UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON NUCLEAR WASTE
WASHINGTON, DC 20555 - 0001

March 9, 2005

MEMORANDUM TO: John T. Larkins, Executive Director
ACRS/ACNW

FROM: Neil M. Coleman, Senior Staff Scientist
ACRS/ACNW

SUBJECT: TRIP REPORT: ATTENDANCE AT WORKSHOP #2 OF THE DOE PROBABILISTIC VOLCANIC HAZARD ANALYSIS UPDATE (ALTERNATIVE MODELS)

ACNW Member William Hinze and I attended the subject meeting which was held during February 15-17 in Las Vegas, NV. Dr. Hinze's trip report is enclosed as attachment 1. The meeting agenda is provided as attachment 2. This was the second of a series of workshops that comprise DOE's update of the Probabilistic Volcanic Hazard Analysis (PVHA) for Yucca Mountain. The results of the previous PVHA expert elicitation were published in 1996. The update will incorporate data and interpretations obtained since 1996 to refine the estimated probability that future volcanism could intersect a potential repository at Yucca Mountain. NMSS and CNWRA staff attended the meeting as observers and announced that they would not actively participate in the technical discussions. Chuck Connor (University of South Florida), a former CNWRA senior scientist, served on the expert panel and gave multiple presentations regarding his personal views about volcanism in the Yucca Mountain region. Representatives of the State of Nevada also attended as observers but did not participate. DOE will provide for all attendees a CD-ROM that contains presentation materials from this meeting.

Extensive new information is available to the PVHA Update panel that was not available to the 1995 panel. The information includes:

- Results of a new high-resolution aeromagnetic survey of the Yucca Mountain region;
- Tomographic imaging of the crust and upper mantle in the southern Great Basin (G. Biasi, University of Nevada Reno);
- Seismic velocity structure of the Yucca Mountain region (L. Preston, University of Nevada Reno);
- GSA Special Paper 333 (Cenozoic Basins of the Death Valley Region, 1999)
- Nye County drilling data;
- Improved understanding of the petrology and radiometric ages of basalts in the region
- Bedrock geologic map of the Yucca Mountain area (Day et al., 1998, USGS Geologic Investigations Series I-2627);
- Bedrock geologic map of the central block area, Yucca Mountain (Day et al., 1998, USGS Miscellaneous Investigations Series Map I-2601);
- Detailed mapping in the ECRB (cross drift tunnel) [Construction of the 2.8 km long ECRB did not begin until December 1997. Although this tunnel completely crosses the repository block from east to west, geologic mapping of the tunnel walls did not reveal any basaltic dikes.]; and
- Dating of several buried basalts (i.e., anomaly "B" in the Amargosa Desert, and Nye County's borehole 23P, located south of Yucca Mountain).

The basalt detected in Nye County's borehole 23P had not previously been associated with a magnetic anomaly. The new aeromagnetic map reportedly indicates a magnetic anomaly in that area. At the ACNW meeting in September 2004, a Nye County representative reported that the basalt penetrated by 23P may be a boulder field that was fluvially transported to that area and subsequently buried. A Miocene age has been determined for this basalt.

The expert panel has not been tasked to evaluate the consequences of dike intersection. However, they will be elicited regarding their views on the size of a volcanic conduit that could hypothetically intersect the facility at repository depth. DOE plans to use this to estimate the number of waste packages that could be impacted by the low probability occurrence of a conduit intersection.

During the afternoon of February 17th I gave a talk that was based on the paper I recently published with B. Marsh and L. Abramson in *Geophysical Research Letters* (GRL), "Testing claims about volcanic disruption of a potential geologic repository at Yucca Mountain, Nevada," *GRL*, vol. 31, doi:10.1029/2004GL021032, Dec. 2004. This paper (not subject to copyright) was distributed to the panelists and meeting attendees. The *GRL* paper and my presentation slides (Attachment 3) examined recent claims that the frequency of basaltic dike intersection could be 1×10^{-6}/yr or higher. We find that these claims fail simple tests at four time scales. Our results were obtained using the NMSS staff's PVHA model (ver. 2) and data sets published with the model. We estimate the probability that a repository could be intersected by a basaltic dike to be in the range of 10^{-8}/yr to 10^{-7}/yr, which is the same result reported by NRC and CNWRA staff in a paper published in the *Journal of Geophysical Research* in 2000 (*JGR*, vol. 105, p. 417-432). The probability that a volcanic conduit could intersect the potential repository would be substantially less than the probability of dike intersection because dikes tend to be much longer than conduits are wide. Reference information was provided to the PVHA panelists in the event they choose to examine the NRC model as part of their review.

Along with independent model results, our *GRL* paper also described a simple statistical technique that derived an upper bound on dike intrusion frequency of 2.3×10^{-7}/yr based on the Poisson distribution and the fact that no dikes have been found inside the potential repository footprint. This statistical analysis partly corroborates the model results. One panelist suggested that use of this statistical method seemed to be "disingenuous" (i.e., artificial). I replied that the technique has meaning only for sites like Yucca Mountain that have been very extensively studied through borehole drilling, geologic mapping, tunnel investigations, and geophysical studies. Professional judgement must be applied to assess whether the geological studies have been reasonably adequate to locate basaltic dikes. One highly eroded Miocene-aged dike has been mapped just west of and outside the repository footprint. This dike was not detected by the new high-resolution aeromagnetic survey, but its surface trace has been mapped over a distance of hundreds of meters.

I offered to the panelists a few thoughts about event clustering. Natural processes tend to occur in clusters (I. e., earthquakes, volcanism, hurricane landfalls, floods, etc.). Therefore short-term recurrence rates for a process such as volcanism can change significantly over time. Care is needed to identify time frames of interest. Event frequencies during clustered activity do not represent long-term expectations. High recurrence rates that represent clusters should only be used if evidence demonstrates that clustered activity has returned. As an example I described a process that affects human health and safety each year - hurricane landfalls. A cluster of four hurricanes (three major) struck Florida in 2004 and caused extensive loss of life, injuries, and property damage. Should risk assessors (such as insurance underwriters) now

assume that coming years will have similar elevated activity? The expectation for this is very low. Climate experts at Colorado State University (Gray and Klotzbach) have concluded that the cluster of damaging hurricanes in Florida was an unusual event, likely occurring only about once every 100-200 years. Likewise, the frequencies of volcanism within past clusters of activity (such as the ~1 Myr volcanoes in Crater Flat) do not represent long-term recurrence rates. I reported to the panel that our *GRL* paper tested the hypothesis that the Lathrop Wells event may have begun a new pulse of volcanism in the Yucca Mountain region. For a dike penetration rate of 10^{-6}/yr our PVHA results indicate that 4-19 volcanic events would have been expected in the region in the last 100,000 yrs. Only one is known, therefore there is no evidence that a new cluster of volcanic activity has begun.

DOE has identified ten magnetic anomalies as potential targets for drilling exploration, five in Crater Flat/Amargosa Desert and five in Jackass Flats. Any basalts that are found by drilling will be radiometrically dated. In his attached trip report, Dr. Hinze makes a key point ! that if Plio-Pleistocene basalts are found in Jackass Flats that could have an important impact on probability estimates for volcanic intrusion. I agree with this, and would add that more than one post-Miocene basalt would have to be found to significantly affect the probabilities. Our *GRL* paper predicts that any buried basalts that may be found by DOE's drilling program will be older than Pleistocene (i.e., >1.8 Myr old), consistent with superposition relations, sedimentation rates, and depths of burial. Identification of additional Pliocene basalts is possible. However, to date there are no known post-Miocene (i.e., <5.3 Myr) basalts on Yucca Mountain or in Jackass Flats.

Recommendation: Workshop #3 of the PVHA Update is currently planned for August 2005. I suggest that an ACNW member and consultant attend future meetings of the PVHA Update to closely monitor DOE's progress in this area.

Attachments:
1. Trip report from Dr. William Hinze (PVHA Workshop #2)
2. Agenda for PVHA Workshop #2
3. Presentation slides by Neil Coleman (ACNW staff)

cc: Mike Scott, ACRS/ACNW Branch Chief
Sharon Steele, ACNW Team Leader

Attachment 1

Date: February 21, 2005

To: US NRC/ACNW

From: William Hinze

Subject: YMP/DOE Workshop 2 – Alternative Models Probabilistic Volcanic Hazard Analysis Update (PVHA-U)

I attended the second workshop of the Probabilistic Volcanic Hazard Analysis Update (PVHA-U) held by the Yucca Mountain Project office of the DOE on February 15-17, 2005 in Las Vegas, Nevada. Also attending was Neil Coleman of the ACNW. The purpose of the PVHA-U is to determine the probability of volcanic disruption of the proposed Yucca Mountain HLW repository by expert elicitation. Expert elicitation is being used because of the lack of acceptable standardized methodologies and germane data and parameters for probability evaluation. The PVHA-U is being held in view of concerns regarding the result of the 1996 PVHA and the potential for newly acquired information and data to have a significant effect on the probability currently being used by the DOE in their analyses of the performance of the proposed repository.

The expert elicitation is being held within the guidelines of the appropriate NRC documents by the same facilitators using the same methodology as the original PVHA. Eight of the 10 PVHA-U experts in volcanology and related disciplines were members of the original PVHA panel. The two new members are very well qualified to serve on the panel and are knowledgeable regarding the Yucca Mountain geology. Chuck Connor, University of South Florida, was formerly director of the CNWRA volcanic processes program for the NRC and Frank Spera, University of California-Santa Barbara, was an expert on the ICPR panel. Kevin Coppersmith is the PVHA-U Lead and Elicitation Manager/Facilitator.

Much of the work of the panel will be conducted on an individual basis by the experts drawing on their knowledge and information, data, and interpretations provided by other members of the panel and other special experts. However, workshops are held for informational purposes and interactions among the expert panel members. The objective of the first workshop, December 12-14, 2005, was to present relevant new information related to igneous activity in the Yucca Mountain region. The presentations and summary of the meeting are available to members of the ACNW on a CD and the summary of the Workshop prepared by the DOE/YMPO is attached to this memo. A total of 5 workshops are planned. The third workshop, 2a, is a bridge between workshop 2 and the preliminary expert assessments workshop, workshop 3, and is tentatively planned for 2 days during the week of August 22, 2005. The final report of the PVHA-U is scheduled for mid-2007, presumably after the license application is submitted by DOE to NRC.

The objectives of workshop 2 were to review the project goals, plans, schedule and operational procedures of the expert elicitation and to discuss alternative tectonic models for constraining the probability estimates of volcanic disruption of the proposed repository and for characterizing the spatial and temporal distribution of future volcanism, the characteristics of possible future volcanic events, and alternative approaches to volcanic hazard analysis. A total

of 22 formal presentations were made during the workshop by members of the expert panel and others. The majority of these were supported by handouts of the presentations. A summary of the workshop plus the presentations will be available on a CD from DOE/YMPO in 2 to 4 weeks. In addition, there were informal presentations, extensive discussions among the expert panel, and opportunities for comments from the observers.

The expert panel was informed that DOE was expecting to submit a license application using a TOC of 10,000 years and, thus, the probability was to be made on that basis. Additionally the experts are in no way constrained by their previous advice on probability. Management made it clear to the panel that the consequences of volcanic disruption were not an issue. Nonetheless, on several occasions during the workshop consequence-related issues were mentioned, particularly as they are discussed in the ICRP panel report. Neither are any aspects of the tephra derived from an erupting volcano a subject of the expert elicitation. Nonetheless, concern with the characteristics of possible future volcanic events should provide useful input to the consequence issue (e.g., diameter of conduit at repository level, eruption cloud height).

It is important to note that both the NRC (including the CNWRA) and the State of Nevada experts attending the meeting as observers were prevented by their agencies from making comments or entering into the discussions. However, Chuck Connor made several presentations using materials that he and other personnel of the CNWRA developed while he was a staff member at the CNWRA.

Observations

No effort will be made here to review the individual formal presentations made at the workshop. These materials are available on the handouts soon to be available to the ACNW on a CD. Nonetheless, a few personal observations may be insightful.

First, there is a great deal of additional information and data available since the original PVHA. There is more complete and higher resolving power geophysical data including magnetic, seismic reflection, and crustal and upper mantle tomography. There is a much more comprehensive suite of major and trace element chemistry and age dates of the volcanic rocks of the Yucca Mountain region. Much better and additional tectonic models are now available to explain the development of the region leading to the volcanic action of the past 15 million years. There are also much better modeling codes and more detailed parameters describing volcanic characteristics. In my view the two most important data bases, that is those that have the best opportunity to affect the probability determinations in a significant way, are the high-resolution airborne geophysical survey and the seismic tomography modeling of the velocity of the mantle and crust of the Yucca Mountain region.

The magnetic data of the airborne geophysical survey are currently being interpreted and were the subject of considerable discussion by the expert panel. The DOE requested input from the panel on the magnetic anomalies that should be drilled in 2005. The DOE will drill up to 10 holes starting in April to determine if selected magnetic anomalies represent buried volcanic centers. If basalts are encountered in the drilling they will be dated by isotopic methods and used by the expert panel in their probability estimates. We can anticipate that several holes will be drilled in the northern Amargosa Valley, Crater Flat, and in Jackass Flats. I believe the latter drill holes are particularly significant because the presence of Plio-Pleistocene basalts on the east side of Yucca Mountain could have a particularly important impact on probability estimates. It is important to note that the EM data collected during the airborne geophysical survey was not shown to the panel. Private conversations with the principals of the survey suggest that the EM data are not of sufficiently high quality for use in the analysis because of the larger terrain clearance than planned for the survey.

The seismic velocity tomography study of the Yucca Mountain region indicates up to several percent variation in the P-wave velocity at critical levels in the upper mantle that could be caused by a variety of effects affecting the melting of the mantle and, thus, providing a source for future basaltic volcanism. Previous, less detailed, studies had indicated a low-velocity zone beneath Crater Flat that could be interpreted as a hotspot. This has been a critical piece of evidence in some theories on the origin of the basaltic volcanism and the potential for further volcanic activity. The results presented at this meeting do not confirm this interpretation. No obvious correlation exists between the mantle velocities and geologically recent volcanism except that the basaltic vents occur on a gradient between higher and lower velocity zones. The implications of this observation are unclear.

Second, although there are differences of opinion regarding the waxing and waning of volcanism of the Yucca Mountain region, there appears to be a tendency to accept the hypothesis that the volume of individual volcanic events is waning, but that the frequency is waxing. The prediction of the frequency of volcanic events involving both spatial evaluation and temporal evolution will continue to largely rely on past events, but the definition of volcanic event remains controversial and is likely to remain so, leading to differences in conclusions regarding probability among the expert panel.

Third, we should anticipate a much more thoughtful and objective prediction of probability than from the previous PVHA largely because of improvements in the data base and scientific understanding of the volcanic process. This may not lead to any significant change in the probability estimates, but it should lead to a decrease in the range of probabilities as a result of decreasing uncertainties. It is perhaps unwise to prejudge the results of the deliberations of the expert panel, but in my view the only data that could change the previous probability estimates by a significant amount are the results of the drilling on the magnetic anomalies of the high-resolution survey and the dating of the basalts found in the drill holes. A significant change in the probability estimate is possible, but I believe unlikely. In any event the elicitation process should result in a more realistic estimate of the probability and one that is more defensible. Subjectivity will remain and uncertainties will continue to be of concern.

Copies of handouts at the PVHA-U workshop will be available from the ACNW staff.

PROBABILISTIC VOLCANIC HAZARD ANALYSIS UPDATE
YUCCA MOUNTAIN PROJECT

WORKSHOP 1
KEY ISSUES AND AVAILABLE DATA

October 12-14, 2004
Las Vegas, Nevada

SUMMARY

The Workshop on Key Issues and Available Data was the first of four workshops that will be conducted by the U.S. Department of Energy (the DOE) in support of the Probabilistic Volcanic Hazard Analysis Update (PVHA-U) for the Yucca Mountain Project. The PVHA-U relates to the technical bases that will be provided in the project's License Application to the U.S. Nuclear Regulatory Commission. The goals of this workshop were to (1) introduce members of the expert panel of volcanologists to the PVHA-U project goals, their roles, and the expert elicitation process; (2) describe how the results of the PVHA completed in 1996 were used to support the performance assessment and identify the key issues the experts will need to address during the project; (3) review the additional data acquired since completion of the original PVHA in 1996 (PVHA-96); (4) identify those data sets that the experts will use in their evaluations; and (5) train the experts in methods for quantifying uncertainty, avoiding bias, and using probabilities to express uncertainties.

DAY 1 – TUESDAY, OCTOBER 12

Greetings and introductory presentations were offered by four PVHA-U project team members: Mr. Eric Smistad, technical lead for volcanism at the U.S. Department of Energy (the DOE); Dr. Jerry King and Mr. Michael Cline, PVHA-U project managers for Bechtel-SAIC (BSC); and Dr. Kevin Coppersmith, the PVHA-U technical facilitator/integrator.

Dr. Coppersmith (Coppersmith Consulting) welcomed the meeting participants and asked them to introduce themselves. Dr. Coppersmith identified the members of the expert panel, comprising eight from the PVHA-96 expert panel and two new members. The expert panel members introduced themselves and spoke briefly about the volcanology research they had performed since PVHA-96.

Then Mr. Smistad (DOE) spoke, thanking members of the expert panel for participating, noting his own role as technical lead for volcanism at the DOE, and mentioning that Tim Sullivan was the DOE's technical lead for the PVHA-96. Mr. Smistad then described reasons for requesting an update to the PVHA-96. These reasons include (1) new information has been gathered since 1996 that is relevant to estimating volcanic probability, and (2) the concerns expressed by the U.S. Nuclear Regulatory Commission (NRC) about the sensitivity studies conducted by the Yucca Mountain Project (YMP) utilizing aeromagnetic data obtained in 1999. Mr. Smistad described the relevance of estimating volcanic probabilities to NRC regulations and the calculation of doses. He stated that the DOE has committed to providing the PVHA-U to the NRC in Fiscal Year 2006 during the review period for the Yucca Mountain License Application.

Dr. King, Disruptive Events Manager for BSC, welcomed the workshop participants. Dr. King noted that the PVHA-U is being conducted based on the acquisition of additional relevant data. He briefly described analyses performed by the YMP regarding the sensitivity of hazard results to data that became available after completion of the PVHA-96, as well as the DOE's commitment to collect additional data in support of updating the PVHA-96. Dr. King then named members of the PVHA-U Methodology Development Team, the expert panel members, and the technical presenters scheduled to address the workshop regarding data collected since 1996. Mr. Cline (BSC) continued the introductory comments, reviewing the planned schedule of studies of igneous-related activities for the YMP in FY05, including both igneous event probabilities (including the PVHA-U) and igneous event consequences. Mr. Cline reviewed the PVHA-U schedule, noting key dates for workshops and elicitation interviews. Dr. Coppersmith noted that the hazard calculations would be completely redone as part of the PVHA-U.

Dr. Coppersmith gave the third introductory presentation, in which he described some of the expert elicitations completed since the PVHA-96 (including several for the YMP). Noting that much had been learned about expert elicitation processes in the past 9 or 10 years, he described relevant procedures and guidance in the BSC quality assurance procedure, *Expert Elicitation* (LP-AC.1Q-BSC); the NRC *Yucca Mountain Review Plan* (NUREG-1804); the *Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program* (NRC NUREG-1563); and the Senior Seismic Hazard Analysis Committee's *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts* (NUREG/CR-6372). Dr. Coppersmith described the types of participation in the PVHA-U, including the role of the experts; reviewed ground rules for the workshops; and discussed the criteria for selecting experts, including criteria for continued participation on the expert panel. He discussed the integration of expert evaluations and the goal of developing a defensible basis for using equal weights to combine the experts' assessments. The steps being taken to achieve this goal were discussed, as were the roles/responsibilities of project participants in achieving integration. A major goal of expert elicitation is to have the composite representation across the expert panel members reflect the larger informed technical community.

Workshop participants discussed the use of expert judgment and the extent to which the PVHA-96 results had been accepted by the community of volcanologists. Differences in opinions in the technical communities of Europe versus the United States were noted. How to identify appropriate analogs and relevant data sets was discussed, particularly regarding fault control of volcanism. Potentially publishing the final results of the PVHA-U also was discussed.

After a short break, Mr. Cline gave a talk on "Igneous Consequences and Igneous Scenario Class for the TSPA Model." He listed the consequence analysis and modeling reports prepared by the YMP and stated the regulatory and technical bases for addressing volcanic consequences. He discussed the key points of the Igneous Consequence Peer Review conducted by the DOE and reviewed the model cases used in the Total System Performance Assessment (TSPA) for igneous events—both intrusive and volcanic extrusive events. He mentioned the Lathrop Wells volcano is used as a useful analog for assessing the characteristics of future potential volcanism in the repository area. The ASHPLUME code that implements a mathematical ash dispersion model was described. The probability-weighted dose estimates from igneous disruption, including the uncertainty in dose estimates, were also described.

After a break for lunch, Dr. Robert Youngs (Geomatrix Consultants) presented a talk titled, "Overview of 1996 PVHA, Application of Results, and Required Outputs of Update." He reviewed the process and results of the PVHA-96, summarized how those results were applied to developing inputs to the TSPA, and described the additional outputs that will be required from the PVHA-U, particularly outputs related to event definition. Dr. Youngs described the analyses needed to assess volcanic consequences in the TSPA for both intrusive and extrusive disruption effects. He described the parameters needed, which include conditional distributions for the lengths and azimuths of intersecting dikes within the repository footprint and for the number of eruptive centers within that same footprint. He concluded his talk by providing descriptions of the geometries of intrusive and extrusive events needed for the PVHA-U. The workshop participants discussed definitions of volcanic events. Dr. Coppersmith specifically asked experts to inform him if they did not feel capable of giving the assessments that will be required for the PVHA-U.

After a short break, Dr. Frank Perry (Los Alamos National Laboratory [LANL]) resumed the workshop with a talk titled, "Review of Yucca Mountain Region Basaltic Volcanism and Data Gathered since 1996." He summarized the volcanic framework of the Great Basin region surrounding Yucca Mountain, including the spatial and temporal distribution of basalts, the geochronology of the area, and associated geochemical data. Then, he briefly described significant data published since 1995 in the categories of geophysical data, geodetic strain data, geologic mapping, structural data, geochronology, and petrology/geochemistry. These data are available in journals, organization reports (e.g., by LANL), and YMP reports.

Dr. Don Krier (LANL) gave the next talk, co-authored with Dr. Greg Valentine (LANL), on the characteristics of volcanic events in the Yucca Mountain region. He discussed those parameters of dikes and conduits that directly affect the probability of an intersection between an igneous event and the repository footprint. Also discussed were field observations of volcanic features, including dike lengths, orientations, and widths, along with the occurrence of multiple dikes, at Paiute Ridge and Crater Flat in southwest Nevada and at San Rafael Swell in Utah. Conduit diameters were discussed, using data from Grants Ridge, New Mexico, as well as other locations.

The scheduled talks for the day having concluded, Dr. Coppersmith opened the meeting to comments from participants. Topics included the forward time frame for which the experts must make their evaluations (e.g., for the next 10,000 years or longer), potentially publishing the results of the project in a peer-reviewed journal, and available data sets.

Dr. Coppersmith adjourned the meeting for the day.

DAY 2 – WEDNESDAY, OCTOBER 13

Day 2 of the workshop began with a discussion of the U.S. Geological Survey (USGS) 1999 Amargosa aeromagnetic survey, presented by Dr. Rick Blakely (USGS). He provided a list of the USGS publications that describe this study, which focused on the tectonics and hydrology of the Amargosa Desert, Nevada. He showed a series of regional maps, briefly describing the basin boundaries and the role of features such as Stateline fault in the formation of the basins near Yucca Mountain. Dr. Blakely described the processing performed to emphasize shallow features and identify magnetic lineaments. Dr. Blakely's conclusions emphasized that although the survey highlights structures in the volcanic terrain, including evidence of exposed and concealed vents, it is probably inadequate for identifying typical volcanic dikes.

Dr. Allen Cogbill (LANL) presented the next talk, which described the recently completed 2004 DOE aeromagnetic survey in the region surrounding Yucca Mountain. He described the survey objectives: to reliably map possible basaltic rocks within the upper 400 m of the subsurface, to distinguish between magnetic tuffs and basalts, and to provide uniform coverage of the area of interest. He described the data acquisition process and showed maps displaying the survey results. Dr. Perry continued the talk by describing preliminary interpretations of the 2004 aeromagnetic data. He stated that the new survey data will be combined with information obtained from other studies in the area, including borehole and ground magnetic investigations. Interpretations of various features were discussed, including possible locations of faults that are identified on geologic maps based primarily on surface data. Workshop participants discussed the characteristics and importance of faults.

After a short break, Dr. Chuck Connor (University of South Florida) presented, "Ground Magnetic Studies by the CNWRA" (Center for Nuclear Waste Regulatory Analyses). In his introduction to the talk, Dr. Coppersmith noted that Dr. Connor previously was employed by the CNWRA, where he contributed to some of the work he was going to describe, but that he was no longer associated with the CNWRA. Dr. Connor provided a list of CNWRA publications on magnetic studies. He described the basic goal of the studies: to identify, map, and interpret magnetic anomalies that may be caused by basaltic volcanic rocks buried in the shallow subsurface. He showed maps of anomalies and described some of the modeling work and interpretations developed by CNWRA investigators. He showed results of analyses of the relative confidence that various anomalies were basaltic volcanoes (as described in Hill and Stamatakos, 2002). Dr. Connor then described his conclusions (noting that they were his personal opinions and not necessarily those of the CNWRA), stating that buried volcanoes underlie many areas of the Yucca Mountain region. Workshop participants discussed the rate of sedimentation in Crater Flat and the importance of obtaining age dates for anomalies (increased anomaly depths being roughly correlated with increased age).

Dr. Glenn Biasi (University of Nevada at Reno) then presented a talk titled, "Tomographic Imaging of the Crust and Upper Mantle in the Southern Great Basin." He outlined the findings for both the region and the local Yucca Mountain area based on teleseismic tomography. He described the method and source data; showed mapped data that indicate a vertical, high-velocity structure at increasingly greater depths; and then showed cross sections along lines of varying azimuth. After providing a regional summary, Dr. Biasi presented a local area model, again providing images from layers at various depths and displaying a series of cross sections. A potential low velocity zone at depths of approximately 80 – 100 km was discussed.

Following a lunch break, Dr. Tom Brocher (USGS) gave a talk on seismic reflection and gravity surveys. He described a survey conducted in 1988 to obtain tectonic information along an east-west line in the Amargosa Desert. He showed several seismic reflection lines, both with and without interpretation lines, and pointed out the Gravity fault, lava flows, and other structural features that could be interpreted from the images. Dr. Brocher then described a second survey, conducted in 1994, along a reflection line that crossed both Crater Flat and Yucca Mountain, extending into Jackass Flats. He showed cross sections, indicating interpretations of the seismic reflection data, and then showed the seismic lines containing the features that formed the basis for the interpretations. The gravity and ground magnetic data collected along the seismic lines were described, as were the models developed to be consistent with the data sets.

Dr. Christopher Potter (USGS) gave the next talk on geologic mapping in the Yucca Mountain vicinity from 1996 to the present. He showed maps at various scales, noting the complexity of the regional geology, before focusing on Yucca Mountain and the adjacent basins and calderas to the north. He showed maps of selected areas at various scales, describing features that included a dike along part of the Solitario Canyon fault (dated at 10 MY or older) and the Sundance fault. He showed a cross section indicating the moderate to steeply dipping block-bonding faults (e.g., the Solitario Canyon and Bow Ridge faults) and intra-block faults that commonly are sub-vertical. He described the most recently published geologic map of the Yucca Mountain region (Potter and others, 2002; 1:50,000 scale). He then provided a list of the geologic maps and publications available for the Yucca Mountain area.

After a short break Dr. Connor gave his second talk of the day, "Nature of Volcano-Tectonic Interaction and Application to PVHA at Yucca Mountain," focusing on the structural geology and tectonic models developed by CNWRA staff. He stated that volcano-tectonic interaction has a strong effect on the spatial distribution of volcanoes and the timing and recurrence rate of volcanism. He described data sets that provide the bases for tectonic models. He showed volcanic features from a range of field locations and discussed relationships between the rate of extension in a region and the rate of volcanism, as well as relationships between rates of seismic activity and volcanism.

The final talk of the day, presented by Dr. James Davis (Smithsonian Astrophysical Observatory, Harvard-Smithsonian Center for Astrophysics), concerned the acquisition and analysis of geodetic data for the YMP. The goals of this work are to make highly accurate determinations of present-day crustal deformation near Yucca Mountain. He described the two observational techniques used: temporally continuous surveying/geodetic monitoring with the Global Positioning System (GPS) (providing high temporal resolution) and measurement of spatially continuous deformation using interferometric synthetic aperture radar (InSAR) (providing high spatial resolution). Focusing on the GPS data, he described the data acquisition and the factors that affect the accuracy of the analysis. The GPS data products of horizontal site velocities can be reported relative to stable North America or relative to a frame of selected instrument locations. Next, Dr. Davis discussed the accuracy assessment and analysis validation of the GPS data based on independent analyses that indicated only small errors in the surveys. He then briefly described InSAR data, the potential applications of which currently are being examined.

DAY 3 – THURSDAY, OCTOBER 14

Dr. Coppersmith began the day by reviewing the objectives for the morning session: (1) to develop a list of the additional data sets that the experts need to conduct their evaluations, and (2) to review the data collection activities planned by LANL. Dr. Coppersmith displayed a list of issues to be addressed in the PVHA-U, organized into three primary areas: spatial evaluation, temporal evaluation, and event definition (Table 1). In the discussion that followed, members of the expert panel expressed the concern that the list of issues should not limit the flexibility of the experts to develop new approaches or conceptual models. Dr. Coppersmith agreed that as long as spatial, temporal, and event definition issues are addressed, the experts are free to use whatever approaches or conceptual models they would like. Given the technical issues that the PVHA-U must address, the panel discussed a number of data sets that would be useful to obtain and identified issues for which additional information is needed. Those items are listed in Table 2 of this workshop summary.

Following a short break, Dr. Perry gave a talk titled, “Planned Activities: Drilling of Aeromagnetic Anomalies, Geochronology, and Geochemistry.” The goals of this additional data collection effort will be to better constrain the number and ages of volcanic events, to reduce uncertainty, and to facilitate consideration of alternative conceptual models for the PVHA-U. Dr. Perry explained the criteria for selecting anomalies to be drilled. He then showed the drilling targets in the Crater Flat/Amargosa Desert area and in Jackass Flats, discussing the rationales for potentially drilling or not drilling specific anomalies. Because of the long lead time required to obtain drilling permits, permits already are being pursued for a number of sites. Additional information on the processed aeromagnetic data will be provided to the members of the expert panel in approximately six weeks. When the drilling program will begin is uncertain, although Mr. Smistad indicated that December 2004 or January 2005 were likely starting times.

Workshop participants discussed how the aeromagnetic data should be interpreted and the rationale for selecting various candidate drilling sites. Participants made recommendations for additional processing of the aeromagnetic data, including developing cross sections and subduing features that are not of interest to the expert panel (e.g., features located at great depths are of little interest because they are not suspected of containing young basalt). Also discussed were the relative importance of drilling in Crater Flat versus Jackass Flats and the importance of characterizing features such as possible alignments of volcanic cones. Dr. Youngs discussed the results of sensitivity studies performed after PVHA-96 was completed to assess the influence of increased event counts on hazard results. He stated that increasing the number of young basaltic events in Jackass Flats could have a large effect on the probability that an igneous event would intersect the repository footprint. His analysis, however, did not change any of the models used in the PVHA-96.

After a lunch break, Dr. Coppersmith distributed the BSC *Expert Elicitation* quality assurance procedure (LP-AC.1Q-BSC) for the experts to review. He stated that he had collected Conflict-of-Interest forms from all the experts, and reminded them to provide their biographies for inclusion in the final project report. Dr. Coppersmith then introduced Dr. Karen Jenni (Geomatrix Consultants), a decision analyst who will be the PVHA-U normative expert (defined as having a theoretical and conceptual knowledge of probability and practical experience in the elicitation of judgments from individuals). Dr. Jenni then gave a talk, “Introduction to Probability Assessment and Elicitation.” She began by reviewing the objectives of the project; the roles of the expert panel members and other project team members; and the general PVHA-U process, including the series of workshops and individual meetings. Next she discussed the use of probability to quantify uncertainty, beginning with a short history of uncertainty and the evolution of the concepts of probability and risk assessment. She then discussed the representation of uncertainty, covering terminology, probability trees, probability distributions, and expected values. She distributed some exercises for the experts, asking them to answer questions about different expressions of uncertainty, to provide estimates of specific (but unknown) quantities.

Following a short break, Dr. Jenni discussed using probabilities to communicate about uncertainty and the probability assessment process. She described cognitive and motivational biases that complicate the process of assessing and expressing subjective judgments, including “anchoring” (the tendency to focus on an initial estimate, failing to adjust sufficiently for uncertainty or new data). The exercises and questions answered before the break provided an illustration of some of

the cognitive biases, prompting discussion among the panel members about potential cognitive and motivational biases that might impact their judgments in this project. The experts discussed the potential to anchoring on the prior assessments made in PVHA-96, or to overweight data sets with which they have extensive personal experience. Dr. Jenni described the six-step probability assessment process that will be followed: motivate the elicitation, structure the assessment and the uncertain quantities to be elicited, condition the expert to help counter cognitive biases, encode the probability judgments, verify that the assessments accurately capture the expert's judgment, and, when necessary, convert continuous probability distributions into an appropriate discrete approximation for use in probability trees. During discussion of the overall process, the structuring step was highlighted as the point in the process where each expert will describe and define the sub-issues they feel they can best use to characterize spatial evolution, temporal evolution and event characteristics. It was acknowledged that different experts may have different structures, and that each structure would ultimately address those three primary issues. Dr. Jenni described how these steps fit into the PVHA-U (e.g., motivating occurs in the group meetings and workshops; encoding full probability distributions occurs during the individual elicitation interviews). Aggregation of expert assessments was discussed.

Dr. Coppersmith thanked all the meeting participants and adjourned the workshop. The second workshop for the PVHA-U is tentatively scheduled for February 15-17, 2005.

TABLE 1

ISSUES AND POTENTIAL SUBISSUES TO ADDRESS IN PVHA-U
PVHA-U Workshop 1: Key Issues and Available Data

Spatial Evaluation
- Region of interest
- Spatial Model
  - Source zones
    - Alternative zonations
    - Nature of zone boundaries
  - Spatial smoothing
    - Smoothing operator
    - Smoothing distance
  - Other conceptual models?

Temporal Evaluation
- Homogeneous
- Non-homogeneous
- Other conceptual models?
- Time period of interest
- Event rates (for various magnitudes? [see event definition below])
- Undetected events

Event Definition
- "Magnitude" of event (e.g., violent Strombolian, Strombolian)
- Intrusive event geometry
  - Dike system length, azimuth, and location relative to point event and dike width (similar to 1996 assessment)
  - Description of dike swarm (e.g. number and spacing of parallel dikes along length of dike system)
  - Influence of repository opening on dike intersection
- Extrusive event geometry
  - Number and location of eruptive centers (conduits) associated with volcanic event
  - Conduit diameter at repository level
  - Influence of repository opening on eruptive conduit location

TABLE 2
DATA AND INFORMATION IDENTIFIED BY THE EXPERT PANEL
PVHA-U Workshop 1: Key Issues and Available Data

Note: The following data and information were identified by the expert panel during Workshop #1 as being needed to address the PVHA-U Issues (attached below).

1. List of references that address probabilistic volcanic hazard assessments around the world
2. Information on detection limits for dikes in the shallow subsurface
3. Data on dike swarms
4. Modeling and processing information for the 2004 aeromagnetic survey needed to provide recommendations on location and priorities for drilling, including modeling of specific anomalies for source depth and profiles of data
5. Reference pertaining to area containing lava tubes with possible implications to dikes that were subsequently evacuated and are now open fractures
6. Dike propagation information
7. Information on boundaries between zones in YMR, particularly between Crater Flat and Yucca Mountain block
8. Teleseismic tomography data in analog areas
9. GPS data in analog areas having high data density
10. GPS information using PANGA data set
11. GPS data processed to indicate magnitude of strain in Crater Flat
12. Geodetic information for the Basin and Range area (based on extensional tectonics near Yucca Mountain, combined with strike-slip faulting typical of Walker Lane)
13. Reference on directional drilling results at Inyo Craters
14. Results of CNWRA magnetic survey between Red Cone and Black Cone
15. Compilation of data pertaining to volcanism in Crater Flat, based on drilling, age dating, etc.
16. Information on repository characteristics (e.g., drift geometry, waste package configuration, projected thermal history)
17. Additional information on USGS magnetic data (including for anomaly “A”)