# U.S. NUCLEAR REGULATORY COMMISSION, OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS, REVIEW OF THE U.S. DEPARTMENT OF ENERGY AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA: IGNEOUS ACTIVITY KEY TECHNICAL ISSUE AGREEMENTS 2.19 ADDITIONAL INFORMATION NEEDED AND 2.20 ADDITIONAL INFORMATION NEEDED

## 1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during the prelicensing period is to ensure that the U.S. Department of Energy (DOE) has assembled enough information about a given issue for NRC to accept a license application for review. NRC staff resolution during prelicensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. Also, and equally important, NRC resolution of an issue during prelicensing does not prejudge NRC staff's evaluation of the issue during the licensing review. NRC staff resolves issues during prelicensing when it has no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments about a previously resolved issue.

This review addresses additional information DOE supplied in its July 26, 2005, letter from Joseph D. Ziegler to C. William Reamer, which responded to staff additional information need (AIN) for Igneous Activity (IA) Key Technical Issue (KTI) Agreements 2.19 and 2.20. Agreements IA.2.19 and IA.2.20 were originally made between DOE and NRC during the IA, Technical Exchange and Management Meeting (Reamer, 2001). DOE provided an initial response to these two agreements in Technical Basis Document No. 13: "Volcanic Events" (Bechtel SAIC Company, LLC, 2003). Staff reviewed the DOE response and requested additional information in a letter from Lawrence E. Kokajko to Joseph D. Ziegler (Kokajko, 2005).

Agreements IA.2.19, IA.2.20, and subsequent additional information requests relate to the potential release and transport of radionuclides during and after a potential igneous event. In Travers (2003), staff described the basis for risk-ranking the KTI agreements. Agreements that affected risk calculations through moderate increases in radionuclide transport characteristics were considered to have medium significance in performance calculations. The NRC preliminary analyses indicate these two agreements have a medium significance to risk calculations (Travers, 2003).

## 2.0 WORDINGS OF THE AGREEMENTS

IA KTI Agreement 2.19 is defined in an NRC staff letter (Reamer, 2001), which summarizes the IA Technical Exchange and Management Meeting held September 5, 2001. The wording of the agreement is as follows:

IA.2.19 "DOE will evaluate waste package response to stresses from thermal and mechanical effects associated with exposure to basaltic magma, considering the results of evaluations attendant to IA Agreement 2.18. As currently planned, the evaluation, if implemented, would

include: (1) appropriate at-condition strength properties and magma flow paths, for duration of an igneous event; and (2) aging effects on materials strength properties when exposed to basaltic magmatic conditions for the duration of an igneous event, which will include the potential effects of subsequent seismically induced stresses on substantially intact waste packages. DOE will also evaluate the response of Zone 3 waste packages, or waste packages covered by backfill or rockfall, if exposed to magmatic gasses at conditions appropriate for an igneous event, considering the results of evaluation attendant to IA Agreement 2.18. If models take credit for engineered barriers providing delay in radionuclide release, DOE will evaluate barrier performance for the duration of the hypothetical igneous event. The results of this investigation would be documented in an update to the technical product *Waste Package Behavior in Magma* CAL–EBS–ME–000002, which would be available by the end of fiscal year 2003, or other appropriate technical document."

The AIN associated with Agreement 2.19 is related to the damage to waste packages from volcanic gases in drifts adjacent to an emplacement drift intersected by a basaltic dike. The AIN is as follows:

IA.2.19 AIN–1 "In any potential license application, DOE should provide analysis which considers a realistic range in rock permeabilities in evaluating gas flow and its affect on canister performance in Zone 2 or demonstrate that the accelerated degradation on canister performance in Zone 2 is not significant."

IA KTI Agreement 2.20 is defined in an NRC staff letter (Reamer, 2001), which summarizes the IA Technical Exchange and Management Meeting held September 5, 2001. The wording of the agreement is as follows:

IA.2.20. "DOE will evaluate how ascent and flow of basaltic magma through repository structures could result in processes that might incorporate HLW, considering the results of evaluations attendant to IA Agreements 2.18 and 2.19. As currently planned, the evaluation, if implemented, would include the potential for HLW incorporation along reasonable potential flow paths that could develop during an igneous event. The evaluation would also include the physical and chemical response of HLW and cladding after heating and potential disruption of waste package and contents, for waste packages remaining in drifts. The evaluation would examine effects that may result in increased solubility potential relative to undisturbed HLW forms. The results of this investigation would be documented in a new AMR to document the waste form response to magmatic conditions, which is expected to be available by the end of fiscal year 2003. DOE will describe the method of HLW incorporation used in DOE models, including consideration of particle aggregation and the effect on waste transport. If models take credit for engineered barriers providing delay in radionuclide release, DOE will evaluate barrier performance for the duration of the hypothetical igneous event. This will be documented in an update to the igneous consequences AMR, ANL–WIS–MD–000017, which is expected to be available in fiscal year 2003, or another appropriate technical document."

The AIN associated with Agreement 2.20 is related to transgranular fracturing of the waste form and the effect of such fracturing on radionuclide transport. The AIN is as follows:

IA.2.20 AIN–1. "DOE should provide information in any potential license application which either demonstrates that transgranular fracturing will not significantly increase the rate of waste dissolution, or demonstrates that the mechanical effects on the waste form from an intrusive event will not significantly increase transgranular fracturing."

## 3.0 SIGNIFICANCE OF ISSUES TO PERFORMANCE

Agreement IA.2.19 and AIN IA.2.19 AIN–1 request that DOE provide additional support for models of waste package response to conditions associated with basaltic intrusive events. In particular, IA.2.19 AIN–1 is focused on the potential effects on the corrosion rates of steel and other metal alloys from advection of magmatic gases from drifts potentially intersected by basaltic magma into adjacent, non-intersected drifts. Low rock permeabilities used in models for gas flow may underestimate the amount of gas advected into an adjacent, non-intersected drift (i.e., Zone 2 in Bechtel SAIC Company, LLC, 2004a).

This information is important because assumptions for the number and extent of damaged waste packages control the source term for radionuclide release calculations during igneous intrusive events. Multiple drifts could be intersected by a potential intrusive igneous event, and an even larger number of waste packages could be damaged in adjacent drifts from flow of magmatic gas from an igneous intrusion, because exposure to magmatic gases could significantly accelerate metal corrosion rates and increase radiological source-terms in Zone 2. Thus, a large increase in radionuclide source term might occur if many or all the waste packages in intersected drifts were extensively damaged during potential intrusive igneous events. Based on available risk insights (Travers, 2003; Mohanty, et al., 2004; NRC, 2004), staff determined that waste package response to conditions during intrusive igneous events has a medium significance to waste isolation.

Agreement IA.2.20 and AIN IA.2.20 AIN–1 request that DOE provide additional information about the response of the waste form to the physical conditions of a potential igneous event. This information is important because the thermal, mechanical, or chemical conditions of a potential igneous event could affect the characteristics of the wasteform and increase radionuclide release rates during subsequent hydrologic flow and transport. In particular, transgranular fracturing of fuel could increase spent nuclear fuel dissolution rates. Higher dissolution of fuel could lead to higher rates of aqueous radionuclide release from the engineered barrier system and thus potentially higher doses and groundwater radionuclide concentrations. Based on available risk insights (Travers, 2003; Mohanty, et al., 2004; NRC, 2004), staff determined that waste form response to conditions during intrusive igneous events has a medium significance to waste isolation.

## 4.0 EVALUATION AND COMMENT

Agreements IA.2.19 AIN–1 and IA.2.20 AIN–1 are relevant to understanding important aspects of IA Subissue 2, "Consequences of IA," and have been reviewed by staff in that context. Staff evaluated the information provided by DOE using review methods for the "Volcanic Disruption of Waste Packages and Mechanical Disruption of Engineered Barriers" sections in the Yucca Mountain Review Plan (NRC, 2003).

4.1 Agreement IA2.19 AIN–1

In response to this AIN, DOE stated that "...[u]ncertainties in permeability data from basalt analogs are irrelevant to gas flow calculations because nearly the entire volume of gas exsolves from the magma immediately following intersection of a drift." In addition, DOE indicated that the fracture permeability used in the gas flow models was $0.91 \times 10^{-12}$ $m^2$ and therefore contend that "…realistic and appropriate permeabilities for the host rock are used…." in its models.

The DOE response also discussed its dual-permeability approach for gas flow modeling. It used a drift instantaneously filled with gas as the source, and individual permeabilities and porosities for rock matrix and fractures were considered. Section 6.2.1.5, of the accompanying Drift-Scale THC Seepage Model, Revision 04 analysis model report (Bechtel SAIC Company, LLC, 2005), described the TOUGHREACT code, used to model the gas flow, which incorporates the dual-permeability modeling approach, and the accompanying analysis model report, "Dike/Drift Interactions," Revision 01 (Bechtel SAIC Company, LLC, 2004b) discussed the specific modifications made to the model to realistically analyze migration of magmatic gases from Zone 1 to Zone 2.

The DOE response appears to consider the potential effects of magmatic gas migration between potentially intersected drifts (Zone 1) and adjacent, non-intersected drifts (Zone 2) on the corrosion rates of steel and other metal alloys. The dual-permeability approach DOE used to model the advective–diffusive transport of magmatic gas, in conjunction with the values of matrix and fracture permeabilities and porosities used in this model, should constitute a reasonable approach for simulating the movement of corrosive gas between drifts in Zone 2. Furthermore, the value of $0.91 \times 10^{-12}$ $m^2$ specified by DOE for the fracture permeability of the repository host rock for the gas transport model is identical to the value specified in the "Calibrated Properties Model" analysis model report (Bechtel SAIC Company, LLC, 2004c) for the repository host rock.

In conclusion, DOE has adequately clarified the approach and inputs of corrosive magmatic gas flow modeling between drifts potentially intersected by basaltic magma and adjacent, nonintersected drifts. Staff therefore concludes that the DOE response to IA.2.19 AIN–1 is sufficient to close this agreement at this time.

4.2 Agreement IA.2.20 AIN–1

In response to the AIN, DOE stated "...for the Total System Performance Assessment, waste in damaged waste packages is simulated as degraded and considered immediately available for dissolution and transport because waste packages in drifts intersected by dikes are assumed to provide no protection for the waste (Enclosure 3, Section 5.1)."

The DOE response briefly discussed spent nuclear fuel surface area with respect only to nominal repository conditions and did not address potential transgranular fracturing and attendant surface area changes from an igneous event. In Section 6.4.8.3 of the "Drift/Dike Interactions" analysis model report (Bechtel SAIC Company, LLC, 2004b), which was attached to the DOE letter, the brief discussion of spent nuclear fuel surface area is limited to nominal repository conditions.

Although the DOE statement considers the spent nuclear fuel in damaged waste packages as degraded and immediately available for dissolution, it is not clear whether spent nuclear fuel continues to dissolve at a nominal rate, nor how the nominal rate was determined, after an intrusive igneous event (with no credit taken for the waste package and cladding), or spent nuclear fuel in affected waste packages is considered fully degraded to allow 100 percent release of radionuclides on contact with groundwater. If DOE assumes that spent nuclear fuel dissolves at a nominal rate, then transgranular fracturing resulting from an igneous event could increase the spent nuclear fuel effective surface area and should be included in the abstraction. If DOE has conservatively adopted complete degradation of spent nuclear fuel (i.e., 100 percent radionuclide available for release on contact with groundwater), any potential increase in effective surface area is bounded by this assumption. Thus, DOE needs to provide additional clarification on the assumed condition of the spent nuclear fuel waste form after an intrusive igneous event.

## 5.0 SUMMARY

Staff evaluated the DOE responses to two additional information requests for IA KTI Agreements IA.2.19 and IA.2.20. The DOE responses were provided its July 26, 2005, letter from Joseph D. Ziegler to Lawrence E. Kokajko (Ziegler, 2005). Staff concludes that the information DOE provided satisfies the AIN requested in IA.2.19 AIN–1. Additional information is needed, however, to satisfy the AIN for IA.2.20 AIN–1 with regard to increased dissolution of fuel due to possible transgranular fracturing of waste during a potential basaltic intrusive event.

## 6.0 STATUS OF THE AGREEMENT

Based on the preceding review, the information provided by DOE satisfies the intent of IA KTI Agreement IA.2.19 AIN–1. Therefore, NRC considers this agreement complete. KTI Agreement IA.2.20 AIN–1 is, however, considered incomplete, until DOE provided additional information.

## 7.0 REFERENCES

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