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EVALUATION OF A POTENTIAL NUCLEAR FUEL REPOSITORY CRITICALITY: LESSONS LEARNED

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ABSTRACT

This paper presents lessons learned from a Probabilistic Risk Assessment (PRA) of the potential for a criticality in a repository containing spent nuclear fuel with high enriched uranium. The insights gained consisted of remarkably detailed conclusions about design issues, failure mechanisms, frequencies and source terms for events up to 10,000 years in the future. Also discussed are the approaches taken by the analysts in presenting this very technical report to a nontechnical and possibly antagonistic audience.

INTRODUCTION

When the U.S.A. decided not to reprocess spent nuclear fuel (SNF), both low-enriched uranium (LEU) from nuclear power plants and high enriched uranium (HEU) from the DOE, the policy became one of disposing of SNF in a mined geological repository. Along with this policy change came the need to address the possibility of a nuclear criticality in the repository. The challenge

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presented to the Idaho Chemical Processing Plant safety analysts was to determine the frequency of postulated criticalities and the source term available for migration to the environment. The estimated frequency of criticality is $3x10^{-7}$/year, and the additional source term resulting from a criticality is small compared to the fission product inventory upon emplacement in the repository.

BACKGROUND

When the Performance Assessment (PA) was completed during 1993, one of the main comments was, since HEU was involved, the next PA (Rechard, et. al., 1995) should include the effects of a criticality. Preliminary results were reported (Evans, 1994). This paper looks at the lessons learned in that effort.

INSIGHTS GAINED

To determine the incremental source term resulting from a criticality, one must ascertain the most likely mechanisms for criticality and the power range. The following are examples of the types of questions we needed to address:

Would the approach to criticality be fast or slow? A slow approach would have lower power ratings, and greater involvement by physical shutdown mechanisms. As it turned out, a slow approach would also be more likely to be stable

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for a long period of time, having a greater total energy release and greater inventory of fresh fission products.

What would be the duration of criticality? Again, the duration of the criticality affected the total energy release and inventory of fission products. A moderated "slow cooker" -- at 1 kw consuming about a milligram of ^{235}U/day, regulated by natural temperature feedback mechanisms -- was determined to be a bounding event in terms of total energy release and source term, for the scenarios evaluated.

What proportion of the waste container would go critical? The mass of fissile material involved in the excursion had effect on the total energy release and fission product inventory. In 10,000 years, a maximum of 3.65 kg of ^{235}U (about 1%) could be consumed by the slow cooker.

How many of the waste containers in a repository would be involved in each event? The more waste containers involved, the greater the total energy release and fission product inventory. Also, more waste containers were involved only with lower probability events.

Should the waste container be stored horizontally on a slightly sloped floor or vertically in a cylindrical pit? The orientation of the waste container brought up such

issues as fuel or neutron absorber slumping causing a criticality, water retention within the pit, cross-sectional area of the waste container exposed to dripping water, and ability of a impermeable plug (sealing the waste container in the pit) to keep out water. The results were mixed, based up the strengths of the engineered barriers.

<u>What was the frequency of glacial (i.e., wetter) conditions?</u> Work had been done in the area of predicting the next ice age (wet period or "pluvial"), with a model that showed greater rainfall in temperate areas (e.g., at the repository) accompanying the ice sheet growth at the poles. Superimposed on the "pluvial" cycle are micro-pluvials (small wet-dry cycles). The micro-pluvials are 100 times more likely, but represent less moisture. Did we need to include them in the PRA? After further study, we determined that the micro-pluvials did not represent enough moisture to justify increasing the flooding frequency.

<u>How does the surface water infiltrate down to the repository level?</u> Previous modeling work had generated two models. One model assumed the earth above the repository was homogeneous, allowing uniform saturation and a tendency for the percolating water to travel around voids. The other model assumed the predominant seepage route was flow down fractures and dripping into the voids. The scientific consensus was that the truth lay somewhere in between these

two models; The first model approximated a 95% upper bound, and the second, a 5% lower bound. Only the 5% lower bound model threatened to convey enough water during glacial conditions to cause a criticality, due to water percolation conditions in the tail distribution.

How long will the waste container retain its integrity under conditions varying from dry to submerged in groundwater? Although the waste containers and internal structure (i.e., spacers) were made of stainless steel, in an anoxic (low oxygen) environment stainless steel behaves no better than carbon steel. Under the expected conditions, bulk corrosion would be very minor, but stress corrosion cracking very extensive. Models had to be constructed, taking these issues into account, in order to determine under what conditions a criticality would occur.

Will the boron poison dissolve or remain in place? The boron-poisoned stainless steel materials were available from only one company in the USA, and they had ceased corrosion testing. So, longterm behavior had to be derived from first principles (Gibb's Free Energy).

LESSONS LEARNED

One of the most difficult aspects of the job was to predict failure mechanisms for the next 10,000 years. In a nuclear

reactor PRA, the analyst only needs to predict the failure mechanisms for the next 40 years (e.g., "Will the maintenance man cause the failure of two redundant pumps?").

In a repository PRA, the analyst needs to predict failure mechanisms over the next 10,000 years (e.g., "Will a future matriarchal society honor restrictions on repository access set up by a deposed patriarchal society?", or "Is the world climate monotonic, cyclic or catastrophic?").

Political aspects had to be considered. On the one hand, PRA is a black box with extreme credibility. For example, in some review situations in the past, the mere mention that a PRA had been done settled many reviewer objections. Therefore, we had to be careful not to abuse this credibility, or stretch beyond our capabilities. Competent and thorough reviews were a must to guard against potential abuses.

On the other hand, when scientists disagree, the public believes the worst. Therefore, scientists must avoid disagreements in public. The criticality analyses for the low-enriched and high-enriched fuels were carried on by separate teams. We had to make sure our assumptions, mechanisms and results (where applicable) were consistent with theirs.

Sometimes, the public thinks visually or by emotions, not technically. Therefore, we had to be careful what images our

technical treatment could lead to. For example, the Media -- and the public -- may view a criticality very negatively, as a major catastrophe.

Therefore, we wanted to put a criticality into perspective, pointing out worst case energy yields and mechanical force equivalents, and comparing the resulting radioactivity with other existent radiation sources. We also wanted to point out that only a milligram of the fissile material in a waste container would be consumed in one day during the largest energy criticality.

Some reviewers encouraged us not to bring up this issue at all. The reasons for this are as follows:

1) If the issue is not brought up, it's automatically settled in our favor (Not to argue at all is better). As reputable analysts, we would be required to bring up any credible threats, but, since a criticality would have no significant mechanical effect upon the repository, we could dismiss the issue in good faith.

2) Although we feel we have a strong technical argument, the issue ultimately may not be settled upon its technical merit, but its emotional value.

3) In the public arena, a complex argument is a weak

argument. Several times in the evolution of the PRA we opted for more conservative arguments because they were simpler. We received some criticism from reviewers for this, but the resulting arguments would be easier to support in an intervenor environment.

4) Exaggerations of the consequences of a criticality may be brought up by the intervenor, at which time we could present the technical arguments against such exaggeration, held back as a contingency.

One final observation from this project is that scientists tend to "think out loud" too carelessly. In the nuclear reactor industry, we learned the lesson of how a worst case disaster treatise (WASH-740) could create negative images long after the initial assumptions were disproved. As scientists, we need to be careful what we say.

For instance, if the conclusions of your report require qualifications and stipulations, picture your bare conclusions in the morning paper. All stipulations will become invisible after the report is in the public domain. It's human nature. For example, give the following test to some of your colleagues:

1) STEP 1: Read all steps before writing anything on the paper.

2) STEP 2: Print your name and title on the top of the paper.

3) STEP 3: Answer the following questions....

A high proportion of your colleagues will begin writing on the sheet of paper before reading all the questions, contrary to the first stipulation. We all have this tendency. As Pogo said, "We have met the enemy, and the enemy is us."

CONCLUSIONS AND RECOMMENDATIONS

PRA has proven to be a powerful tool in predicting complex mechanisms that potentially could take place over the next 10,000 years. However, because the public is such an influential part of the audience, many nontechnical issues need consideration: maintaining credibility, avoiding inflammatory words or images, and not being more technical than the audience requires.

REFERENCES:

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