HLWYM HEmails

From: Oleg Povetko
Sent: Friday, March 18, 2005 6:58 PM
To: Sitakanta Mohanty
Subject: Criticality memo
Attachments: Potential geologic repository criticality issues031705.wpd

Sitakanta,

See attached a memo on criticality issues. Let me know your comments.

Oleg.

Hearing Identifier: HLW_YuccaMountain_Hold_EX
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Subject: Criticality memo
Sent Date: 3/18/2005 6:57:57 PM
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From: Oleg Povetko

Created By: opovetko@cnwra.swri.edu

Recipients:
"Sitakanta Mohanty" <smohanty@cnwra.swri.edu>
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M E M O R A N D U M

March 18, 2005

TO: Sitakanta Mohanty

FROM: Oleg Povetko

SUBJECT: Potential Yucca Mountain HLW geologic repository criticality related issues

Regulatory Background

10 CFR Part 63.112 requires that the preclosure safety analysis of the GROA must include ...
(6) Means to prevent and control criticality...

For postclosure period
10 CFR Part 63.114 requires PA to ...
(d) Consider only events and processes that have at least one chance in 10,000 of occurring over 10,000 years.
(e) Provide the technical basis for either inclusion or exclusion of specific FEPs in the PA...

Definition and Underlying Physics

Criticality accident - the release of energy as a result of accidental production of a self-sustaining or divergent neutron chain reaction (ANSI/ANS standards).

TSPA-SR defines criticality as follows in its Glossary. (1) is not a definition but rather a not quite accurate description of main contributing factors to criticality event in repository.
Criticality - (1) A condition that would require the original waste form, which is part of the WP, to be exposed to degradation followed by conditions that would allow concentration of sufficient nuclear fuel, the presence of neutron moderators, the absence of neutron absorbers, and favorable geometry.
(2) The condition in which nuclear fuel sustains a chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle. The state is considered critical when a self-sustaining nuclear chain reaction is ongoing.

Criticality In Context of HLW Geologic Repository

The difference between criticality and igneous or seismic events is that probability of criticality depends not only on observed and well documented geosphere properties and past history, but on properties of the various types of SNF and other waste forms, on properties and performance of EBS (designed to prevent release of RAM, not to prevent criticality event) and performance of specific criticality controls that are not EBS. This dependency makes preclosure and postclosure criticality safety issues heavily integrated since the probability of postclosure criticality event depends on the performance of the design basis EBS and criticality controls.

SNF configuration and composition design is optimized to go and stay critical in presence of moderator and reflector (mainly water, graphite, heavy water or their combinations). After nuclear fuel has been utilized in reactor, it still contains significant amount of fissile material. For example, at one million years, 21-PWR WP (or whatever is left of WP by that time) loaded with average CSNF at time of emplacement, would have about 130 kg of U-235, only three times less mass of freshly

manufactured fuel. A significant number of emplaced WPs each will contain and maintain critical mass of fissile material over one million year time period.

Criticality Metrics And Its Behavior During Postclosure Period

The delicate balance required for criticality depends upon the composition, quantity, and shape of the material, and its environment.

Criticality measure - k-eff and its derivative, reactivity r= (k-eff-1)/k-eff. If k-eff<1, system is subcritical, if k-eff=1, system is critical, if k-eff >1, system is supercritical.
Examples of U/water critical systems:
-20 liters of water would make 5 wt% enriched UO2 critical under favorable geometry;
-Spherically shaped enriched U-235 heterogeneous oxide/water ball with 300-mm thick water reflector would have 2.5 and 160 kg U critical mass limit for 5% and 2% enrichments, respectively;
- Natural U (0.711 wt% of U-235) metal rods are critical in water if they are of appropriate diameter and spacing.

CSNF-WP system in emplacement configuration with burnup credit taken for actinides only would reach maximum reactivity at ~ 20K yrs after emplacement, then it slowly decreases. For example, for GBC-32 prototypic cask k-eff ~ 0.98 at time of emplacement, ~0.92 at 100 years, ~ 0.97 at 20 kyrs, ~0.96 at 50K yrs, ~0.95 at 100K yrs.

Assessment of DOE Approach.

Current proposed DOE design basis for WP: fully flooded WP is subcritical if no degradation of internals has occurred.
Major modifications of WP emplacement composition and configuration necessary to take place for criticality to occur after emplacement:
- failure of WP;
- significant neutron moderator presence (water, silica, graphite) within WP;
- reduction of neutron absorber efficacy by its partial degradation, removal or repositioning within WP.

Modification that might facilitate or trigger criticality event:
- partial collapse of basket;
- preferential removal of neutron absorbing isotopes out of WP;
- rock fall impact.

DOE consider three major categories of criticality events: in-package events, near-field events, and far-field events. The fuel can be in either intact or degraded condition for in-package events that occur within the waste package or near-field events that occur within the drift. Far-field events occur in the unsaturated zone or saturated zone below the repository and can only occur after the fuel degrades and releases fissile material. NRC considers acceptable the division of criticality events based on the location of the event (e.g., in-package, near-field, and far-field).

DOE considers two potential criticality events:
- steady state criticality (examples: Okla natural reactor, NPPs, research reactors);
- transient criticality (examples: > 60 criticality accidents around the world, most recent at Tokai Mura plant. Total number of fissions varied from 10^{15}-10^{21}, doses - up to several thousands rads to personnel).

Risk Insight Considerations

Risk insights pertaining to the performance of barriers preventing in-package criticality is the most significant consideration in evaluating the probability of criticality. Similar to the overall performance of the repository, a release or criticality event cannot occur without either the degradation of engineered barriers or the mechanical disruption of engineered barriers. Accordingly, risk insights involving the engineered barriers risk significant to waste isolation are likely to be risk significant with respect to in-package criticality. Since the low significance of nuclear criticality events to waste isolation is dependent in part to the expectation of limited failures of the waste packages and drip shields during the regulatory period, inconsistency of DOE's licensing basis with this expectation would likely result in an increased probability of nuclear criticality. Nuclear criticality events are also prevented by the co-location of neutron absorbers and fissile materials. While degradation of the waste form and cladding and release mechanisms risk insights have been developed, risk insights directly pertaining to waste package internals have not. Based on the available risk insights, important questions to be answered regarding the probability of in-package criticality events are

1. Does DOE's calculated probability of in-package criticality events consider processes that have the potential for the failure of significant numbers of waste packages and drip shields, including the loss of the waste package passive film, accumulated rockfall on engineered barriers, and the availability of aggressive chemistries.

2. Has DOE considered processes beyond the flooding of the waste package and failure of the neutron absorber that may increase the reactivity of the waste package, including fuel with pinhole leaks and cracks, non uniform presence of neutron absorbers, and potential homogeneous configurations.

3. Has DOE evaluated whether models considered conservative for waste isolation may be non-conservative with respect to criticality?

4. If DOE does not use an accepted methodology to calculate the probability of criticality events, does DOE systematically identify what configurations can occur, determine how likely they are, and then determine whether criticality events can result from the configurations?

5. Has DOE provided the justification for the calculated reduced reactivity of the fuel due to irradiation applicable to disposal?

Probability of potential criticality events

Four cases are considered by DOE. Current DOE analysis demonstrates that probability of criticality is below one in 10,000 (1.44x 10-8) over 10,000 for base (zero probability), seismic, rock fall (zero probability) and igneous cases. Naval fuel contribution - 1.4x10-8.
Major SAPHIRE nputs for base case:
- 10% of WPs fail;
- no dripshield failures;
- zero probability of water passing through the drip shield to a failed WP

Consequences of potential criticality events

DOE discontinued work on criticality consequences.

Limited exploratory study conducted by NRC for 10K year-period considered only incremental

increase of inventory as a result of criticality event. Conditional dose increment is several times as high as base case dose for steady state and more than three orders of magnitude higher than base case dose for transient event.

Criticality Related Issues of Concern

1. DOE is planning to request from NRC burnup credit allowance for fissile materials and fission products. It would allow DOE to place more fissile material within each WP than would be allowed otherwise. NRC has not granted burnup credit to any of its licensees up to now.

2. DOE planned to use Neutronit A-978 (it is an alloy of SS-316 with 1.6% of boron) in WPs as neutron absorber (SER, 2002). In 2004, LLNL reported on poorer than expected performance of the Neutronit in long term corrosion tests. Initial corrosion test results indicated 5 - 20 times higher corrosion rates than expected. Because of this poor performance in tests, DOE abandoned reliance on Neutronit and initiated development of a new neutron absorber material. DOE is planning to rely on a new neutron absorber (Ni-Gd alloy) that is currently under development. It has not been used in the past and is now going through testing. The material might or might not be sandwiched between C-22 plates.

Issue Resolution

DOE originally documented its criticality analysis methodology in a topical report in 1998. The NRC documented its review of the original TR in a Safety Evaluation Report in 2000 which identified 28 open items. DOE provided a revision 2 of TR in 2003. The NRC staff conducted an acceptance review of the revised TR (DOE 2003) along with the matrix addressing the open items (Ziegler 2004). The staff determined that there was not sufficient information in the TR alone to address the open items. NRC discontinued the topical report approach for criticality postclosure issues and has no plans to issue a revised SER. However, the revised TR (DOE 2003) in general has the type of information needed to allow a technical review and therefore a number of agreements are closed. NRC considers criticality related agreements CLST 5.04, ENFE 5.03, and RT 4.03 to remain open.