# CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

## TRIP REPORT

**SUBJECT:** Foreign Trip Report for Brittain Hill
AI 06002.01.051.355

**DATE/PLACE:** September 3–17, 2003
Cambridge (Cambridge University), Portsmouth (International Association of Mathematical Geology) and Bristol (University of Bristol), England

**AUTHOR:** Brittain Hill, Senior Research Scientist,
Center for Nuclear Waste Regulatory Analyses

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**DATES OF TRAVEL AND COUNTRIES/ORGANIZATIONS VISITED:**
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**AUTHOR, TITLE, AND AGENCY AFFILIATION:**
Brittain Hill, Senior Research Scientist, Center for Nuclear Waste Regulatory Analyses

**SENSITIVITY:**
Not applicable

**BACKGROUND/PURPOSE:**
Rising basaltic magma is a pressurized fluid, with sufficient force to fracture rock and dilate the fractures to widths of 1 meter. Although the likelihood is relatively small for rising magma to intersect the potential Yucca Mountain repository site, the radiological consequences of magma intersection appear to be relatively high. In order to review a DOE license application for Yucca Mountain, staff will need an independent technical basis to evaluate the potential effects of rising basaltic magma interacting with subsurface repository systems. Because these effects are not discussed in the scientific literature, NRC and CNWRA staff have been working for several years with consultants at the University of Bristol, Cambridge University, and the University of Twente to develop and test numerical and analog experimental models for potential magma-repository interaction processes. Previously completed investigations indicate that magma-repository interaction processes have the potential to disrupt significantly more waste packages than modeled by the DOE. Thus, the ongoing investigations directly affect staff reviews of highly risk significant processes for the proposed repository site. The results from this team investigation also will help increase public confidence that the NRC independently develops and publishes a wide range of techniques to evaluate important safety issues.

**ABSTRACT:**
Ongoing technical investigations by consultants to the CNWRA remain focused on evaluating risk significant processes associated with potential magma-repository interactions at Yucca Mountain, Nevada. Review and discussion of work completed in fiscal year 2003 indicates that significant progress was made in developing simplified analog experiments for potential magma-flow processes and in modeling the results of these experiments. A key uncertainty in evaluating the risk significance of these potential processes is the behavior of a gas phase in flowing magma. Additional experiments and models are planned in fiscal year 2004 to evaluate gas segregation processes and quantify the risk significance of remaining model uncertainties.

Pending budgetary approval, the completed investigations should provide staff with the technical basis necessary to support a high quality review of magma-flow process models in the DOE license application for Yucca Mountain. Meetings and discussions in this trip were technical in focus and no policy or management issues were discussed. NRC support and participation in the planned technical investigations should continue, as these investigations focus on the review of processes with high risk significance to the Yucca Mountain repository program.

**DISCUSSION:**

The purpose of this trip was to meet with consultants from the University of Bristol and Cambridge University who are conducting these ongoing investigations. Goals of the trip were to discuss the results of ongoing investigations for magma-repository interactions, verify that models are evaluating appropriate conditions for the proposed repository system, and assure that investigations remain focused on key licensing issues affecting public health and safety. Dr. Hill also discussed recent developments in the DOE program and modified work plans as needed.

Dr. Hill first traveled to Cambridge University, to review modeling and experiments conducted during fiscal year 2003. This work focused on evaluating (i) relationships between rising basaltic magma and elastic deformation of surrounding rock, and (ii) fluid dynamics for potential horizontal diversions of magma through repository drifts, with subsequent vertical break-outs. Numerical models were discussed for the effects of variably pressurized magma on wall-rock deformation, including likely interrelationships between magma flow rates and rock deformation rates. The models show that in many cases, rising magma in a dike gradually narrows with height above the source reservoir as overpressure of the magma relative to the minimum horizontal stress in the crust decreases through frictional dissipation. This relationship develops an upper bound on magma flow rate that is sensitive to overpressure in the magma system. Using realistic variations in magma volatile content, magma pressure, and the ratio of minimum-to-maximum principal stresses in the crust, eruption rates are expected on the order of 0.1–3 $m^2/s$ per unit length of a dike. Results of these models are presented in a report that is currently in CNWRA review. During fiscal year 2004, these models will be modified to evaluate effects of potential magma diversions into horizontal drifts.

Fluid dynamic experiments at Cambridge University also were reviewed for a variety of flow conditions and conduit geometries, including bubbly and bubble-absent conditions. These experiments will help staff to evaluate models for the waste entrainment capability of potential horizontal diversions of magma through a repository drift. Initial experimental results show that although bubble segregation will occur during horizontal flow, turbulent mixing during renewed vertical ascent appears sufficient to reincorporate bubbles into the magma. Experiments were planned for fiscal year 2004 to more rigorously evaluate the physical conditions necessary for a vertical break-out to occur away from the point of initial magma intersection. In addition, modeling will focus on the ability for horizontal flow to occur in the presence of restricted drift openings, and to evaluate potential entrainment effects for dense waste fragments.

Following work at Cambridge University, Dr. Hill participated in the International Association of Mathematical Geology meeting in Portsmouth, England. Special sessions focused on recent developments in quantifying geologic risks using geographic information systems, and statistical applications to volcanic risk assessments. Several presentations discussed statistical methods

for determining recurrence rates of infrequent geologic events, which may be useful in evaluating uncertainties for volcanic recurrence in the Yucca Mountain region. Of particular interest was a paper presented by Gusev and others that used multiple statistical techniques to describe clustering behavior in the temporal structure of Holocene volcanic activity on Kamchatka, Russia. These episodic patterns are consistent with ordinal clustering behavior, which is the tendency of the largest eruptions to be unusually close neighbors in a time-ordered event list. A paper by Bardossy and others evaluated the suitability of a low-level waste facility in Hungary using simplified numerical models with "fuzzy numbers," which were reported to capture a full range of model and parameter uncertainty. These methods, however, resulted in only very small uncertainties on calculated mean releases. Electronic copies of the meeting papers are available from Dr. Hill.

Work at Bristol University in fiscal year 2003 focused on evaluating potential fluid dynamic effects for sustained magma flow in a vertical conduit that potentially intersects a horizontal tunnel. Many models for flow in erupting volcanic conduits contain zones with contrasting densities due to gas segregation effects. However, the potential for mixing these different density zones, and possible effects on eruption characteristics, are poorly constrained. Experiments at Bristol University were conducted to evaluate flow and mixing effects for bubble-absent fluids of contrasting densities. Initial experiments on bubbly flows also were conducted. In all cases, density segregations occurred in the horizontal tube connecting the vertical conduit, with some degree of mixing between the different density fluids. Bubbly liquids in the horizontal tube rapidly segregate into an upper foam layer that grades into a bubble-absent basal layer. The denser basal layer initiates a return flow into the vertically rising conduit. Experiments were planned for fiscal year 2004 to quantify the fluid dynamics of the return flow and evaluate the potential for waste incorporation from potential convection effects. In addition to the sustained flow experiments, investigations for quantifying pressure-gas content relationships for initial decompression experiments were completed this year. A final series of experiments was planned at Bristol University in fiscal year 2004 to examine decompression effects of gas-bearing magmas, which supplement the gas-absent experiments completed last year. Results of these final experiments will be evaluated using previously developed numerical models for decompression-induced flow.

As a result of the completed and planned investigations, staff anticipates developing a technical basis by the end of fiscal year 2004 for the evaluation of hazard models for potential magma-repository interactions at Yucca Mountain, Nevada. This technical basis will guide staff reviews of anticipated models and analyses by the Department of Energy, which likely will be used in the forthcoming license application. With completion of the planned investigations, staff will have an enhanced ability to independently evaluate the uncertainties of proposed magma-repository interaction models and determine credibility of alternative conceptual models.

**PENDING ACTIONS/PLANNED NEXT STEPS FOR NRC:**
Statements of work are being completed for proposed fiscal year 2004 investigations, pending final approval of the CNWRA budget request. Staff anticipates a meeting at NRC headquarters in the Summer of 2004 for consultants and NRC staff to discuss the results of these investigations.

**POINTS FOR COMMISSION CONSIDERATION/ITEMS OF INTEREST:**
Staff continues to develop the independent technical basis necessary to review DOE models for high level waste source terms during potential igneous events at Yucca Mountain, Nevada. Consistent with Commission guidance on the use of risk insights, ongoing work remains focused on relatively uncertain processes with potential for high risk significance. Alternative conceptual models for magma flow processes during potential igneous events likely result in significant differences of calculated risk.

**ATTACHMENTS:**
None.

**"ON THE MARGINS":**
None.

**SIGNATURES:**

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Senior Research Scientist

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Date

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