development of the Crater Flat basin from 13 Ma to the present. He estimated the percent of extension for two tectonic models: a tilted-block model and combination listric fault and tilted-block model. He discussed spatial and temporal patterns of extension rates, and implications for tectonic models from observed deformation patterns.

Next, Dr. Rich Schweickert presented his model for a major strike-slip fault system in the Yucca Mountain region. He proposed that a 250-km-long zone of dextral simple shear extends from Amargosa Valley, through Crater Flat and Yucca Mountain, continuing northwest of the Timber Mountain caldera. He described the fault system and outlined the evidence for it, emphasizing the caveat that the data are only permissive for his model. He proposed a geometry for the fault system after a model originally proposed by Hardyman and Oldow (1991), that kinematically links normal and oblique-normal faults at the surface with a detachment and strike-slip fault at depth. He then highlighted some of the tectonic implications of his model that are relevant to seismic hazards in the region.

The third speaker was Dr. Warren Hamilton, who presented a rolling hinge tectonic model for Yucca Mountain. He first described the model in general, emphasizing that the model explains how low-angle normal faults cutting steeply-dipping beds can evolve from initially high-angle normal faults cutting flat-lying beds. He provided examples of low-angle normal faults in the surrounding region (the Funeral and Whipple Mountains), highlighting characteristics of these fault systems that fit the rolling hinge model. Finally, he described how the rolling hinge model may apply to the Yucca Mountain region and highlighted structural features and aspects of the tectonic history that fit the rolling hinge model.

Next, Dr. John Stamatakos gave Dr. David Ferrill's presentation on their tectonic studies of Bare Mountain and Crater Flat, as Dr. Ferrill was absent on jury duty. Dr. Stamatakos first presented data and interpretations on the uplift and tilting history of Bare Mountain. He then summarized their interpretation of significant Tertiary tectonic events at Bare Mountain,

highlighting tilting to the northeast, no observed vertical axis rotation, greater uplift to the south, and some differences in the timing of uplift with previous presentations. He then presented data and interpretations in the geometry and structural style of the Bare Mountain fault and faults in Crater Flat, culminating in two models represented by balanced cross-sections. In both models, the Bare Mountain fault is listric, but one model shows a detachment fault cut-off by the Bare Mountain fault at about 5 km whereas in the other model, the Bare Mountain fault soles into a detachment fault at about 10 km. He noted that he would discuss the models and their key points further in his presentation on Wednesday.

Dr. Mark Tynan wrapped up the evening session with a brief introduction and overview of the Exploratory Studies Facilities (ESF) to prepare everyone for the trip into the tunnel the next day (Tuesday).

TUESDAY, NOVEMBER 19, 1996

The field trip on Tuesday focused on faulting in the Yucca Mountain block and on the east side. It consisted of two main components: a trip into the ESF tunnel to view subsurface exposures of the Yucca Mountain block, and visits to various surficial exposures along the Ghost Dance, Bow Ridge, and Paintbrush Canyon faults. Because of logistical constraints on the ESF trip, participants split into two groups. Group 1 visited surficial exposures in the morning while Group 2 visited the ESF tunnel. In the afternoon, Group 2 visited surficial exposures while Group 1 visited the ESF tunnel.

The ESF trip began with an introduction by Dr. Steve Beason who distributed handouts including maps and some summary data. After safety training and an introductory video, participants were outfitted with safety gear and proceeded into the tunnel. The excursion was led by Dr. Beason who was assisted by Dr. Robert Lung. Stops were made at key exposures of faults, fractures, cooling joints, and tilted beds, to allow direct observations and discussion of the exposures.

Some highlights of the trip included: 1) the 2-m-wide Bow Ridge fault; 2) smaller intrablock reverse and normal faults, some of which are identified at the surface and some of which are not; 3) cooling joints and small faults accommodating settling during cooling; 3) breccia in the imbricate fault zone at station 5+50 m; 4) the Drill Hole Wash fault; and, 5) the Ghost Dance fault. Throughout the trip, discussions focused on the character and style of deformation; density, distribution and origin of structural features; correlations with observations of structures at the surface; and the tectonic and seismogenic significance of the features. The ESF visit ended at about station 42+50 m due to respirator requirements beyond this point.

Visits to surficial exposures on Yucca Mountain started at Trench 14D on the Bow Ridge fault. For Group 2, Dr. Christopher Potter and Dr. Whitney presented results of paleoseismic investigations for Dr. Christopher Menges, who was in the ESF tunnel with Group 1. They presented evidence for at least two, probably three surface-faulting events since before 250,000 to 340,000 years ago, with a total net slip of 60-70 cm, resulting in a slip rate of 0.003 mm/yr. Slickensides rake 47° to 67° SW and displacements are 20 to 25 cm for each event. The most recent event occurred before ~50 ka and the penultimate event occurred between 140 and 150 ka. Dr. Potter also described nearby along-strike variations in the character of the Bow Ridge and small subsidiary faults that they had observed during their mapping.

The next stop was where Split Wash crosses the Ghost Dance fault. Dr. Potter discussed their detailed bedrock mapping in the area, emphasizing differences with previous interpretations by Spengler and others, particularly that Dr. Potter and his colleagues do not interpret the Sundance fault to be a through-going fault that offsets the Ghost Dance fault based on nearby continuous exposures of volcanic tuff beds. Dr. Whitney then presented results from Trenches 4a, 4b and 4c, located in Split Wash across the projection of the Ghost Dance fault. These trenches were excavated to see if older, buried Quaternary deposits in the wash were faulted. Dr. Whitney pointed out that no faults were exposed in Trenches 4b and 4c, only unfaulted late Quaternary alluvium and colluvium; whereas some bedrock fractures that are probably not part of the Ghost Dance fault were exposed in Trench 4a. Uncertainties in interpreting faulting history from the exposures were discussed.

The next stop was at the Antler Ridge pavement, an excavated bedrock surface which exposes the Ghost Dance fault. Dr. Potter described how this exposure in the Tiva Canyon Tuff was made and the characteristics of the Ghost Dance fault. Next, Dr. Whitney presented findings in two nearby trenches (Trench 5 and 5a) excavated in alluvium burying the Ghost Dance fault. Although suggestive evidence for a possible Quaternary fracturing event was found in Trench 5, they found no evidence for Quaternary fracturing in Trench 5a.

The next stop was at a trench exposure on the Ghost Dance fault in bedrock at the top of Whaleback Ridge. Dr. Potter described characteristics of the Ghost Dance fault determined from mapping and next Dr. Whitney presented results from cosmogenic isotope studies of the ridge surface, which suggests that the ridge morphology is about 500,000 years old. He also discussed Dr. Emily Taylor's interpretation of the faulting history based on the trench exposure. They found no evidence for any Quaternary events on the Ghost Dance fault at this site, in contrast to work at this site by Dr. John Bell, who next presented his interpretation. Dr. Bell found suggestive evidence for a possible Quaternary fracturing or small faulting event that occurred after 400 to 500 ka. Just south of Whaleback Ridge, we visited another

bedrock exposure of the Ghost Dance fault at the UZ 7a drill pad. Dr. Potter pointed out the distinct breccia zones that are probably related to different periods of faulting.

At the end of the day, the two groups rendezvoused at the top of Yucca Crest. Dr. Potter described characteristics of the Paintbrush Canyon fault and associated faults, visible to the east along Fran Ridge. For those who had not visited the exposure of the Paintbrush Canyon fault at Busted Butte, Dr. Whitney described this exposure and summarized the paleoseismic record, which is one of the longest and most complete faulting records in the Basin and Range province. (Note: some of Group 1 had split off to visit the Busted Butte exposure before meeting at Yucca Crest.) Finally, using the global vantage point, Dr. Whitney briefly recapped the field trip.

WEDNESDAY, NOVEMBER 20, 1996

Wednesday was divided into a morning workshop session on constraints on tectonic models, and an afternoon field trip to Bare Mountain.

Dr. Dennis O'Leary set the stage for the morning workshop by generally discussing structural constraints on tectonic models. He outlined four general constraints: 1) the extent of knowledge relative to the complexity of the object one is attempting to model; 2) the model should account for observed physical phenomena; 3) the model should contain key structural features with certain properties and histories; and 4) the model should contain realistic material properties and mechanical behavior. Throughout his presentation, he elaborated on aspects of these constraints particularly relevant to Yucca Mountain and highlighted caveats in developing various tectonic models. This included key points (with pros and cons for Yucca Mountain) for: detachment, pull-apart, strike-slip, and caldera tectonic models.

Next, Dr. Stamatakos presented fundamental geological observations from their studies and key points of their finite-element modeling and balanced cross-sections of the Bare Mountain fault. Dr. Stamatakos also distributed summary material and excerpts from their Type 1 fault study, but he did not discuss this material as their final report is still forthcoming. Key points to their tectonic models include: 1) listric faults (depth for curvature on the Bare Mountain fault is 5 to 15 km); 2) dominantly dip slip; 3) displacements and fault dip increasing to the south; and 4) minimum depth of 5 km for any detachment fault. His presentation concluded with questions from the experts and discussions of specific constraints and assumptions in the models. He emphasized that the surficial mapping data they used for the Yucca Mountain area was outdated (Scott and Bank, 1984) and that it would be beneficial to revise the cross-sections, incorporating new mapping data by Day and others (in press; distributed at the last workshop).

Dr. Thomas Brocher gave the next presentation on implications from seismic reflection data for high angle faulting in the shallow crust at Yucca Mountain. He re-emphasized that based on distinctive zones of truncated reflectors, the Bare Mountain fault appears planar to a depth of 6 to 7 km, dipping 65°E. He also emphasized that west-dipping faults at Yucca Mountain appear relatively planar and high-angle, which is in general agreement with interpretations by Lawrence Berkeley National Laboratories (LBNL) in their seismic reflection studies. He then reiterated that a major difference between the USGS and LBNL interpretations was the USGS proposes large offsets of the Tertiary-Paleozoic contact along the Ghost Dance and Solitario Canyon faults based on their interpretation of the seismic data, whereas LBNL interprets the Tertiary-Paleozoic contact to be fairly smooth with only small offsets across these faults based largely on gravity models. Finally, Dr. Brocher discussed implications for a ~12-km depth of the seismogenic crust based on seismic data, seismicity data, thermal constraints, and rheologic models.

After the break, Dr. John Bell presented results and tectonic implications from recent and ongoing fault studies conducted by the Nevada Bureau of Mines and Geology. He discussed the newly recognized east Lathrop Cone fault, the poorly understood West Dune Wash fault and several, small, down-to-the-east faults. He also pointed out how some of their interpretations for the paleoseismic history of the Ghost Dance, Bare Mountain and southern Solitario Canyon-Windy Wash faults differed from other investigators (these differences were discussed in more detail during the field trip). Finally, he highlighted aspects of the 1932 Cedar Mountain earthquake that are significant to seismic source characterization at Yucca Mountain.

Next, Dr. Robert Smith presented his insights into seismotectonic issues for normal faults, focusing on examples from the Basin and Range province and the Intermountain seismic belt. These included: 1) the caveat that many big earthquakes nucleate below the brittle-ductile transition and so we could be underestimating rupture area and seismic moment; 2) the need to consider viscoelastic deformation and long-term behavior because a significant component of the surface deformation we observe may not be coseismic; 3) the need to better understand relationships between volcanism and extensional tectonism; 4) observations of contagion behavior and triggered slip; 5) the need to consider both historic seismicity and geodetic data as contemporary strain indicators; and 6) some issues in using scaling relationships to estimate earthquake magnitudes. He provided abstracts for many references and also gave a brief introduction to application of finite and boundary element modeling to investigate normal fault interactions. This stimulated discussion among the experts of triggered slip on faults.

Next, Dr. Coppersmith facilitated a discussion of the implications of tectonic models to seismic source characterization. Discussion centered around: 1) what are the major earthquake sources at Yucca Mountain?; 2) what is the current role of Yucca Mountain faults (are they seismogenic and is activity waxing or waning)?; 3) issues of fault-rupture continuity, segmentation and distributive faulting; and 4) issues of slip rates and earthquake recurrence.

The afternoon was devoted to a field trip to Bare Mountain. The first stop was at the Tarantula Canyon trench site on the northern Bare Mountain fault. Mr. Larry Anderson presented results from their mapping and trench studies, providing an overview of the fault and the site geology, discussing their paleoseismic interpretations, and highlighting differences with previous studies. Mr. Anderson provided handouts, including a paper on the Beatty scarp and a comment paper on work by Ferrill *et al.* (1996) submitted to GEOLOGY. Next, Dr. Bell discussed their unpublished interpretations of the paleoseismic record at this site, which includes two surface-faulting events that occurred post-Q2 (post roughly 150 ka), in contrast to the one event interpreted by Mr. Anderson. In both interpretations, 1.5 m of vertical slip occurred during this time so the differences do not affect slip rate, only paleomagnitude estimates, recurrence intervals and rupture behavior.

The next stop was at the southern end of the Bare Mountain fault at the Sterling site and trench BMT-3. Mr. Anderson presented evidence for two late Pleistocene surface-faulting events, vertical slip rates of 0.01 mm/yr, and near-surface fault dips of 60° to 65°. Next, Dr. Bell discussed how their interpretations differed for this site, with an additional post-Q2 surface-faulting event, similar to the Tarantula Canyon site. Finally, Dr. Stamatakos discussed evidence for long-term uplift rates on the Bare Mountain fault that are higher by at least a factor of 3 than the shorter-term slip rates determined from the paleoseismic record, including 30 m of subsidence of a surface at the southern end of the fault thought to be about 1 Ma.

The last stop of the day was at an exposure near the Gold Ace Mine on the west side of Bare Mountain. Dr. Stamatakos pointed out that although the Gold Ace Mine fault is pre-Miocene, exposures like this provide analogues for what Paleozoic rocks might look like under Yucca Mountain. Their studies indicate that a dominant set of northeast-striking faults have a high slip tendency in the present stress regime and these faults may be prime candidates for non-surface faulting earthquakes in the region.

THURSDAY, NOVEMBER 21, 1996

The workshop sessions on Thursday focused on three issues: the synchroneity of faulting events, the characterization of future faulting in the repository, and the maximum background earthquake. Mr. Ramelli began the session on synchroneity of faulting events with a

presentation on basaltic ash exposures and evidence for a distributed late Quaternary surface-faulting event at Yucca Mountain. He discussed the location, character, age, interpretations and implications of ash exposures at several localities along many of the faults (southern Windy Wash, Fatigue Wash, Solitario Canyon, Bow Ridge, Stagecoach Road, and Paintbrush Canyon). He pointed out problems with absolute dating, and uncertainties in interpreting certain exposures and the potential involvement of corresponding faults. He also discussed the implied association of volcanism and faulting, and suggested possible explanations for the interaction of volcanism and faulting. A discussion then followed on any evidence for faulting south of Lathrop Wells and Mr. Ramelli pointed out that he and Dr. Bell were planning to finalize their fault map by the January workshop (a draft map was included with Dr. Bell's presentation package).

Next, Dr. Whitney discussed event rupture scenarios presented in the Seismotectonic Synthesis Report and implications to earthquake recurrence, maximum magnitudes and slip rates. Dr. Whitney outlined nine reasons in favor of distributive faulting at Yucca Mountain. He discussed the effects of various rupture scenarios on the slip rate data, which are generally negligible due to the long-term nature of the data. He also discussed the effect on recurrence and magnitude estimates, highlighting the trade-off between decreasing recurrence values and increasing maximum magnitudes for distributive faulting, depending on how magnitudes are calculated.

Dr. David Schwartz then gave the first presentation in the session on characterization of future faulting in the repository. He discussed various coseismic slip models and various issues in generally characterizing fault displacement, including: 1) observations of slip at a point versus along-strike slip distributions for a fault; 2) precision and uncertainties of surface and trench data; 3) whether single-event displacement measurements at the surface are representative of the slip at depth; 4) complexity of displacement patterns near segment boundaries and where faults overlap; and, 5) variations in displacements at a point for successive events. In regards to the last issue, he presented preliminary findings from a worldwide database that indicate characteristic behavior is dominant but not universal.

Next, Dr. Potter discussed the nature of fault interactions at Yucca Mountain. He first described characteristics and displacement histories for block-bounding faults, focusing on the Bow Ridge and Solitario Canyon faults. He next described interactions between block-bounding faults and northwest-striking faults. He also noted that many of the faults post-dated most of the tilting. Finally, he summarized key points on deformation in the potential repository area.

Dr. Donald Sweetkind gave the next presentation on the fracture network at Yucca Mountain and correlation between surface and subsurface structures. He described joint networks and

discussed how discontinuous faulting is accommodated on pre-existing cooling joints. He explained that correlations are generally good between surface and subsurface mapping of structures, giving many examples. He also pointed out a few examples where correlations were poor and discussed factors affecting correlations. He noted that isotope studies indicate a connected structural pathway of cooling joints and small-scale faults, corroborating the complex interactions observed in mapping studies.

Next, Dr. Frank (Bert) Swan presented results from their fault studies in Midway Valley and discussed implications for fault displacement at Yucca Mountain. He first discussed intrablock faults in Exile Hill. He then discussed characteristics, origin and history of fractures exposed in trenches in Midway Valley. Key points included: 1) fractures show a variety of orientations, but those extending into Quaternary alluvium dominantly strike north-northeast; 2) no detectable displacements were observed; 3) fractures could be tectonic or nontectonic; 4) fractures associated with the Exile Hill fault do not extend into Quaternary deposits; and, 5) evidence exists for repeated fracturing events on some features but all fractures terminate below Qa4 alluvium (estimated to be 30 to 100 ka). Finally, based on intrablock fault analogies, he highlighted possible implications for the faulting and fracturing history of the Ghost Dance fault.

Next, Dr. Silvio Pezzopane presented results from additional work on his study of historic surface-faulting earthquakes in the Basin and Range province. This work was stimulated by discussion at SSC Workshop #2. He reviewed the data and approach and described various scaling relations. These included scaling between: 1) moment magnitude and maximum surface-rupture width; 2) moment magnitude and the ratio of maximum primary displacement to maximum secondary displacement; 3) moment magnitude and the ratio of average primary to maximum secondary displacement; 4) maximum lengths of primary and distributed surface ruptures; 5) moment magnitude and maximum length of distributed rupture; and, 6) maximum lengths of distributed and principal rupture. He also analyzed the along-strike location of maximum fault parameters and the spatial relation of the length of distributed faulting to the principal rupture. He also described relations among maximum secondary rupture length, displacement, and moment magnitude. Finally, he concluded with miscellaneous ideas on various tectonic and paleoseismic issues.

After lunch, Dr. Coppersmith outlined what is next for the SSC experts, emphasizing what is expected of them by the next SSC workshop in January 1997. This included preliminary evaluations of five key issues, which were detailed in a handout.

Next, Dr. Pezzopane gave a presentation on minimum faulting earthquakes and maximum background earthquakes in the Great Basin. He analyzed the geologic effects (except liquefaction) associated with 100 historic earthquakes, including the frequency of surface-

faulting and cracking as a function of magnitude. He also developed a model for the average and maximum background earthquake that is dependent on rupture area (both shape and size).

Dr. Coppersmith gave the next presentation for Dr. Robert Youngs on some skeletal advice from the Fault Displacement Working Group regarding methodologies for characterizing fault displacement. He described required products, necessary data and interpretations, possible approaches, and differences between SSC for fault displacement and ground motion. He discussed models for characterizing the length of rupture and amount of displacement within the repository. He also discussed considerations for characterizing displacement at various designated points. Dr. Swan clarified how the Working Group envisioned this might be done to allow assessments for different teams to be easily compared.

The next presentation was by Mr. Wong on assessing the contributions from background earthquakes at Yucca Mountain. He pointed out that his assessment of the background earthquake for the ESF study conflicts with results from studies of precariously-balanced rocks and their assessment may be too conservative due to assumptions and simplifications made in modeling the background earthquake. He highlighted the significant issues and presented results from a recent study for the Waste Handling Building, including sensitivity analyses of recurrence of maximum background earthquakes.

Next, Dr. Allin Cornell gave a brief unscheduled presentation on background earthquakes and uncertainties in the Yucca Mountain region. He discussed problems with using the "standard background model" typically used in western U.S. hazard studies at Yucca Mountain where faults are better known, without consideration as to the resolution and detail of available information. He emphasized considering resolution of the data in developing background earthquake zones for Yucca Mountain.

Mr. Craig dePolo gave the final presentation of the workshop on determining the size of the maximum background earthquake. He clarified his definitions of primary and secondary faulting and discussed magnitudes for some historic Basin and Range earthquakes. He highlighted the observed overlapping magnitude ranges for non-surface rupturing, secondary surface-rupturing, and primary surface-rupturing events.

Finally, Dr. Coppersmith opened the floor to observers for comments and questions. Dr. Leon Reiter had several comments, including: 1) given the new configuration proposed for the repository block, the Nuclear Waste Technical Review Board is concerned with the need for additional subsurface data, and consequently, they believe that an E-W drift in the ESF would be very valuable; 2) he hopes that the SSC experts give due attention to the northeast splay of the Solitario Canyon fault that extends into the proposed repository block; 3) the importance of avoiding inconsistencies (including with other project data and models) in

developing SSC assessments; and 4) a useful approach in evaluating models is to try and disprove them. Dr. Bakr Ibrahim commented that he appreciated the extensive efforts made in discussing uncertainties and he thought that the geophysical data needed to be better incorporated with the geologic mapping data in developing structural models for the repository block. Next, Dr. Thomas Hanks commented that there was a lot of discussion about the size of background earthquakes but what about rates of recurrence? He also emphasized that characterizations of background and fault-related earthquakes need to be consistent with each other and given careful consideration as to how they are integrated. Dr. Richard Parizek asked about the significance of the apparent randomness of seismicity around the site and Dr. Coppersmith clarified that it is up to the experts to make any determination about this. Dr. Parizek also wondered if the issue of the southern extent of Quaternary faults at Yucca Mountain would be one of the issues covered by the experts and Dr. Coppersmith explained that this would be covered as part of the issue related to defining geometry of earthquake sources. Finally, Dr. Mark Tynan commented that the Geophysical Synthesis Report, the synthesis report on surface fracture data, and some of the ESF mapping and subsurface fracture data are available for the SSC experts. He also mentioned that Dr. Day would be producing cross-sections from the 3-D structural model of the repository block that will be made available to the expert panel. The workshop was adjourned around 4:00 pm.

TABLE 1. YUCCA MOUNTAIN SEISMIC SOURCE CHARACTERIZATION FIELD TRIP AND WORKSHOP ON ALTERNATIVE MODELS AND INTERPRETATIONS

November 18-21, 1996

Attendance List

Name	Affiliation
1. Abrahamson, Norm	Consultant
2. Ake, Jon	U.S. Bureau of Reclamation (USBR)
3. Anderson, Ernie	U.S. Geological Survey (USGS)
4. Anderson, Larry	USBR
5. Arabasz, Walter	University of Utah (UU)
6. Bell, John	UNR
7. Biggar, Norma	WCFS
8. Brocher, Tom	USGS
9. Bruhn, Ron	UU
10. Brune, James	UNR
11. Coppersmith, Kevin	Geomatrix
12. Cornell, Allin	Consultant
13. Day, Warren	USGS
14. dePolo, Craig	UNR
15. Doser, Diane	University of Texas, El Paso
16. Fridrich, Chris	USGS
17. Hamilton, Warren	Colorado School of Mines
18. Hanks, Tom	USGS
19. Ibrahim, Bakr	U.S. Nuclear Regulatory Commission (NRC)
20. Justus, Phil	NRC
21. King, Jerry	M&O/SAIC
22. Knuepfer, Peter	State University of New York at Binghamton
23. McCalpin, Jim	GEO-HAZ Consulting, Inc.
24. McGuire, Robin	Risk Engineering
25. Menges, Chris	USGS
26. O'Leary, Dennis	USGS
27. Olig, Susan	Woodward-Clyde Federal Services (WCFS)
28. Parizek, Richard	Technical Review Board
29. Penn, Sue	WCFS
30. Perman, Roseanne	Geomatrix
31. Pezzopane, Silvio	USGS
32. Pomeroy, Paul	Advisory Committee on Nuclear Waste

TABLE 1 (CONT). YUCCA MOUNTAIN SEISMIC SOURCE CHARACTERIZATION FIELD TRIP AND WORKSHOP ON ALTERNATIVE MODELS AND INTERPRETATIONS

November 18-21, 1996

Attendance List

Name	Affiliation
33. Potter, Chris	USGS
34. Quittmeyer, Richard	WCFS
35. Ramelli, Alan	UNR
36. Reiter, Leon	NWTRB
37. Rogers, Al	EQE International
38. Savino, John	SAIC
39. Savy, Jean	Lawrence Livermore National Laboratory
40. Schwartz, David	USGS
41. Schweickert, Rich	UNR
42. Slemmons, Burt	WCFS
43. Smith, Ken	UNR
44. Smith, Robert	UU
45. Soeder, Daniel	USGS
46. Stamatakos, John	CNWRA
47. Stepp, Carl	WCFS
48. Stuckless, John	USGS
49. Sullivan, Tim	DOE
50. Swan, Bert	Geomatrix
51. Sweetkind, Don	USGS
52. Taylor, Emily	USGS
53. Toro, Gabe	Risk Engineering
54. Tynan, Mark	DOE
55. Engelbrecht von Tiesenhausen	Clark County Nuclear Waste Division
56. Whitney, John	USGS
57. Wong, Ivan	WCFS
58. Yount, Jim	UNR

Civilian Radioactive Waste Management System
Management & Operating Contractor

Summary of Seismic Source Characterization Preliminary Interpretations Workshop

SSC Workshop 4

Salt Lake City, Utah
January 6-8, 1997

Prepared for:

U.S. Geological Survey
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January 31, 1997

INTRODUCTION

The U.S. Geological Survey (USGS) is carrying out a probabilistic seismic hazards analysis (PSHA) for Yucca Mountain, Nevada as part of the Department of Energy's (DOE) project to characterize this site as a potential geologic repository for high-level radioactive waste. This study was initiated in April 1995 and resumed in June 1996. The aim of the analysis is to provide the annual frequency with which various levels of vibratory ground motion and fault displacement will be exceeded at the site. These results will be used as a basis for developing seismic design inputs and in assessing the waste isolation and containment performance of the site.

The PSHA involves development by two panels of experts of input interpretations and assessments of uncertainties required by the hazards calculations. One panel (consisting of six teams of three experts) addresses characterization of seismic sources and fault displacement, while the other (consisting of seven individual experts) deals with vibratory ground motion. Development of interpretations is being facilitated through a series of structured workshops to evaluate available data, to explore the range of interpretations allowed by the data, to examine critically the interpretations proposed by the experts, and to provide feedback on the implications of various interpretations for the seismic hazard at the site. This report summarizes the fourth workshop in the characterization of seismic sources and fault displacement: the Seismic Source Characterization (SSC) Preliminary Interpretations Workshop.

The primary goals of the workshop were to: (1) provide an opportunity for the expert teams to present and discuss their preliminary interpretations regarding key issues in SSC; (2) train the expert teams on the process of elicitation and uncertainty characterization; and (3) present and discuss additional information and interpretations of importance to SSC at Yucca Mountain. To accomplish these goals, a series of presentations (primarily made by the SSC expert panel members) and group discussion sessions were conducted, with emphasis on interaction among the SSC experts. Five key SSC issues were identified: (1) tectonic models; (2) potential seismic sources; (3) maximum magnitudes; (4) earthquake recurrence; and (5) fault displacement methodology. For each of these issues, two teams of experts were assigned to present their preliminary interpretations. These presentations were followed by group discussion of each issue, during which time the other teams were given the opportunity to present their preliminary interpretations. The focus of the presentations and discussions was on understanding the interpretations, their technical bases, their consistency or inconsistency with data, and the expression of uncertainty. Discussion was facilitated to ensure that each team understood the interpretations of others, including the degree to which

they were supported by earthquake and faulting process models and observed data, and could then more knowledgeably re-evaluate their own team interpretations. The overall goal is for interpretations given at the upcoming elicitation interviews to be well-reasoned, technically-supported, and complete.

The workshop agenda is included as Attachment 1. Copies of overhead transparencies shown by presenters and additional material distributed during the workshop are included as Attachment 2. Table 1 is a list of participants and their affiliations.

MONDAY, JANUARY 6, 1997

The first day of the workshop included a series of presentations to provide additional information on a variety of specific issues outstanding from previous workshops. Kevin Coppersmith gave an introduction, describing the purpose and approach, and outlining the workshop agenda. He emphasized the overall goal was to prepare for the SSC elicitations such that the expert panel's interpretations were well-reasoned, technically-supported and complete. He also emphasized that team interpretations were still preliminary and experts should: feel free to explore the issues thoroughly, ask questions that will help them during the elicitations, and continually keep in mind the characterization of uncertainties. Miscellaneous questions about developing team assessments, scheduling elicitations, and the status of the historical seismicity catalogue were then discussed.

Next, Christopher Potter gave a presentation on the Sundance fault, reviewing previous studies from a historical perspective and discussing the evolution of interpretations as additional data were collected. In particular, he compared studies by Spengler et al. (1994) with those of Potter *et al.* (1995), describing in detail differences in scope, approach, products and results. He explained many differences in interpretations with site-specific examples from maps, highlighting one of the most significant differences was that although Spengler *et al.* (1994) interpreted the Ghost Dance fault to be offset by the Sundance fault by as much as 52 m, Potter *et al.* (1995) concluded that the Sundance fault did not even intersect the Ghost Dance fault based on mapping of continuous volcanic subunits. He pointed out probable causes for differences in interpretations, including the broader area covered by Potter *et al.* (1995), their emphasis on a geologic-based rather than engineering-based approach to defining rock units, and their mapping of several zones in the upper Tiva Canyon Tuff that provided good marker beds, which were not identified in the mapping used by Spengler *et al.* (1994).

Ernie Majer gave the next presentation on geophysical interpretations of the Yucca Mountain vicinity developed by Lawrence Berkeley National Laboratories (LBNL). Due to scheduling conflicts, Dr. Majer had not been able to attend earlier workshops to discuss the LBNL interpretation of these data. He described the data they used, including seismic reflection,

gravity, magnetics, magnetotellurics, and vertical-seismic-profile well data. He pointed out that their studies were summarized in the Geophysical Synthesis Report, which has been made available to the experts. He reviewed the LBNL interpreted cross-sections, laid out seismic lines for the experts to review, and highlighted key differences with geophysical interpretations developed by Thomas Brocher and his colleagues at the USGS. Dr. Majer had met with Dr. Brocher during the last month to discuss these differences, and he had concluded that alternative interpretations are permitted by the data depending on the data sets emphasized and the approach to modeling. After extensive discussion during several meetings with USGS personnel, Dr. Majer still believes that smaller offsets of the top of Paleozoic rocks across the Ghost Dance fault are more reasonable based on the LBNL modeling of the gravity data and considering the data from a 3-D perspective. He pointed out, some ways that processing of seismic data could be improved, and discussed the uncertainties associated with each type of data. He emphasized the difficulties inherent in applying geophysical methods at Yucca Mountain and concluded that without additional drill-hole data, or perhaps simultaneous inversion of gravity and seismic data, multiple geophysical interpretations are permitted by the data and should be considered by the experts when they express their uncertainties.

John Stuckless gave the next presentation on some hydrological and geochemical considerations for evaluating movement on the Ghost Dance, Solitario Canyon, and Paintbrush Canyon faults. He discussed how spatial variations in temperatures, oxygen isotopes, and carbon isotopes of aquifers at Yucca Mountain suggest that block-bounding faults (such as the Solitario and Paintbrush Canyon faults) may be acting as conduits between aquifers, but the Ghost Dance fault does not. He pointed out that the relief on Paleozoic basement rocks, as interpreted from gravity data, has a northeast trend and probably is not related to offset on the Ghost Dance fault, but could be related to "sealed" pre-Miocene faults or erosional paleotopography and may not even be fault-related. He concluded that the hydrological and geochemical data suggests that offsets of the top of Paleozoic rocks across the Ghost Dance fault are not significant and are smaller than offsets across the Solitario and Paintbrush Canyon faults.

Next, Dennis O'Leary discussed the Yucca Mountain faults in a regional context, focusing on the southern extent of faults and their relation to surrounding tectonic features. He reviewed characteristics of the four classes of faults and constraints on spatial and temporal patterns of extension. He discussed the southern extent of the Bare Mountain fault, the southern margin of the Crater Flat basin, and the extent and role of the inferred fault, based on the Bouguer gravity field gradient, that strikes north-south along the eastern margin of the Amargosa trough. He also discussed the Spotted Range-Mine Mountain fault system, the caldera complex, the Kawich Range faults to the north of the caldera, and a faulted block of rocks on the southern flank of Mid Valley that may be an appropriate structural analog for Yucca

Mountain. Dr. O'Leary's presentation stimulated much group discussion, including input from Burt Slemmons, John Whitney, Chris Fridrich, and Alan Ramelli on the southern extent of Yucca Mountain faults and faults east, west, and south of Bare Mountain.

The next presentation was given by Brian Wernicke on whether or not shallow-dipping normal faults (SDNF) generate significant earthquakes. He said his talk would largely follow the outline of a paper he recently published on this topic, and he provided reprints of the paper (Attachment 2). He described the apparent paradox about SDNF, that they are prominent and prevalent crustal-scale features that have accommodated significant amounts of brittle extension, and yet historical seismicity patterns and mechanical considerations suggest that SDNF are not seismically active and are not even capable of producing large earthquakes. He reviewed the limited number of historic, large normal-faulting earthquakes observed worldwide and presented kinematic and mechanical arguments as to why SDNF would have very long recurrence intervals. Thus, he argued that perhaps the general lack of observed large earthquakes on SDNF may be due to the historical record being too short. He also presented paleothermal interpretations for some SDNF in the Basin and Range province that suggest the faults initiated at a shallow dip, implying that they were active at a shallow dip and have not evolved from an active high-angle normal fault to an inactive SDNF. Dr. Wernicke then switched topics to review results from geodetic studies he worked on for the Center for Nuclear Waste Regulatory Analyses, which John Stamatakos had also presented at Workshop #2. At the end of Dr. Wernicke's presentation, there was discussion about the general lack of background seismicity on SDNF and the nature of a possible detachment under Yucca Mountain, which Dr. Wernicke believes is no longer active.

The final presentation of the afternoon was given by James Brune on studies of precarious rocks conducted by him, John Whitney, and associates at UNR, and their implications to paleoseismicity. He presented results from studies in southern California and Nevada of the spatial distribution of precarious rocks and their relation to (i.e. away from) major active faults and the area affected by NTS blasts. He showed examples of the many (~100) precarious rocks they had identified in the Yucca Mountain area and discussed age data that indicates all of the rocks they dated have likely been precariously balanced for longer than 10,000 years. He emphasized that these results have implications for longer recurrence of background earthquakes and the need to allocate some historical seismicity to faults in the area. He pointed out some new developments in thinking about ground motions since their report on precarious rocks was written, which was distributed to SSC experts (Attachment 2). He also presented results from a study of precarious rocks and ground motions from the Little Skull Mountain earthquake.

There were no comments from observers at the end of the day. Finally, the seismologists on the expert panel met to discuss issues related to the status of the seismicity catalogue. Ivan

Wong distributed handouts on preliminary magnitude conversions and completeness intervals for the catalogue (Attachment 2).

TUESDAY, JANUARY 7, 1997

Tuesday was devoted to team presentations and discussion of four of the key SSC issues: tectonic models, potential seismic sources, maximum magnitudes and earthquake recurrence. Dr. Coppersmith gave an introduction, outlining the issues.

Jim McCalpin gave the first presentation on tectonic models, representing the team of Jon Ake, Burt Slemmons, and himself. He said the models they considered were primarily based on Chapter 8 of the Yucca Mountain Seismotectonic Synthesis Report, which included caldera, detachment, volcanic, planar fault-block, and lateral shear models. He described the models, discussed their strengths and weaknesses based on tectonic processes, tectonic development of Yucca Mountain, and observed data; highlighted implications; and gave the team's preliminary assigned weights to the various models. He also discussed their preferred composite tectonic model which is based primarily on the planar fault model with integrated components of the lateral-shear and volcanic models. This stimulated discussion about one problem with the planar fault model; normal dip-slip on north-south striking faults does not appear to be consistent with strike-slip focal mechanisms and northwest-directed extension determined from historical seismicity data.

Robert Smith gave the next presentation, discussing his team's preliminary tectonic models. His other team members are Craig dePolo and Chris Menges. He outlined four classes of models prioritized by their preferability: half-graben (including planar and curved faults), detachment (not likely to be shallow), volcanism, and strike-slip. He highlighted relevant features of the Tertiary tectonic setting and relative variations in strain rates through time. He discussed necessary characteristics and considerations of seismotectonic models for Yucca Mountain, emphasizing constraints from geophysical and structural data, such as low contemporary strain rates (10^{-16}/s to 10^{-17}/s); seismogenic depths of 12 to 16 km; elastic thicknesses of 5 to 15 km, normal and strike-slip focal mechanisms that indicate northwest extension; and the closely-spaced complex, interconnecting nature of faults, many of which likely merge at depth and may be truncated by the Bare Mountain fault. He also discussed the transient aspects of the tectonic regime, which may be related to asperities in the lower crust causing transient loading rates on upper crustal faults. He also noted that stress-field rotations could lock-up structures, stimulating discussion about whether the stress-field is understood well enough to reliably conclude such structures are inactive.

During the discussion session that followed, Ernie Anderson presented a tectonic model, first proposed by Al Rogers to explain observed seismicity patterns, that relates oblique-slip on north-south-striking fault blocks to southward-directed translation of the blocks rather than

dextral shear. As many teams seemed to favor the half-graben/planar fault block model, John Whitney next brought up some information relevant to a question raised earlier regarding whether the sum of late Pleistocene slip rates on Yucca Mountain faults was comparable to the late Pleistocene slip rate observed on the Bare Mountain fault. Dr. Whitney, Dennis O'Leary, and Alan Ramelli all discussed indirect geomorphic and geophysical evidence for additional buried traces of the Bare Mountain fault to the one that is visible and was trenched at the surface. Thus, although this trace has definitely been the most active during the late Quaternary, slip rates determined solely from this trace may still be minimums for the entire fault zone. David Ferrill then reiterated the higher longer-term slip rates that he and his associates have interpreted along the southern Bare Mountain fault based on 30 m of subsidence of a basalt flow inferred to be one million years old. Finally, Dr. Coppersmith reviewed the tectonic models presented and some of the key points that were discussed.

Chris Fridrich gave the first presentation on potential seismic sources, representing the team of Diane Doser, Bert Swan and himself. Dr. Fridrich described five types of seismic sources they had considered: 1) background sources; 2) regional fault sources based on mapped Quaternary faults identified in the Seismotectonic Synthesis Report; 3) local Quaternary faults, including a three-fault segment rupture model; 4) a strike-slip shear zone, which may truncate the southern end of some Yucca Mountain faults; and 5) a detachment fault. They defined seven domains for the background sources within 300 km and three domains within 100 km: the northeastern Walker Lane, the southeastern Walker Lane, and the northern Basin and Range. Bert Swan asked if there were any additional faults other teams had considered and Craig dePolo mentioned the buried fault inferred from the Bouguer gravity gradient bounding the Amargosa trough and buried faults in Crater Flat. Dr. Swan clarified that they considered the latter to be included with background sources and explained that they would zone the maximum magnitude for the background domains using a lower magnitude centered around Yucca Mountain where the resolution for identifying and characterizing potential fault sources is better because of more detailed study.

Jim Yount gave the next presentation on potential seismic sources, representing the team of Larry Anderson, Al Rogers and himself. He began by mentioning some additional buried faults under Jackass Flats that they had wondered about either characterizing explicitly or including them implicitly in the background source. Kevin Coppersmith said that the former approach was probably better for all nearby faults because the specific geometry of a source can be significant to the hazard, whereas details of geometry become less significant as sources become more distant. Dr. Yount then described the three types of seismic sources that his team considered: fault, hidden/background, and volcanic. He defined the criteria they used for considering faults as potential sources and then listed potential fault sources with their assigned probabilities of being sources and the bases for the probabilities. Next, he discussed whether volcanic sources need to be considered as potential sources of earthquakes.

He pointed out that although previous volcanic studies by Crowe *et al.* (1995) concluded that there is not a causative relation between structure and volcanism, paleoseismic evidence for the "ash event" (Event U in Chapter 5 of the Seismotectonic Synthesis Report) indicates some faulting events are synchronous with volcanism, suggesting that volcanic seismic sources may need to be considered.

Next, Larry Anderson presented another approach to characterizing potential sources that they were also considering in addition to the fault-specific approach. This approach was motivated by the apparent random pattern of paleoseismic events on faults through time. It would treat Yucca Mountain as a faulted volume with a composite recurrence of earthquakes uniformly distributed on faults. Finally, Al Rogers discussed the team's two models for background source zones, both of which include three zones. One model determines recurrence solely based on the historical seismicity in each zone and the other model attempts to first remove some seismicity that may be associated with mapped faults before calculating recurrence for each zone.

Peter Knuepfer started the discussion session off with questions about the Ghost Dance and Sundance faults as potential seismic sources, which stimulated discussion about general criteria for defining sources and the specific characteristics of these faults. Allin Cornell reiterated his concern about misusing the background earthquake as a crutch in characterizing sources and Burt Slemmons pointed out that it may be worthwhile to specifically consider some buried sources such as possible Quaternary faults in Crater Flat that are indicated on seismic lines. Dr. Cornell further stated that the background zone should be considered as the expression of a team's uncertainty in its seismic source interpretations; that is, its uncertainty that all sources have been included in the interpretation.

Jon Ake gave the first presentation on maximum magnitudes, representing the team of Slemmons, McCalpin and himself. He pointed out that maximum magnitudes are dependent on tectonic models and definition of seismic sources. For estimating maximum magnitudes on fault sources, his team chose to use regression relations by Wells and Coppersmith (1994) that relate average displacement, maximum displacement, or surface-rupture length to maximum magnitude. He discussed some assumptions and prejudices, and the reasoning behind their approach. He said they had only looked at closer fault sources so far, which had raised some questions about characterizing uncertainties and concerns about some possible inconsistencies. This initiated discussion about the shortcomings of using their approach for closely-spaced, short faults with long recurrence intervals. Difficulties in assessing displacements with limited data were also discussed, along with apparent discrepancies between short fault lengths and larger than expected displacements. Kevin Coppersmith pointed out that of the three sources of uncertainty (statistical, process, and parameter), the latter was probably the greatest, but all need to be considered.

Craig dePolo gave the next presentation on maximum magnitudes, representing the team of Robert Smith, Chris Menges, and himself. He outlined the different approaches his team would use to estimate maximum magnitudes depending on the type of data available for each seismic source. Types of data included surface and possibly subsurface rupture length, average and maximum displacement, down-dip width (to determine area), and slip rate. He discussed many different regression relations they might use and the factors they would consider in weighting the different relations. Next, he discussed their approach to assessing the maximum background earthquake, which would likely be about M_w 6.3 (+0.3, -0.1). He also discussed the problem of potentially double-counting seismic moment when characterizing fault and background sources in the same area. Finally, Robert Smith brought up concerns about uncertainties in magnitude conversions to M_w, and possible systematic biases introduced during declustering of the seismicity catalogue.

Next, two unscheduled presentations were given by David Ferrill and James Brune. Dr. Ferrill presented results of laboratory deformation studies used as a physical analog for the development of pull-part basins. He discussed similarities and differences of features in the lab experiments to those observed at Yucca Mountain. He also reiterated results from their slip-tendency analysis of Yucca Mountain faults (presented by John Stamatakos at Workshop #2), emphasizing implications for a low-slip tendency on shallow-dipping faults. Dr. Brune also discussed results from laboratory modeling experiments. He pointed out that implications from his foam rubber models are that SDNF are much more mechanically stable than shallow-dipping reverse faults because of different dynamic effects, implying that SDNF are not likely seismogenic. Following the presentations was considerable discussion about complexities in using displacement data to estimate maximum magnitudes.

Diane Doser gave the first presentation on earthquake recurrence, representing the team of Chris Fridrich, Bert Swan and herself. She discussed how they planned to use the seismicity catalogue to calculate earthquake recurrence for their background source zones. She emphasized that there were many issues in preparing the catalogue and making the calculations and she highlighted some of these. Bert Swan then discussed how their team would characterize recurrence for fault sources. He said they would use a seismic moment rate approach, explaining how they would estimate slip rates for each of three different structural/behavioral models. He pointed out that they would try to calculate average net slip rates, using ratios of vertical to net slip of between 1:1 and 1:1.4. He also noted they would use three different recurrence models: models developed by Wesnousky *et al.* (1983), Schwartz and Coppersmith (1984), and an exponential model. Paleoseismic data on recurrence intervals would only be used as a "sanity check."

Larry Anderson gave the next presentation on recurrence, representing the team of Rogers, Yount, and himself. He focused on fault sources and had compiled a space-time diagram of

paleoseismic events on Yucca Mountain faults to assist in evaluating synchroneity of rupture behavior and estimating earthquake recurrence. He discussed estimated recurrence intervals for different structural and behavioral models, pointing out ambiguities and associated uncertainties in the paleoseismic record. Al Rogers then discussed their approaches to estimating earthquake recurrence for each of their two background earthquake models, outlining the steps they used in processing the seismicity catalogue and explaining how they would allocate seismicity to faults for one of the models.

During the following discussion session, Allin Cornell asked if any team had considered using a real-time approach, stimulating discussion about advantages and disadvantages of doing so and the data needed. Next, Tom Hanks expressed concern that some of the maximum magnitudes assigned to sources would result in forcing high stress-drop events to occur in a low stress-drop regime. He urged the experts to at least keep implications for stress drop in mind when developing their characterizations. Finally, Kevin Coppersmith asked for comments from observers. Clarence Allen pointed out that the relation of historical seismicity to mapped faults is problematic in many other areas in addition to Yucca Mountain. He also cautioned experts about the uncertainties in extrapolating observations of small earthquakes to make inferences about large earthquakes. Bakr Ibrahim expressed concern about whether triggered events were adequately being considered. Leon Reiter suggested to confirm whether or not results will be used for both pre-closure design and post-closure performance assessments, the latter making it especially important that low probability scenarios be included and carried through the analysis. Jerry King suggested that additional guidance regarding which faults at what distance needed to be considered would help the experts.

WEDNESDAY, JANUARY 8, 1997

The entire morning session was devoted to addressing the last SSC issue, developing methodologies for characterizing the fault displacement hazard. Walter Arabasz gave the first presentation on their approach to characterizing fault displacement, representing the team of Ernie Anderson, Alan Ramelli, and himself. He outlined premises to their approach and discussed their two types of sources, primary and non-primary. Their approach is to directly use displacement per event data wherever it exists and for other faults to use various scaling relations to estimate slip per event. He pointed out how fault aspect ratios generally observed for moderate to large earthquakes have implications for expected fault rupture lengths at Yucca Mountain, given a certain depth of rupture penetration and vice versa. He discussed scaling relations to estimate slip per event from length and cumulative slip, including some examples developed specifically for Yucca Mountain faults. He said they were considering both recurrence interval and slip rate approaches to incorporate the frequency of displacement events into the assessment. Finally, he mentioned how scaling

relations from Chapter 9 of the Seismotectonic Report can be incorporated into the methodology developed by Coppersmith and Youngs (1992) to assess displacement within the repository, particularly various characteristics of secondary displacement.

Next, Alan Ramelli discussed the spatial distribution of faulting within the proposed repository. He focused on issues of how does the potential for secondary faulting vary and what areas of different potential can be defined. Both he and Ernie Anderson described similarities of the Clover Mountain area, which they believe provides a structural analog to Yucca Mountain and may have implications for the shallow depth of penetration of some faults, particularly non-primary faults. Discussion followed about possible problems with using some of the scaling relations in an area where deformation rates are transient and much of the total throw occurred during the Miocene. Finally, Kevin Coppersmith emphasized that the methodologies developed by the experts need to be appropriate for the entire Controlled Area, not just the proposed repository.

Ron Bruhn gave the next presentation on their team's fault displacement methodology, representing the team of Ken Smith, Peter Knuepfer, and himself. He said that there would be two parts to their presentation, he would focus on the displacement aspects and Ken Smith would discuss assessing rates using historical seismicity and paleoseismic data. Dr. Bruhn then outlined the conceptual framework of their approach, which is based on statistical analyses used in mining engineering. He emphasized that their goal was to develop an algorithm for estimating the probability of exceedance of a specified displacement at a point within a rock mass without prior knowledge of the point, but given that certain statistical and structural properties of observed faults in the rock mass are known or can be estimated. He provided details of the technical description of his method in a handout. He outlined the general steps in his talk, highlighting assumptions and the data needed for each of the three steps. He discussed application to an analog repository in Leagerdorf, Germany. Finally, he emphasized they were still working on incorporating recurrence into the assessment and he discussed some of the issues and considerations related to both direct and indirect approaches. David Schwartz offered suggestions on using paleoseismic data from primary faults to provide maximum constraints on recurrence rates. Ken Smith then discussed their preliminary analysis of the seismicity catalogue and resulting recurrence curves both with and without the incorporation of paleoseismic data for Yucca Mountain faults.

After the break, Jim McCalpin presented an approach to characterizing fault displacement that entails developing probability density functions for fault density. He discussed issues and considerations in using available data to construct the curves for Yucca Mountain faults. Next, Robert Youngs, representing the Fault Displacement Working Group, presented what he referred to as the earthquake approach to characterizing fault displacement, which uses a displacement attenuation function for secondary faulting. He discussed how scaling relations

and data presented in Chapter 9 of the Seismotectonic Synthesis Report could be used to perform this type of analysis.

Throughout the morning session, there were questions raised about more specifically defining the fault displacement objective. During the discussion session, Carl Stepp emphasized that the primary need from the SSC teams is a methodology to predict fault displacement at any point in the Controlled Area given that a particular feature exists. Kevin Coppersmith elaborated by listing four things that the Seismic Design Team were looking for regarding fault displacement: (1) fault displacement hazard curves at selected locations; (2) fault dip and sense of slip; (3) the width over which displacement occurs on a fault; and (4) recommended methodologies for assessing displacements at other locations. Silvio Pezzopane presented a "strawman" selection of points and classes of features that should be represented by the points. John Whitney suggested adding a point in Midway Valley. After some discussion, it was decided that a list of the classes of features and a map of the selected points would be distributed to the experts shortly after the workshop (Attachment 2). Other topics discussed included aspect ratios of fault ruptures at Yucca Mountain, available displacement data for tunnels and mines elsewhere in the world, availability and access to ESF fault and fracture data, and the likelihood of future displacement on intrablock and other Tertiary bedrock faults which show no evidence for Quaternary faulting but for which Quaternary movement cannot be precluded. Also discussed were problems in predicting slip for future events based on a long-term displacement record (in some cases Miocene) in an area where displacement rates have varied significantly through time.

Just before lunch, Kevin Coppersmith outlined upcoming steps in the SSC elicitation process, which had already begun with each team's preparation of preliminary interpretations for this workshop. Next would be the elicitation interview and follow-up, with draft assessments due to the Calculations Team by March 10. Preliminary results would be presented at the Feedback Workshop, which was originally scheduled for April 16-18 but was moved up to April 14-16. After this last workshop, elicitation summaries would be finalized. Dr. Coppersmith emphasized that elicitations and development of the team's interpretations were an ongoing process that would continue until the final summary was written. He then asked for comments from observers. Leon Reiter commented on the need to know the resolution for all types of data and the importance of considering this in the assessments. He also reiterated a point he had made earlier that it would be helpful to the experts if a minimum threshold of engineering concern for displacement could be defined at some level above 0 cm. He believed this would help experts to better focus on characterizing the displacements of main concern to design. Carl Stepp responded that the Management Team advised against doing this because they wanted to avoid any possible conditioning of the experts' interpretations. Kevin Coppersmith then added that in terms of guidance on the distance of interest for SSC characterization for ground motion hazard, experts needed to characterize

sources out to 100 km, with detailed characterization of sources out to 50 km from Yucca Mountain.

The final afternoon session was devoted to elicitation training, conducted by Peter Morris. Ivan Wong introduced members of the ground motion panel, who had arrived to also participate in the elicitation training (participants in the Ground Motion Workshop on Methods and Models are not included in Table 1, but will be included in a separate report on the Ground Motion Workshop). Peter Morris referred to the training as a workshop in probability assessment. The topics covered included using probability to quantify uncertainty, representing and manipulating probabilities, and assessing probabilities. The information presented followed his handout closely (Attachment 2), with the addition of many real-life examples and interactive exercises with the experts. The workshop was adjourned after the elicitation training, at about 5:00 pm.

TABLE 1. YUCCA MOUNTAIN SEISMIC SOURCE CHARACTERIZATION WORKSHOP #4 - PRELIMINARY INTERPRETATIONS

January 6 to 8, 1997

Attendance List

Name	Affiliation
1. Ake, Jon	U.S. Bureau of Reclamation (USBR)
2. Allen, Clarence	Nuclear Waste Technical Review Board (NWTRB)
3. Anderson, Ernie	U.S. Geological Survey (USGS)
4. Anderson, Larry	USBR
5. Arabasz, Walter	University of Utah (UU)
6. Bell, John	UNR
7. Bruhn, Ron	UU
8. Brune, James	UNR
9. Chaney, Tom	USGS
10. Coppersmith, Kevin	Geomatrix
11. Cornell, Allin	Consultant
12. dePolo, Craig	UNR
13. Doser, Diane	University of Texas, El Paso
14. Ferrill, David	Center for Nuclear Waste Regulatory Analyses
15. Fridrich, Chris	USGS
16. Hanks, Tom	USGS
17. Ibrahim, Bakr	U.S. Nuclear Regulatory Commission (NRC)
18. Justus, Phil	NRC
19. King, Jerry	M&O/SAIC
20. Knuepfer, Peter	State University of New York at Binghamton
21. Lui, Christiana	NRC
22. Majer, Ernie	Lawrence Berkeley National Laboratory
23. McCalpin, Jim	GEO-HAZ Consulting, Inc.
24. McGuire, Robin	Risk Engineering
25. Menges, Chris	USGS
26. Morris, Peter	Applied Decision Analysis, Inc.
27. O'Leary, Dennis	USGS
28. Olig, Susan	Woodward-Clyde Federal Services (WCFS)
29. Parks, Bruce	USGS
30. Penn, Sue	WCFS
31. Perman, Roseanne	Geomatrix
32. Pezzopane, Silvio	USGS

TABLE 1 (CONT). YUCCA MOUNTAIN SEISMIC SOURCE CHARACTERIZATION WORKSHOP #4 - PRELIMINARY INTERPRETATIONS

January 6 to 8, 1997

Attendance List

Name	Affiliation
33. Pomeroy, Paul	Advisory Committee on Nuclear Waste
34. Potter, Chris	USGS
35. Quittmeyer, Richard	WCFS
36. Ramelli, Alan	UNR
37. Reiter, Leon	NWTRB
38. Rogers, Al	EQE International
39. Savy, Jean	Lawrence Livermore National Laboratory
40. Schwartz, David	USGS
41. Sheaffer, Patricia	USGS
42. Slemmons, Burt	WCFS
43. Smith, Ken	UNR
44. Smith, Robert	UU
45. Stamatakos, John	CNWRA
46. Stepp, Carl	WCFS
47. Stuckless, John	USGS
48. Sullivan, Tim	DOE
49. Swan, Bert	Geomatrix
50. Toro, Gabriel	Risk Engineering
51. Wernicke, Brian	Cal Tech
52. Whitney, John	USGS
53. Wong, Ivan	WCFS
54. Youngs, Robert	Geomatrix
55. Yount, Jim	UNR