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Modeling Igneous Disruption in Yucca Mountain Total System Performance Assessment

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Introduction

Although the probability of volcanic activity at Yucca Mountain is small, consequences of igneous disruption of the potential repository have been included explicitly in the total system performance assessment for the Yucca Mountain Site Recommendation (TSPA-SR) with results showing releases during the 10,000-year regulatory period.[1] This paper summarizes igneous disruption modeling for the TSPA-SR, and presents results in terms of the probability-weighted annual dose to an average member of the critical group as specified by the United States Nuclear Regulatory Commission (NRC) in proposed 10 CFR 63.113(b).[2]

Probability analysis used the results of an expert elicitation, updated to apply to the current design. Consequence analysis included conceptual models of the magmatic environment in repository drifts with resulting waste package failure modes and releases based on a design without drift backfill. Modeling addressed both intrusive disruptions, in which waste packages are damaged by magma that enters drifts, and extrusive disruptions, in which waste is brought directly to the land surface by a volcanic eruption.

Probability of Igneous Disruption at Yucca Mountain

The probability of future igneous activity used in the TSPA-SR is based on the Probabilistic Volcanic Hazard Analysis conducted by the United States Department of Energy (DOE) in 1995 and 1996.[3] The result was a distribution for the annual probability of intersection of the repository by dike intrusion which, adjusted for the current repository footprint, yields a mean of 1.6×10^{-8} (ref. 4). The TSPA-SR Rev. 00 analyses use sampled values drawn from the full distribution of frequencies, which spans roughly 2 orders of magnitude. The probability of extrusive disruption was calculated assuming that an eruptive conduit that develops along a dike that intersects the repository may or may not form within the repository footprint and intersect waste. Assuming the current repository design and uniform distribution of conduits along dikes resulted in a multiplier of 0.36 times the intrusive probability to determine the extrusive probability.

Modeling the Consequences of Igneous Disruption at Yucca Mountain

Conceptual models of the magmatic environment in the repository drifts resulting from intrusive and extrusive igneous disruption led to consideration of three different levels of waste package damage[5] in the TSPA-SR; disruption sufficient that the packages provide no further protection to the waste, disruption sufficient to allow water to enter packages, and negligible damage to packages in drifts that are not intersected by the magmatic event. The nature of waste package damage combined with the release mechanism for intrusive and extrusive disruption determined the manner in which the release was modeled.[6] Extrusive release modeling used the ash plume dispersion code ASHPLUME (version 1.4LV).[7] Intrusive release was modeled using a groundwater pathway and the same flow and transport parameters used for undisturbed performance.

Eruptive event release modeling used distributions for dike and conduit properties combined with the repository layout to calculate the number of waste packages encountered by conduits. Waste packages in the path of the conduit were assumed to be sufficiently damaged that they provide no protection, resulting in all waste being transported to the surface (level 1 damage). Input and derived parameters used by ASHPLUME to characterize the eruption include eruptive power, duration, column height, and total volume of erupted material.

The distribution of contaminated ash from a volcanic eruption is a function of wind speed (0 to approximately 2,000 cm/s, median 650 cm/s) and direction (fixed blowing southward toward the critical group for all realizations) and the volume and particle size of ash and waste erupted. Values for future wind speed and direction are based on past observations in the region. Waste particle diameters (1 to 500 μm, mode 20 μm) were based on laboratory observations of particle sizes of unaltered spent nuclear fuel following mechanical grinding.[8] Ash particle diameters (0.01 to 1 mm) were based on observations from violent eruptions at modern analogue volcanoes.[9]

For the intrusive event it is expected that dike intersection with drifts will result in shock wave propagation accompanied by pyroclastic flow with groundwater percolating into damaged packages after the intrusion as the mechanism of waste release. Three waste packages on either size of the dike and one at the point of dike are assumed sufficiently damaged that all contents are immediately available for transport (level 1 damage). Waste packages in intersected drifts not immediately adjacent to the dike are damaged by high temperature and pressure, resulting in openings of varying size in the package lids (level 2 damage). Groundwater dissolution and transport of waste from this zone will occur following the same models as for sources from breaches from other causes. Because current design plans call for backfill in the main access drifts,[10] waste packages in drifts that are not intersected by the intrusion will experience far smaller effects, and are assumed to have negligible (level 3) damage.

Results and Interpretation

For dose calculation igneous disruption consequences are multiplied ("weighted") by the probability of occurrence to yield the annual probability-weighted risk following NRC guidance.[11] Dose was calculated for 10,000 years following repository closure per proposed regulations.[2] For additional confidence, TSPA-SR analysis was performed for igneous disruptions for 50,000 years after closure.

Total probability-weighted dose from igneous disruption is the sum of doses from the eruptive and intrusive groundwater pathways. For approximately the first 2,000 years, volcanic eruption dose dominates, with a peak mean of approximately 0.004 mrem/yr roughly 300 years after closure, dropping off due to decay of relatively shorter-lived radionuclides. After the 2,000-year period, groundwater release dose from packages damaged by igneous intrusion dominates. The mean dose rate from intrusion reaches its peak of approximately 0.08 mrem/yr, at 10,000 years. Beyond 10,000 years the dose rate increases slowly to approach 0.2 mrem/yr at 50,000 years and is dominated by the releases from intrusion.

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