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Criticality Potential of Waste Packages Containing DOE SNF Affected by Igneous Intrusion

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INTRODUCTION

The Department of Energy (DOE) is currently preparing an application to submit to the U.S. Nuclear Regulatory Commission for a construction authorization for a monitored geologic repository. The repository will contain spent nuclear fuel (SNF) and defense high-level waste (DHLW) in waste packages placed in underground tunnels, or drifts.

The primary objective of this paper is to perform a criticality analysis for waste packages containing DOE SNF affected by a disruptive igneous intrusion event in the emplacement drifts. The waste packages feature one DOE SNF canister placed in the center and surrounded by five High-Level Waste (HLW) glass canisters. The effective neutron multiplication factor (k_{eff}) is determined for potential configurations of the waste package during and after an intrusive igneous event.

Due to the complexity of the potential scenarios following an igneous intrusion, finding conservative and bounding configurations with respect to criticality requires some additional considerations. In particular, the geometry of a slumped and damaged waste package must be examined, drift conditions must be modeled over a range of parameters, and the chemical degradation of DOE SNF and waste package materials must be considered for the expected high temperatures. The secondary intent of this calculation is to present a method for selecting conservative and bounding configurations for a wide range of end conditions.

IGNEOUS INTRUSION SCENARIO DESCRIPTION

The igneous intrusion scenario features an igneous basaltic dike (magma filled crack) that intersects one or more repository drifts, followed by flow of magma into the drifts. It is possible that magma or pyroclastic debris could occupy the entire emplacement drift volume around a waste package. The intruding magma or pyroclastic flow is predicted to have a maximum temperature in excess of 1100 °C [1].

Possible subsequent events stemming from the initial igneous intrusion scenario are listed [2]. This list represents possible events for many different cases; not all of the events will occur in every case.

- Emplacement Drift Internals are Destroyed
- Waste Package Slumps and Breaches
- Magma Enters into the Waste Package
- Magma Cools
- Magma Fractures after Cooling
- Seepage Returns
- Waste Form Degrades
- Fissile Material is Transported from Waste Package

ANALYSIS

The analysis begins by developing the scenario described above. Starting with the initiating event (igneous intrusion in the emplacement drift), an event diagram is developed based on the possible responses of the waste package materials to igneous and subsurface conditions. All of the final end states are identified, and a subset of these end states is chosen for criticality analysis.

Material degradation is the most complicated part of the events to model. Due to the wide range of conditions that are possible during and subsequent to the igneous event, it is nearly impossible to accurately predict the final composition and geometry of a degraded waste package. Instead, a bounding configuration must be identified among all the possible variations – preferably without analyzing each and every case. A procedure is employed to help identify controlling parameters and reduce the number of cases that must be analyzed. In addition, guidance is provided on calculating uncertainty values that will bound cases not analyzed.

Criticality analyses are performed for the end states using MCNP [3]. To determine if a configuration is critical, the reactivity of the system (k_{eff}) and its associated uncertainty is calculated. The value of k_{eff} is then compared to the critical limit for that particular configuration, which is derived using benchmark experiments and statistical techniques.

Criticality evaluations are presented in this document for DOE owned representative spent nuclear fuel, which has been categorized into nine fuel groups [4]. A representative fuel type was chosen as a bounding case for each group. Table I shows the nine DOE fuel groups and their corresponding representative fuel.

TABLE I. DOE Fuel Groups and Representative Fuel Types.

DOE Fuel Groups	Representative Fuel Type
Uranium Metal	N-Reactor
Uranium-Zirconium/ Uranium-Molybdeum	Enrico Fermi
Uranium Oxide (High Enriched Uranium)	Shippingport Pressurized Water Reactor
Uranium Oxide (Low Enriched Uranium)	Three Mile Island (debris)
Uranium-Aluminum	Advanced Test Reactor
Uranium/Thorium/ Plutonium Carbide	Fort St. Vrain
Mixed Oxide	Fast Flux Test Facility
Uranium/Thorium Oxide	Shippingport Light Water Breeder Reactor
Uranium-Zirconium-Hydride	Training Research Isotopes General Atomics

RESULTS AND CONCLUSIONS

A method is detailed by which complicated chains of events can be analyzed while minimizing the number of criticality calculations that must be performed. The method provides a way to identify the major parameters that influence reactivity in a complex system, to identify the bounding condition(s), and to derive an uncertainty (or a "trend") for k_{eff} that bounds the cases not analyzed.

Applying this method to the problem of an igneous intrusion affecting emplaced waste packages containing DOE SNF yields the following results and conclusions:

- k_{eff} is highly sensitive to the presence and geometry of magma, glass, and the waste package barriers
- The temperature, porosity, and water content of the waste package surroundings have minimal impact on k_{eff}
- Fully-flooded cases are not always the most reactive configuration depending on neutron absorbers presence
- Potential degradation of uranium into schoepite (UO_3: $2H_2O$) is a major contributor to the increase in k_{eff}

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