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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Department of Energy (DOE)/Nuclear Regulatory Commission (NRC) Technical Exchange on Volcanism (20-5708-461)

DATE/PLACE: February 25–26, 1997
Two White Flint, Washington, DC

AUTHORS: Charles B. Connor, Brittain E. Hill

BACKGROUND AND PURPOSE OF TRIP:

The purpose of this technical exchange was to identify areas of agreement and disagreement between the DOE and NRC at the staff level on: (i) probability of volcanic disruption of the proposed repository, (ii) nature of performance assessments (PA) of the consequences of volcanic activity, and (iii) use of geologic data relevant to probability and consequence issues. Specific goals for the technical exchange, outlined in the agenda were:

- At the staff level, exchange information, foster discussion, determine areas of agreement and disagreement about specific geologic issues, and identify paths for pursuing and resolving areas of disagreement.
- Define the Yucca Mountain region (YMR) magmatic system and evaluate evidence of post-caldera silicic volcanism.
- Examine the technical bases for source-zone definitions for igneous activity (IA), evaluate approaches for incorporating structural data into probability models, and evaluate geophysical data relevant to site characterization and IA.
- Evaluate the technical bases for PA abstractions, especially waste incorporation in erupting magmas, and examine approaches for building confidence in models using geologic data.
- Examine the range of dose estimates from processes, identify and discuss critical uncertainties regarding engineered system behavior during igneous events, and evaluate alternative approaches for understanding geologic processes in the disturbed repository setting.

SUMMARY OF PERTINENT POINTS:

An agenda for the meeting is attached. Copies of the viewgraphs used by the speakers can be obtained from the authors of this report. Introductory comments were made by Mike Bell (NRC), John Trapp (NRC), Stephan Brocoum (DOE) and Tim Sullivan (DOE). Stephan Brocoum expressed DOE's intent

that this meeting focus on the path toward resolution of issues related to IA and that, specifically, this meeting would lead to resolution of the NRC's IA KTI. Brocoum noted that seven interactions on volcanism with the NRC have taken place since 1989 and that these interactions have not resulted in issue resolution.

Tim Sullivan (DOE) stated several similar points. As stated by Sullivan, goals of the meeting should include: (i) reaching a common understanding for the basis of resolving the IA KTI and related subissues, (ii) identifying areas of agreement and disagreement between NRC and DOE, and (iii) discussing new information from the CNWRA and the NRC. Sullivan reviewed the history of several DOE-sponsored studies related to IA. These included TSPA-95 and the Geomatrix probabilistic volcanic hazards assessment (PVHA) expert elicitation. Sullivan indicated that results of the PVHA bounded the annual probability of IA at the proposed repository site between 1×10^{-10}/yr and 1×10^{-7}/yr and that the aggregate mean of the PVHA is 1.4×10^{-8}/yr. He noted that CNWRA probability values of 1×10^{-8}/yr-1×10^{-7}/yr fall within this range. Sullivan indicated that DOE plans to use the entire range of PVHA results in TSPA.

Brittain Hill (CNWRA) and Chuck Connor (CNWRA) presented geologic data relevant to volcanic hazard analyses at the repository site. Hill discussed how temporal, spatial, structural, and isotopic geochemical criteria can be used to define the overall YMR magmatic system. Many probability models used in the PVHA and in the geologic literature (e.g., Ho, 1992) are very sensitive to temporal and spatial definitions of the system extent. Hill emphasized the need to apply geologic criteria clearly and consistently when the YMR system is defined in hazards assessments. For example, Ho (1992) postulated that the probability of future volcanic activity at the repository site can exceed 1×10^{-3}/yr, based on a presumed increase in volcano recurrence rates from the Pliocene (3–4 volcanoes/m.y.) to the Quaternary (7–8 volcanoes/m.y.). Using isotopic geochemical criteria developed subsequently to Ho (1992), the YMR system can be defined to include 6 Ma and younger basalt in the Funeral Formation located about 60 km south of the repository site (Yogodzinski and Smith, 1995; Hill and Connor, 1996). At least 20 volcanoes are preserved in the Funeral Formation (Conway et al., 1997), which ranges in age between 4.0 and 4.8 Ma (Wright et al., 1991). Including the Funeral Formation volcanoes into the YMR system thus increases a Pliocene recurrence rate to around 9 volcanoes/m.y., which is comparable to a Quaternary recurrence rate. This relatively stable long-term recurrence rate supports the hypothesis that volcano recurrence rates should not increase during the next 10^4–10^5 yrs and that probabilities calculated on apparent increases in recurrence rates (e.g., Ho, 1992) do not accurately account for available geologic data.

Hill also discussed the reworked silicic pumice deposits in southern Crater Flat that have been previously dated as 6.3 ± 0.8 Ma based on zircon fission-track techniques (Carr, 1982). The pumice is generally intact, subround to subangular, and appears very coarse-grained in relation to potential source vents. If the 6.3 ± 0.8 Ma date was correct, this pumice would represent a significant post-caldera (i.e., <9–11.5 Ma) silicic eruption in the YMR. Recently completed single-crystal $^{40}Ar/^{39}Ar$ dates (n=12) of anorthoclase in this pumice give a new age of 9.1 ± 0.3 Ma. These dates yield an initial $^{40}Ar/^{39}Ar$ ratio of 294 ± 3, which corresponds to present-day isotopic ratios and thus indicates the new date is reasonably accurate. The new date correlates with 9.2–9.4 Ma Black Mountain Caldera eruptions (Sawyer et al., 1994). Both the Crater Flat pumice and many pyroclastic units from the Black Mountain Caldera system have a similar alkaline mineral assemblage, which supports the age correlation. Correlation of the Crater Flat silicic pumice to Black Mountain Caldera substantiates that there is no available information to suggest the presence of significant post-caldera silicic eruptions in YMR magma system. Therefore,

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current information shows silicic volcanism does not need to be considered in evaluating probability and consequences of YMR IA.

Connor presented data on the geophysical setting of the YMR. This information included review of the gravity data on the site region collected by the USGS and others and ground magnetic data collected in three areas within 8–25 km of the repository site that have been volcanically active in the past. The ground magnetic work is summarized in Connor et al. (1997). Connor summarized by saying that these data provide several criteria by which probability models for volcanic disruption of the site can be evaluated. Probability models should account for the following features:

- Clustered nature of volcanism in southern Crater Flat
- Association of volcanoes and faults
- NE-trend in volcano alignments
- Low and persistent rate of volcanism in the YMR

Little discussion followed this presentation. Stephan Brocoum requested clarification of the nature of NE-trending alignments. Essentially, there is empirical evidence of the importance of this trend. Also, the trend seems reasonable as northeast-trending dikes would be injected perpendicular to the direction of least principal compressive stress in the YMR. Stan Echols (Winston and Strawn) asked if the low rate of volcanism meant that volcanism need not be considered further. This is a question addressed many times previously. There is general agreement, reiterated at this meeting, that the YMR is a geologically active volcanic field. Although the recurrence rate of volcanism is low, there is no expectation that it can be considered zero. Furthermore, in the context of current regulations, its probability of occurrence is sufficiently high to require consideration of consequences.

Kevin Coppersmith and Bob Youngs (Geomatrix) gave a presentation on the results of the PVHA expert elicitation (Geomatrix, 1996). Some discussion focused on the differences between definition of volcanic events in the PVHA study and definitions used by others, for example in Connor and Hill (1995). Sullivan indicated that the PVHA result would be the one carried forward by DOE through PA.

Connor presented results of CNWRA probability analyses. These results are given in Hill et al. (1996) and have been presented previously (Connor et al., 1996a, 1996b). Essentially, Connor presented an approach to minimizing the impact of source-zone definitions on probability outcomes. There was agreement in the discussion that source-zone definition plays a strong role in determining probability, but no real agreement on how this sensitivity would be addressed. Specifically, Connor suggested that most of the lower probabilities in the PVHA result from source-zone definitions that preclude volcanism within the repository boundaries. Connor also suggested applying criteria for assessment of individual models that may help evaluate their significance. Coppersmith indicated that the results of PVHA cannot be revisited, as what is presented in the PVHA report (Geomatrix, 1996) represents the thinking of the expert panel. Sullivan indicated that this entire distribution would be used in PA. Stan Echols asked Connor if the factor of two difference in probability that occurs from incorporating structure would make a difference that is significant. Connor indicated that he believes this factor of two is not significant. However, Connor indicated that the main result of considering structure is that very low probabilities (e.g., 1×10^{-10}/yr) are not supported by structural models.

Hill discussed the current CNWRA conceptual model for waste incorporation into a volcanic eruption. This model provides the geologic bases for current PA calculations for volcanic disruption. Magma has thermal, physical, and chemical characteristics that will adversely affect waste package performance.

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Based on these physical conditions, a starting assumption in PA calculations is that the waste package fails under volcanic eruption conditions. This assumption is supported by initial calculations that show the waste package fails from simple thermal effects on the order of seconds to less than a year, which is the range of duration of most basaltic volcanic eruptions. Waste behavior under eruption conditions also is poorly known. Waste particles will likely be incorporated into ascending magma at some initial grain size. Volatile expansion, temperature, and shear may further reduce waste particle grain-size, which directly affects particle transport into the accessible environment. In addition, the dispersal capabilities of YMR volcanoes are poorly known due to the advanced degree of erosion at most of these volcanoes. Hill presented results from studies at analog and YMR volcanoes that provide geologic constraints on the amount of waste potentially disrupted and the dispersal capabilities of YMR volcanoes. Analogy between YMR and the 1975 Tolbachik volcanoes was discussed without adverse comment. As discussed in Hill (1996), data from 1975 Tolbachik is used to constrain the potential area of subsurface disruption to 49 ± 7 m diameter for that eruption, and by direct analogy to Lathrop Wells volcano. Analog basaltic volcanoes were used to illustrate a range of dispersal characteristics for aerial transport of material, clearly demonstrating that significant amounts of ejecta are transported beyond 8 km from the vent (cf. Link et al., 1982). In addition, the dispersal model of Suzuki (1983) was discussed and results from accuracy and sensitivity studies (Hill et al., 1996) were presented. There was little discussion of these geologic data, however, participants apparently agreed with the major conclusions and interpretations presented.

Tim McCartin (NRC) presented a summary of previous total system PAs by NRC and DOE. These calculations provided a framework for discussion of current dose calculations for volcanic eruptions. Using a 25 MTU/acre load and a repository without backfill, DOE calculated in TSPA-95 a 10,000 yr peak annual individual dose of 0.2 mrem/yr (50^{th} percentile) to 3 mrem/yr (90^{th} percentile) for a maximally exposed individual located 5 km down gradient from the repository site. These calculations assumed an undisturbed repository that was not disrupted by IA or human intrusion. As part of the NRC staff evaluation of the National Academy of Sciences recommendations, NRC calculated peak doses of 4 mrem/yr (50^{th} percentile) to 40 mrem/yr (90^{th} percentile) for a critical group located in the Amargosa Desert. These calculations give a range of undisturbed repository performance from tens of millirems per year to significantly lower values and provided a context to evaluate current dose calculations for volcanic eruptions. This range of values appeared generally reasonable to the audience.

Hill presented current dose calculations for volcanic eruptions, emphasizing that this was an evaluation of model sensitivities to specific critical parameters and not a total system assessment of IA. Current calculations evaluated dose sensitivity to a range of waste-particle sizes and incorporation ratios, as presented in Jarzemba and LaPlante (1996). Critical groups located 20 km south of the proposed repository site may receive a peak annual total effective dose equivalent (TEDE) in the time period of interest of ≤ 50 mrem/yr. This value assumes that a volcanic eruption occurs through the repository, 1 waste package (10 MTU) fails, the wind blows south from the repository 14 percent of the time, waste has a mean diameter of 0.01 mm and that tephra particles must be at least twice the diameter of the waste particles in order to transport waste through aerial dispersion. Increasing the median waste-particle size or waste incorporation ratio, in addition to moving the critical group from 20 to 30 km south, results in orders of magnitude lower dose values. Increasing the number of waste canisters disrupted from 1 to 10 likely results in a peak annual TEDE of ≤ 500 mrem/yr. Considering the probability of a future volcanic eruption at the repository site to be $\leq 10^{-3}$ in 10^4 yr (e.g., Hill et al., 1996), the risk presented by the direct volcanic disruption of the repository is thus ≤ 0.5 mrem/yr. The relative significance of this value depends on the evaluation of expected undisturbed repository doses and potential regulatory standards.

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Ensuing discussion of these values focused on perceived significance, rather than the technical basis for the calculations.

Ralston Barnard (Sandia) presented an overview of previous DOE TSPAs that show low risk estimates for volcanism. Plans for TSPA-VA are that disruptive events (i.e., IA) will be incorporated into TSPA-VA to the extent that consequences are expected to be detectable, probabilities are not negligible, their significance is perceived to be large, and that YMP resources permit inclusion. It was not clear from these statements and subsequent discussions the extent to which IA will be considered by DOE in TSPA-VA. Barnard outlined numerous improvements that can be made to IA performance models, primarily concerning subsurface effects. Other potential modifications include new models for dissolution and entrainment of spent nuclear fuel in ascending magma, tephra dispersal modeling as described in Jarzemba (1997), and models for geochemical alteration and vapor movement resulting from IA. Considerable discussion focused on the use of probability distributions in PA models. The approach favored by the NRC is to use the probability of volcanic disruption as a single value, whereas the plan for TSPA-VA is to sample the probability distribution from PVHA. Both sides agreed to consider this topic further, and DOE will apparently evaluate model sensitivity to use of a single value or a sampled distribution.

IMPRESSIONS/CONCLUSIONS

This technical exchange was different from previous volcanism technical exchanges in that few volcanologists attended. Only one of ten experts from the PVHA panel attended part of the meeting (Rick Carlson attended the first day). The technical lead for the DOE on volcanism (Frank Perry of LANL) attended the meeting but did not make a presentation. William Melson (Smithsonian Institution and NWTRB consultant) also was present and participated in discussions. This limited participation, however, restricted any form of technical exchange about outstanding issues in volcanism. For example, there was no opportunity to discuss the use of the PVHA distribution with the PVHA panel experts, or causes of variation in probability estimates. This is unfortunate because DOE is assigning a great deal of weight to these estimates.

A clear discrepancy was elucidated during the meeting between the way NRC staff view the PVHA results and the way DOE staff plan to use the PVHA results. NRC staff proposed using a conservative measure, such as the upper bound or the 95 percent confidence level of the aggregate PVHA curve. DOE stated repeatedly their plan to use the entire curve, sampling this curve during TSPA runs. Although there was agreement on the conservative upper bound, there was no agreement on the lower bound. Thus, use of the entire PVHA range will tend to produce lower probabilities than the NRC currently feels defensible. One approach toward resolution is to evaluate probability models using criteria, such as those proposed by Connor in his presentation and in Connor et al. (1997). However, DOE does not intend to evaluate probability models formulated by the 10 experts on the PVHA panel; their estimates will be used as supported by the PVHA report. This difference in the interpretation of the significance of PVHA results and the way the PVHA study will be used in assessment prevented closure on the probability issue.

There was broad agreement at the meeting on how to move forward with consequence analysis and that probability is sufficiently high to warrant consequence analysis and assessment of risk. Since the risk is a simple multiplication, rather than a convolution as in seismic hazard analysis, lack of agreement on probability is not a significant barrier to progress on consequence analysis. If, however, the risk analysis indicates that differences of about one order-of-magnitude in probability cause significant variation in risk with respect to a given standard, further analysis of differences in probability would be needed.

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The "significance" of IA remains relatively subjective. All participants appeared to agree that the risk of volcanic activity appears low, compared with proposed dose-based standards. There is considerable latitude, however, in perceived significance relative to undisturbed repository performance. If undisturbed performance is on the order of tens of millirems per year, then IA will likely make a minor contribution (i.e., on the order of ten percent) to overall risk. If, however, undisturbed performance is on the order of tens of microrems per year, then IA is the only "significant" (i.e., dose-producing) process in the repository system. It was not clear how DOE perceives the level of significance for IA, relative to the incorporation of igneous processes in TSPA-VA. Although numerous improvements to previous TSPA models were discussed by Barnard, implementation of these improvements in TSPA-VA will only occur if IA is perceived by DOE to be "significant."

The following points were agreed to at the end of the meeting:

- Agreed that the rate of volcanism has been relatively constant over the last 5 m.y. and should remain so during the next 10,000 yr.

- Agreed that based on current information, silicic volcanism need not be evaluated further.

- DOE believes that the PVHA provides a defensible basis for characterizing the probability of disruption. The probability distribution function (PDF) has an upper bound frequency of 10^{-7}, a lower bound frequency of 10^{-10}, and a mean of 10^{-8}/yr. NRC believes probability of 10^{-7}/yr is a reasonably conservative upper bound for extrusive events. There are differing views on the lower bound. DOE will explain how the PDF for probability of disruption will be used in PA, including sensitivity studies, recognizing NRC's comments.

- DOE will consider evaluating new NRC data, such as the size and volume of Little Cones and the number of events at aeromagnetic anomaly A, through hazard sensitivity studies.

- Volcanism is of regulatory interest and its probability and consequences must/will be considered. If determined to be significant with respect to repository performance, the effects of volcanism will be included in the total system PA.

- The treatment of consequences outlined by DOE, which includes extrusive magmatic events (cone and dike formation) and intrusive magmatic events (sill and dike formation) with both direct and indirect effects, is generally appropriate at the level of detail provided.

- Agreed that there is uncertainty in the consequence analysis due to magma-waste package and waste-form interactions. This uncertainty needs to be evaluated.

DOE agreed to provide the NRC with a letter describing the DOE basis for subissue resolution, as specified by the above, for consideration in development of NRC's Issue Resolution Status Report.

RECOMMENDATIONS:

The DOE/NRC technical exchange provided a good basis for moving forward and writing the Issue Resolution Status Report on probability. Ralston Barnard should be sent a copy of Hill (1996) to consider an alternative approach to calculating the volume of waste potentially disrupted by a repository-penetrating volcanic conduit.

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PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

REFERENCES:

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SIGNATURES:

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Brittain E. Hill — March 26, 1997
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AGENDA
DOE/NRC TECHNICAL EXCHANGE - IGNEOUS ACTIVITY PROGRAM
February 25-26, 1997

OBJECTIVE:

To achieve issue definition on the approach to considering igneousactivity in TSPA-VA and identify areas of agreement and disagreement at the staff level on the relevant geologic data, the probability of volcanism, models for calculating consequences, and performance assessment models of igneous activity.

GOALS:

At the staff level, exchange information, foster discussion, and determine areas ofagreement and disagreement, and paths for pursuing, identifying, and resolving areas of disagreement.

Define the Yucca Mountain Region (YMR) system (spatial, temporal, petrogenetic/isotopic constraints; consider buried volcanic features(i.e., those that may be present but undetected); evaluate evidenceof post-caldera silicic volcanism.

Examine technical bases for source-zone definitions; evaluate approaches toincorporating structural models/data into probability models; evaluate geophysical site characteristics relevant to volcanism.

Evaluate the technical basis for performance assessment (PA) abstractions, especially waste incorporation; examine approaches for building confidence in models using geological data.

Examine range of dose estimates from processes; identify and discuss critical uncertainties regarding engineered systems behavior during igneous events; evaluate alternative approaches for understanding geologic processes in disturbed repository setting.

February 25, 1997

8:00	Introduction - Opening Remarks	DOE/NRC/AUG
8:30	Geologic Setting and Relevant Data - CNWRA Field Studies - Definition of the YMR System - Crater Flat 6 Ma Pumice - Ground Magnetic Surveys in YMR	NRC
10:15	Break	ALL
10:30	Probability Models - PVHA Results	DOE

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February 25, 1997 (continued)

12:00	Lunch	ALL
1:00	Probability Models (Continued) NRC Probability Models - Concerns With PVHA Source - Zone Definitions - Structural Setting of YMR Relevant to Repository - Integrated Volcanism Structural Models	NRC
2:00	Caucus	ALL
2:30	Wrap up - Areas of Agreement and Disagreement	ALL
3:15	Break	ALL
3:30	Consequence Models NRC Consequence Models - Tephra Dispersion - Subsurface Area of Disruption - Critical Models used in PA Models for Dose	NRC
5:00	Adjourn	ALL

February 26, 1997

8:00	Comments on Previous Day Discussions	ALL
8:30	Sensitivity Studies and Significance - Results of NRC/CNWRA Sensitivities Studies - DOE Plans for TSPA - VA	 NRC DOE
10:30	Caucus	ALL
12:00	Lunch	ALL
1:00	Itemization of agreements/disagreements - Ensure NRC's comments/technical bases and DOE's responses are understood - Make modifications to suit	NRC/DOE
3:00	Closing comments	ALL
3:30	Adjourn	ALL

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QA: N/A

DOE - NRC TECHNICAL EXCHANGE
IGNEOUS ACTIVITY PROGRAM
February 25-26, 1997
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QA: N/A

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IGNEOUS ACTIVITY PROGRAM
February 25-26, 1997
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QA: N/A

DOE - NRC TECHNICAL EXCHANGE
IGNEOUS ACTIVITY PROGRAM
February 25-26, 1997
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