

**A Comparison of Findings of Select Yucca Mountain
Volcanic Impact Studies**

Prepared for:

Lincoln County Nuclear Waste Project Office

And

White Pine County Nuclear Waste Project Office

Prepared By:

**Intertech Services Corporation
P.O. Box 2008
Carson City, NV 89702-2008**

May 2008

Purpose

The purpose of this paper is to compare the results of several studies that have been conducted by various entities in regards to the impact to the Yucca Mountain nuclear waste repository in regards to potential volcanic activity at or near the site. The main document under consideration is Evaluating Igneous Activity at Yucca Mountain, Technical Basis for Decisionmaking, W.J. Hinzei, B.D. Marsh, R.F. Weiner, N.M. Coleman, Advisory Committee on Nuclear Waste and Materials (ACNW), February 2008.

The second set of documents were produced by the Electric Power Research Institute entitled, Potential Igneous Processes Relevant to the Yucca Mountain Repository: Extrusive-Release Scenario: Analysis and Implications, Document 1008169 Electric Power Research Institute, July 1, 2004 and Potential Igneous Processes Relevant to the Yucca Mountain Repository: Intrusive-Release Scenario, Document 1011165, Electric Power Research Institute, Final Report, August 2005.

The third set of data were found on the Nevada Nuclear Waste Project Office (NWPO) website, (<http://www.state.nv.us/nucwaste/whatsnew.htm>) and the Yucca Mountain LSN website (<http://www.lsnnet.gov/home.aspx?pg=home>) as supporting documents filed by the NWPO. The NWPO documents were gathered from over 2,000 documents out of 47,382 listed as pertinent to volcanism on the Yucca Mountain LSN data base and in no way represent all of the documentation contained on the LSN, but appear to be representative of the position of the NWPO.

Impacts of Volcanism on Yucca Mountain

ACNW

The study Evaluating Igneous Activity at Yucca Mountain, Technical Basis for Decisionmaking presents a summary and analysis of the range of current technical views on the nature, likelihood and potential consequences of future igneous activity at the proposed repository. Two possible scenarios are presented for analysis. "The extrusive (volcanic) scenario involves intersection of a volcanic-cone-forming conduit through the repository to the surface, possibly causing destruction of the waste packages intersected by the conduit and dispersal of contaminated volcanic ash over the Yucca Mountain vicinity. Very small particles of radioactively-contaminated ash from the volcanic eruption would be inhaled by the reasonably maximally exposed individual (RMEI). Current performance assessment calculations indicate that the largest dose from igneous activity is from a volcanic intersection during the first thousand years after closure of the repository. These calculations suggest that the maximum probability-weighted dose is only a fraction of the current dose standard and decreases with time. The principal factors in determining risk from the extrusive scenario are the probability of the event, including consideration of the probable location of future events and their recurrence rate, the number and contents of waste packages disrupted and entrained in the erupted ash, the eruption volume and the dispersal of the contaminated ash, the size distributions of the waste particles and ash, surface remobilization of contaminated ash by water and wind, and inhalation of the ash by humans."

The second scenario involves “intrusion of an igneous dike into the repository, leading to possible damage or destruction of waste packages and premature release of the waste to infiltrating waters that pass through the repository to the vicinity of the RMEI where radioactive materials in the waste could be ingested directly or indirectly from vegetation and animals that have taken up the radioactively contaminated ground water. The maximum effect of the igneous intrusion scenario is not expected to occur for tens of thousands of years due to slow movement of the water from the repository to the vicinity of the RMEI. Present performance assessment calculations indicate the maximum probability-weighted dose from the intrusive scenario also is likely to be only a fraction of the current standard. The major factors in determining risk from the intrusive scenario, in addition to the probability of the event, are the number of waste packages affected by the intruding molten rock (magma) (determined by the viscosity of the magma and the magnitude and duration of the pressure upon entry), the extent of dissolution of radionuclides by infiltrating ground water, the rate at which ground water transports radionuclides to the vicinity of the RMEI, and the amount of radionuclides ingested by the RMEI.”

In both cases, the ACNW document concludes:

1. The nature of the occurrence and consequences of an igneous event in the Yucca Mountain vicinity lead to differing professional judgments and alternative views on the potential effect of igneous activity on the proposed high-level waste repository. As a result, evaluation of risk from an igneous event requires quantitative consideration of credible alternative views taking into account geological evidence and their physical bases. These analyses will be useful in evaluating risk and determining whether further investigations are warranted to reduce uncertainties.
2. There is general agreement on many aspects of the nature of potential igneous events and the range of probability of these events in the future, despite the broad range of conceptual models and parameters that have been used to investigate the potential effects of an igneous event intersecting the proposed high-level waste repository. The consequences of an igneous event on the repository are more controversial and less well understood, but these models and their characterization are evolving. The significance to risk of differences in these views is not well documented.
3. Limitations in fundamental information and knowledge of processes result in inherent uncertainties in evaluating igneous activity models. For example, the very low rate of basaltic volcanic activity over the past 5 million years in the Yucca Mountain region in comparison with other areas of the region leads to lower igneous activity probability estimates, but increases the uncertainty in the probability of such rare events.
4. Both the extrusive (volcanic) and intrusive scenario could occur in the vicinity of the proposed repository in Yucca Mountain. The extrusive scenario is likely to cause a larger risk and the effect is greatest within the first thousand years. In time the shorter half-life, more radioactive nuclides in the waste will largely have decayed. The maximum effect of the intrusion scenario on the RMEI will not occur for several tens of thousands of years.

Preliminary performance assessment indicates that the risk from both scenarios would be only a fraction of the current dose standard.

5. Future igneous activity in the Yucca Mountain region will likely be similar to the characteristics of the small-volume, single-episode basaltic Lathrop Wells volcano and will likely occur within basins as has most of the igneous activity over the past several million years in the region. Certain styles of volcanism are not expected. For example, the conditions necessary for explosive phreatic eruptions (maar volcanism, involving heating and expansion of groundwater) do not exist at Yucca Mountain. There is also no evidence that maar volcanos formed near Yucca Mountain during the last 10 million years and they are not expected in the future.

6. General, but not total, agreement is that the igneous activity at Yucca Mountain is waning, with the probability that future igneous activity based on nearby volcanism over the past several million years is in the range of 10^{-9} to 10^{-7} /yr. The ongoing elicitation of volcanic experts in the DOE's Probabilistic Volcanic Hazard Assessment - Update, which incorporates the latest geophysical and drilling data from the Yucca Mountain region, will be the most up-to-date, credible estimate of the range of igneous activity intersection with the proposed repository.

7. Significant disagreements exist regarding the nature of the flow of magma into drifts of the repository during an intrusive igneous event and the number of waste packages that would be damaged or destroyed by invading magma. The "dogleg" scenario in which the invading magma breaks out to the surface through a secondary vent after traversing along the drifts and interacting with the waste packages is considered to be of extremely low probability based on both available evidence and expert opinion. Magma physics indicates that flow of intruding magma into drifts would be limited and a secondary (satellite) vent branching from a drift (including the "dogleg" scenario) is unlikely to form at any time in the style of volcanism expected at Yucca Mountain.

8. The current technical bases of several aspects of igneous activity appear to be insufficiently developed or supported by available information and analyses. These include the range of waste particle sizes in the ash and the ash that will contribute to inhalation dose, the effects of large floods on the volume and distribution of contaminated ash in the vicinity of the RMEI, the amount of waste incorporated into ash versus lava during the early eruptive phase of the extrusive scenario, and the importance of setbacks of the repository from faults and fractured zones that are likely locations for dikes leading to either eruptive or intrusion scenario events. Also, there is a need to consider newly available information regarding volcanic conduit widths at repository depth.

Electric Power Research Institute

The purpose of **Potential Igneous Processes Relevant to the Yucca Mountain Repository: Extrusive-Release Scenario: Analysis and Implications, Document 1008169** was to provide an independent third party assessment of the igneous eruption scenario for the proposed geologic repository at Yucca Mountain using more realistic

assumptions than presented to date. The study indicates that “current estimates of the probability of a volcanic eruption through the proposed repository are just high enough that dose consequences must be estimated. In general, these estimates have included multiple compounded conservatisms resulting in predicted dose consequences that are significant, albeit still within established regulatory limits.

Perhaps of most interest are analyses presented in this report related to behavior of the waste package(s) potentially impacted by the igneous eruption. Potential structural, mechanical, creep, and erosion mechanisms were considered to evaluate whether the waste packages would remain intact. Other analyses address new mechanisms that potentially mitigate the release of radionuclides into the erupting magma. Finally, EPRI revisited models currently used to determine the amount of potentially contaminated ash deposition at the regulatory compliance point.

Based on multiple lines of evidence discussed in detail herein, EPRI concluded that in the unlikely event that an igneous event were to occur at Yucca Mountain, it is very unlikely that waste packages will be breached by the actions of the magma during the active eruption period or that radioactive material will be released from the repository as a result of a volcanic event. Based on these findings, it is EPRI's position that the expected consequence of an igneous extrusive event within the Yucca Mountain repository footprint would be zero releases of radioactive matter from the repository to the atmosphere during the event. EPRI further concluded that even in the extremely unlikely event that some radionuclides were released to the atmosphere as a result of an extrusive event, only a very small fraction of the material would be transported to the regulatory compliance point, such that conditional dose risk estimates would be many orders of magnitude below the regulatory limit. By the use of so many compounding conservatisms, it appears that dose risk estimates provided by the DOE and NRC for the igneous eruption scenario cause this scenario to take on greater risk importance than is justified.”

Potential Igneous Processes Relevant to the Yucca Mountain Repository: Intrusive-Release Scenario, Document 1011165 states that this report “provides a more realistic estimate of the likelihood and magnitude of doses to the public should such a low-probability event occur. Analyses indicate that, under any reasonable combination of magma intrusion, the contribution to peak dose from an igneous intrusion event would not affect peak dose estimates over the long term.”

The objective of the above report was “to provide an independent third party assessment of the igneous intrusion scenario for the proposed Yucca Mountain repository using more realistic assumptions than presented to date.”

The results stated “there is reasonable expectation that the magma will only affect some waste packages in a drift intersected by a rising dike, with the remaining waste packages in the impacted drifts functioning the same as they would in drifts not intersected by a dike. In this situation, the peak conditional dose from the affected part of the repository is smaller than that produced from the unaffected part of the repository, due to the small

percentage of the total repository waste packages impacted. If the probability of a magma intrusion is also factored in, the contribution to overall probability-weighted peak dose becomes minuscule. Even when a series of conservative, “bounding” assumptions are made (e.g., full penetration of the magma into the drifts, and 100% of the drifts affected), the probability-weighted estimated bounding dose rates only rise to be on par with the peak dose rates from the nominal case. EPRI therefore concludes that there is reasonable expectation that magma intrusion is inconsequential with respect to peak dose.”

EPRI believes that present DOE and NRC assessments of repository performance are conservative, and reliance on more realistic scenarios and input data would result in a performance that demonstrates an even greater margin of compliance. By the use of so many compounding conservatisms, it appears that dose risk estimates provided by the DOE and NRC for the igneous scenarios cause these scenarios to take on greater risk importance than is justified. As a result, EPRI has concluded that no further activities need be pursued to address the igneous scenarios.

Nevada Nuclear Waste Project Office (NWPO)

In sheer numbers, the NWPO offers more studies to present its case, but most of the studies are focused on the historical background of volcanism in the Yucca Mountain region and rely primarily on the University of Nevada, Las Vegas Center for Volcanic and Tectonic Studies research. Also, most of the studies listed were undertaken in the late 1900’s in comparison to the more recent studies of the previous entities discussed. That in no way is to discredit or play-down this research, but more to point out the narrower scope of the studies presented.

This alternative view reflects uncertainties of the igneous processes that have occurred in the region and those that are likely to occur in the future, as well as the interaction of these processes with the proposed repository. General agreement exists that future igneous activity is likely to be a small-volume, single-episode basaltic volcano similar to the 80,000-year-old Lathrop Wells volcano. Although uncertainties remain, this agreement extends to related parameters of the event such as power and duration, volume and type of erupted products, size of the volcanic conduit supplying lava to the surface, spatial relationship of the eruption to the topographic surface, geochemical characteristics of the magma, and igneous dike characteristics from which the volcano originates. Various conjectures are presented in numerous studies as documented in the reference section.

There is general agreement based primarily on the location and recurrence rate of volcanism over the past 5 million years that the range of probability of an igneous event intersecting the proposed repository is from $10^{-9}/\text{yr}$ to $10^{-7}/\text{yr}$. The assumption of igneous event probabilities larger than $10^{-7}/\text{yr}$ is inconsistent with the number of volcanic events that have occurred during the past 5 million years. Moreover, care is necessary in comparing probability estimates because of changes in igneous event definitions during the past few decades that have progressively included the probability of intersecting dikes and sills of igneous material in addition to extrusive (volcanic) activity (Evaluating Igneous Activity...).

One study, A Spatial-Temporal/S-D Model for Volcanic Hazard Assessment: Application to the Yucca Mountain Region, Nevada, Chih-Hsiang Ho, Department of Mathematical Sciences University of Nevada, Las Vegas and Eugene I. Smith, Center for Volcanic and Tectonic Studies Department of Geoscience, University of Nevada, Las Vegas – No Date, offers, “Attempts at long-term forecasting have been made on statistical grounds, using historical records to examine eruption frequencies, types, patterns, risks, and probabilities. As a first requirement, a statistical model for the volcanic risk/hazard assessment must be based on a sound geological interpretation of the tectonic, structural, and magmatic processes governing the distribution of volcanism in space and time. With this information, we can draw on the records of volcanoes with similar settings and styles of eruptive activity to estimate the possible repose intervals, frequencies of eruption, and types of activity. Unfortunately, the statistical record for these factors is still poor.”

Another, VOLCANIC TIME TREYD ANALYSIS, Chih-Hsiang Ho, Department of Mathematical Sciences, University of Nevada, Las Vegas. No Date, “Volcanic activity is governed by the complex interaction of several geological, physical and geochemical factors. Because of this complexity, even with the present knowledge, eruptions cannot theoretically be predicted. Present understanding of eruptive mechanisms is not yet advanced enough to allow deterministic predictions of future activity to be put forward.”

In more laymen’s terms, the report Risk Assessment for the Yucca Mountain High-Level Nuclear Waste Repository Site: Estimation of Volcanic Disruption, Chih-Hsiang Ho, Department of Mathematical Sciences. University of Nevada-Las Vegas. October 1991, metaphorically states, “The task of quantifying volcanism at Yucca Mountain is as complicated as trying to predict the time of the next catch only based on a few piles of dead fish. (People would debate on the unknown fishing technique(s) used (fishing net, a single hook, etc.) to define a single event. They would also disagree on the freshness of each fish measured.)”

On the subject of spent fuel released from packages during a volcanic eruption, the report, Smelters as Analogs for a Volcanic Eruption at Yucca Mountain, Benjamin Ross Disposal Safety Inc., March 2003 concludes, “Data from smelters suggest that the dust partitioning factors in a volcanic eruption would in fact be substantially lower than predicted by this model, and additional research would be useful to quantify the degree to which these elements are less mobile than the magma as a whole.”

Consequences of a volcanic disruption is also addressed in Analyzing Volcanic Hazards at Yucca Mountain, Frank V. Perry, Bruce M. Crowe, and Greg A. Valentine, *Los Alamos Science Number 26, 2000*. This report concludes, “For a full risk assessment of volcanic activity at Yucca Mountain, the probability of a disruption must be weighted with its consequences in terms of public exposure to radiation. Analysis of the consequences examines such issues as magma rise, intrusion geometry at shallow depths, hydrothermal activity, and potential eruption of nuclear waste. A recent study of the Lathrop Wells cone sponsored by the NRC reported high xenolith abundance in some strata (xenolith is underground rock that broke off and became entrained in the magma).

If true, such abundance would imply that a large amount of repository debris could be ejected were a similar volcano to penetrate Yucca Mountain. However, there is insufficient data to constrain the xenolith content of the volcano as a whole, and the study may have overestimated its abundance. Ongoing work at Sandia National Laboratories and at Los Alamos is addressing the interaction between rising magma and repository tunnels as they are specified in the current design.”

In the report Hazard Area and Probability of Volcanic Disruption of the Proposed High-Level Radioactive Waste Repository at Yucca Mountain, Nevada, USA, Chih-Hsiang Ho, Eugene I. Smith and Deborah L. Keenan. November 2005, the summary concludes “we describe site disruption scenarios to validate the incorporation of the size of a volcanic event in the development of the hazard area in a defined volcanic field at Yucca Mountain. Every new eruption that occurs within the hazard area will disrupt the proposed repository. The probability of site disruption by volcanic activity is equal to the chance that a new eruption will occur in the same area. Simple equations are constructed for general application of volcanic hazards that meet specific requirements.”

Further in Yucca Mountain Could Face Greater Volcanic Threat, E. I. Smith and D. L. Keenan, *Eos, Transactions, American Geophysical Union*, Vol. 86, No. 35. August 2005 project “Volcanic recurrence rates for the Reville–Lunar Crater (RLC) are as high as 12 events per million years, four times the rate calculated for the Yucca Mountain area. These figures are minimum estimates because only 70% of the volcanic centers in the RLC are dated.”

Conclusions

There are several basic premises on which most Yucca Mountain studies agree:

1. There is historical evidence of volcanic activity in the Yucca Mountain area
2. No one can predict when the next volcanic activity may occur
3. No one can predict the magnitude of a future volcanic activity in the Yucca Mountain area
4. Parties can generally agree that there will probably be some volcanic activity in the Yucca Mountain area during the life of the nuclear waste repository

Factors which were apparently not addressed in detail by NWPO studies surveyed:

1. Waste package(s) potentially impacted by the igneous eruption
2. Potential structural, mechanical, creep, and erosion mechanisms to evaluate whether the waste packages would remain intact
3. New mechanisms that potentially mitigate the release of radionuclides into the erupting magma.
4. Models currently used to determine the amount of potentially contaminated ash deposition at the regulatory compliance point.

In this limited comparison of identified studies, it appears that in the case of volcanic activity in the Yucca Mountain area there is more evidence and more current research cited and presented by the ACNW and EPRI studies to indicate that “there is reasonable

expectation that the magma will only affect some waste packages in a drift intersected by a rising dike, with the remaining waste packages in the impacted drifts functioning the same as they would in drifts not intersected by a dike. In this situation, the peak conditional dose from the affected part of the repository is smaller than that produced from the unaffected part of the repository, due to the small percentage of the total repository waste packages impacted. If the probability of a magma intrusion is also factored in, the contribution to overall probability-weighted peak dose becomes minuscule. Even when a series of conservative, “bounding” assumptions are made (e.g., full penetration of the magma into the drifts, and 100% of the drifts affected), the probability-weighted estimated bounding dose rates only rise to be on par with the peak dose rates from the nominal case. EPRI therefore concludes that there is reasonable expectation that magma intrusion is inconsequential with respect to peak dose.”

References

A REPORT SUMMARIZES THE STATISTICAL MODELING OF VOLCANIC RISK STUDIES AT THE YUCCA MOUNTAIN NUCLEAR WASTE REPOSITORY SITE,

Chih-Hsiang Ho, Department of Mathematical Sciences, University of Nevada, Las Vegas. December, 1996

A Spatial-Temporal/S-D Model for Volcanic Hazard Assessment: Application to the Yucca Mountain Region, Nevada,

Chih-Hsiang Ho, Department of Mathematical Sciences University of Nevada, Las Vegas and Eugene I. Smith, Center for Volcanic and Tectonic Studies Department of Geoscience, University of Nevada, Las Vegas – No Date

Analyzing Volcanic Hazards at Yucca Mountain, Frank V. Perry, Bruce M. Crowe, and Greg A. Valentine, *Los Alamos Science Number 26, 2000*

Evaluating Igneous Activity at Yucca Mountain, Technical Basis for

Decisionmaking, W.J. Hinze¹, B.D. Marsh, R.F. Weiner, N.M. Coleman, Advisory Committee on Nuclear Waste and Materials, February 2008

Hazard Area and Probability of Volcanic Disruption of the Proposed High-Level Radioactive Waste Repository at Yucca Mountain, Nevada, USA, Chih-Hsiang Ho . Eugene I. Smith and Deborah L. Keenan. November 2005

Nevada Nuclear Waste Project Office Website,
<http://www.state.nv.us/nucwaste/whatsnew.htm>

Potential Igneous Processes Relevant to the Yucca Mountain Repository: Extrusive-Release Scenario: Analysis and Implications, Document 1008169 Electric Power Research Institute, July 1, 2004.

Potential Igneous Processes Relevant to the Yucca Mountain Repository: Intrusive-Release Scenario, Document 1011165, Electric Power Research Institute, Final Report, August 2005.

Risk Assessment for the Yucca Mountain High-Level Nuclear Waste Repository Site: Estimation of Volcanic Disruption, Chih-Hsiang Ho, Department of Mathematical Sciences. University of Nevada-Las Vegas. October 1991

Sensitivity in Volcanic Hazard Assessment for the Yucca Mountain High-Level Nuclear Waste Repository Site: The Model and the Data, Chih-Hsiang Ho, Dcpanment of Mathematical Sciences, University of Nevada at Las Vegas. November 1994

Smelters as Analogs for a Volcanic Eruption at Yucca Mountain, Benjamin Ross Disposal Safety Inc. March 2003

SUMMARY OF THE ACTIVITIES OF THE CENTER FOR VOLCANIC AND TECTONIC STUDIES, UNIVERSITY OF NEVADA, LAS VEGAS FOR THE PERIOD 1986-1996. VOLCANISM STUDIES RELATED TO PROBABILISTIC VOLCANIC HAZARD ASSESSMENT. Prepared by: Eugene I. Smith, Principal Investigator Shirley Morikawa, Research Associate Alex Sanchez, Research Associate January 22,1997

THE AREA OF MOST RECENT VOLCANISM NEAR YUCCA MOUNTAIN, NEVADA: IMPLICATIONS FOR VOLCANIC RISK ASSESSMENT, Eugene I. Smith, Daniel L. Feuerbach, Terry R. Naumann and James E. Faulds, Center for Volcanic and Tectonic Studies Department of Geoscience University of Nevada, Las Vegas. April 1990

THE SLOAN SAG: A MID-MIOCENE VOLCANOTECTONIC DEPRESSION, NORTH-CENTRAL McCULLOUGH MOUNTAINS, SOUTHERN NEVADA, Hayden L. Bridwell, Department of Geoscience, University of Nevada, Las Vega December, 1991

Volcanic Risk Studies for the U.S. and Japanese Geologic Repository Programs F. V.Perry, G. A. Valentine and B. M. Crowe, *Progress Report 1998-2000 Earth and Environmental Sciences*

VOLCANIC TIME TREYD ANALYSIS, Chih-Hsiang Ho, Department of Mathematical Sciences, University of Nevada, Las Vegas. No Date

Volcanism Studies Related to the Probabilistic Volcanic Hazard at Yucca Mountain for the Period 1986-1996, Dr. Eugene I. Smith, Shirley Morikawa and Alex Sanchez, University of Nevada, Las Vegas, January 1997

Yucca Mountain Could Face Greater Volcanic Threat, E. I. Smith and D. L. Keenan, Eos, Transactions, American Geophysical Union, Vol. 86, No. 35. August 2005

Yucca Mountain LSN Website, <http://www.lsnnet.gov/home.aspx?pg=home>