From: Getachew Tesfaye
To: DAFLUCAS Ronda M.
Date: 5/24/2007 7:39:37 AM
Subject: Draft RAI - Severe Accident Evaluation Topical Report

Ronda,
Attached please find draft RAIs for the Severe Accident Evaluation Topical Report (ANP-10268P). Our technical staff will be available on Wednesday May 30 (10:30 AM - 3:30PM) or Thursday May 31 (AM) to discuss the RAIs and to provide any needed clarification. Please let me now as soon as possible which day and time works for you and your staff.
Thanks,
Getachew Tesfaye
Project Manager
NRO/DNRL/NAR1

CC: Edward Fuller; Hossein Esmaili; SLOAN Sandra M

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DRAFT

REQUEST FOR ADDITIONAL INFORMATION (RAI)

ANP-10268P, "U.S. EPR SEVERE ACCIDENT EVALUATION

TOPICAL REPORT" (TAC NO. MD3573)

PROJECT NUMBER 733

RAI-1 Section 2.1.1.1, Figure 2-1:
The figure show an irradiation capsule basket at the periphery, evidently outside the heavy reflector. Please describe the design and contents of this reflector, being sure to mention the structural materials used and what its contents would be. Describe how the basket and its contents would participate in the severe accident progression and in source term evaluations. Were these modeled in the MAAP 4.0.7 analyses? If so, how did they impact core debris and radionuclide inventories? If not, please provide a qualitative discussion of their impacts.

RAI-2 Section 2.1.1.1:
What are the guide thimbles joined to the top and bottom nozzles of the fuel assemblies made of? How are they modeled in the accident progression? What are severe accident implications of including them?

RAI-3 Section 2.2.1:
Previous ALWR designs have safety-related RCS depressurization as part of the response to design basis accidents. The US EPR design considers RCS depressurization as a severe accident function. What kinds of controls will be placed on severe accident-related structures, systems, and components to assure a high reliability comparable to that for other ALWRs (i.e. safety-related functions)?

RAI-4 Section 2.2.1:
It has been stated in presentations to the NRC Staff that the severe accident depressurization valves would be manually opened when the peak cladding temperature would reach 2200°F. How long would it take to perform this action once the signal has been received? What are the existing procedures to assure that the action would be taken? What is the likelihood of successfully performing this action before the hot leg, surge line, or steam generator tubes would be threatened by creep rupture?

RAI-5 Section 2.2.1:
The last paragraph provides discussion on the positive contribution of Pressurizer Relief Tank (PRT) rupture disks in promoting mixing of steam, hydrogen and non-condensable gases in the RCP rooms. However, there is no discussion provided either in this section or under combustible gas control section, on the potential for hydrogen stratification due to jets and/or plumes forming in this area following PRT rupture disk actuation. In addition, please discuss the role of PRT in hydrogen distribution for scenarios where vessel is depressurized and the RPT is failed well before core damage and significant

hydrogen production.

RAI-6 Section 2.2.2.2:
It is stated that, in the event of an accident, communication would be established among equipment rooms to eliminate potential dead end compartments where non-condensable gases could accumulate. What is the likelihood of communication not being sufficiently established, and what would be the consequences of this?

RAI-7 Section 2.2.3:
It is stated that melt retention within the RPV was not a design goal for the U.S. EPR. Nevertheless, actions to arrest core melt progression during the late in-vessel –to-early ex-vessel phase could prevent the molten core material from fully exiting the RPV or the reactor cavity, and thus from reaching the spreading compartment. Discuss the strategy for managing accidents once they have progressed to the onset of core damage.

RAI-8 Section 2.2.3.1:
It is stated that the high iron oxide content of the reactor cavity concrete promotes oxidation of the remaining zirconium and uranium within the melt, before the zirconium bricks would be attacked. How high does the melt temperature increase from this oxidation, and why doesn't this temperature increase lead to a higher melt temperature for spreading?

RAI-9 Section 2.2.3.1:
Please describe how the formation of silicates would lower the radionuclide release from the corium pool. What are the chemical reactions and the resulting vapor pressures of radioactive species?

RAI-10 Section 2.2.3.4:
It is stated that the cooling elements would be flooded with water from the IRWST prior to initial contact between them and the core debris. Is this flooding done automatically? If not, what alerts the operator to initiate the action, and how much time would elapse from initiation of the signal to the flooding?

RAI-11 Section 2.2.3.4:
More information on the operation and location of the two spring loaded flooding valves would be required during design certification application. Is it possible that flooding valves fail prematurely thus arresting the melt spreading? Under what conditions (partial spreading, non-uniform spreading) is it possible for the flooding valves not to open? Also, is this flooding valve actuation passive, or can the operators manually open the valve and start flooding? What are the potential implications of any fuel-coolant-interactions, if delayed release of some core debris (i.e., due to the late melting and relocation of remaining fuel inside the damaged core after cavity plug melt-through) could pour into the already flooded initial melt pool in the spreading room?

RAI-12 Section 2.2.4:
Previous ALWR designs have safety-related containment heat removal systems as part of the response to design basis accidents. The US EPR design considers containment heat removal as a severe accident function. What kinds

of controls will be placed on severe accident-related containment heat removal systems to assure a high reliability comparable to that for other ALWRs (i.e. safety-related functions)?

RAI-13 Section 2.2.4.1:
It is stated that cooling the debris would release steam that would pressurize the containment, and that containment design pressure would not be reached for several hours following the onset of core damage. How long would it take before containment failure pressure would be reached? Is venting a possibility? If so, would the release be scrubbed?

RAI-14 Section 2.2.4.2:
What is the likelihood of core debris particles causing flow blockages in the heat exchanger and causing failure to deliver condensate water to the containment sprays?

RAI-15 Section 2.2.5:
Previous ALWR designs have safety-related instrumentation and controls as part of the response to design basis accidents. The US EPR design considers dedicated instrumentation and controls as a severe accident function. What kinds of controls will be placed on severe accident-related instrumentation and controls to assure a high reliability comparable to that for other ALWRs (i.e. safety-related functions)?

RAI-16 Section 4.1:
Page 4-2 of the topical report states that "containment bypass mode is addressed through preventive features". It is recognized that the placement of IRWST inside containment minimizes the traditional "event V" frequency. However, it is not clear how the issue of steam generator tube rupture (i.e., as accident initiators and/or induced by conditions of the accident) can be eliminated through preventive measures. Please elaborate.

RAI-17 Section 4.2.1:
The core support plate and core reflector represent more massive structures than in current LWRs. These structures may tend to remain in the RPV, potentially restricting the transport of molten core material to the reactor cavity after vessel breach, or they may become part of the core debris exiting the vessel. Discuss how these structures are treated in the analysis of core melt progression, and how the quantity of core debris mass exiting the RPV is assessed. How does this debris participate in potential direct containment heating (DCH) events (for high RPV pressure scenarios), core debris-concrete interactions, and hydrogen production both in-vessel and ex-vessel.

RAI-18 Section 4.2.1:
What model parameters are relevant in the MAAP treatment of the evolution of the two molten pools and multiple pours into the cavity? Please describe any sensitivity studies that include variations of these parameters. Of particular interest would be vessel failure timing, amount and time-dependent temperature of core debris entering the cavity, and any impacts on containment failure time.

RAI-19 Section 4.2.1:
The picture conjectured for the U.S. EPR core melt progression for the phenomenologically-bounding severe accident assumes that the in-core molten pool will have to extend to the heavy reflector and/or the heavy core support plate before it relocates downwards. Please elaborate why this is considered to be bounding. For example, why exclude a scenario that will involve the formation of metallic blockages in the lower region of the core (but well above the core support plate) initially supporting the in-core melt crucible, then followed by side failure of the crucible prior to reaching the heavy metal reflector? In addition, what is the justification for assuming the core support plate to remain intact if a substantial quantity of molten debris is residing above it? What is the time-to-failure for core support plate under substantial loading conditions (heavy mass at high temperature) of severe accidents?

RAI-20 Section 4.2.1:
Although high-pressure scenarios are much less likely than scenarios where the RPV is depressurized, DCH loads and ex-vessel fuel-coolant interactions should still be quantified for the U.S. EPR. Please discuss the magnitude and consequences of these loads for high-pressure scenarios.

RAI-21 Section 4.2.1:
What are the potential implications of Reactor Pressure Vessel (RPV) lower head failure at high pressure? What is the maximum displacement of the RPV for both "localized" and "hinged" failure modes? Please elaborate.

RAI-22 Section 5.0:
Please provide a list of relevant experiments that were performed to test the unique features of U. S. EPR (include major findings and scalability issues), and the use of test data to validate analytical tools and models.

RAI-23 Section 5.1.1.1.1:
How much hydrogen is produced from oxidation of the steel reflectors for the various accident scenarios considered?

RAI-24 Section 5.1.2:
There is a discussion on the impact of convective current aided by hydrogen recombiners on reaching a homogeneous condition inside the containment atmosphere. Please provide the results of typical calculations where gas mixing inside U.S. EPR containment is shown to eliminate stratification, with and without recombiners.

RAI-25 Section 5.1.2.1:
It is stated that "in the event that combustion should occur in an equipment room, the effects of detonation could be locally significant, but the containment would be shielded from the internal compartment event and only minimally affected." Please elaborate. It may be true that local detonation may not affect the containment directly, but what about loop piping and potential for indirect failure of the containment as a result of vibrations and piping shakedown?

RAI-26 Section 5.1.2.2:
It is stated that much of the hydrogen from MCCI is expected to auto-ignite.

Please elaborate. What are the conditions inside the cavity? What calculations have been performed to prove this?

RAI-27 Section 5.2.1.2:
It is stated that "global" and "local" types of failure differ significantly in their impact on subsequent accident progression. How exactly do these types of failure affect accident progression, specifically, their impact on core concrete interaction and melt spreading? It is stated further that "subsequent evaluations suggest that this additional margin was associated with water flowing between cracks within solidified debris and gaps that formed between solidified debris and the vessel." Please provide the experimental evidence to prove this hypothesis.

RAI-28 Section 5.2.2:
Please provide the details of chemical reactions that are expected inside the reactor cavity for corium and sacrificial concrete constituents, with the resulting products and their measured thermo-physical properties as applicable to U.S. EPR conditions.

RAI-29 Section 5.2.2.2.2:
Please provide the basis for the following assertions: (1) "This situation [melt stratification with metallic melt below oxide] will only occur shortly before gate failure at a time when all corium is already added to the MCCI pool.", and (2) "In the mixed mode the ablation rates are generally lower, so the protective layer will be reached by the melt much later and at about the same time as the melt reaches the gate."

RAI-30 Section 5.2.3:
What is the degree of penetration of the protective layer before the melt gate is contacted? What are the uncertainties?

RAI-31 Section 5.2.4.4:
It is stated that during MCCI, as a result of melt stratification (metal at bottom with light oxide on top), the water that pours onto the melt will contact the oxidic melt fraction and the sacrificial concrete layer mainly interacts primarily with the metallic melt. What are the consequences of a mixed layer, i.e., a heterogeneous mixture of metals and light oxides as a result of mixing and gas sparging? It appeared in the OECD-MCCI tests, that the water ingression was dependent on the material and that the addition of concrete to the melt reduced the water ingression. How do these experimental findings affect the top cooling of the "conditioned" melt (i.e., core debris mixed with sacrificial concrete in the cavity) in the spreading subcompartment?

RAI-32 Section 5.2.4.5:
What is the stability boundary of two-phase water flow through the melt stabilization channels for U.S. EPR under the expected range of heat flux and temperature conditions? Please elaborate on the BENSON test rig and the CHF (Critical Heat Flux) conditions in the cooling channels.

RAI-33 Section 5.2.5:
Melt retention in the cavity is necessary for successful ex-vessel cooling and melt spreading. Is it considered conceivable that the concrete above the melt plug

could crack or fragment in contact with core debris, thus cutting short the amount of ablation required to reach the melt plug and premature failure of the plug? What analysis has been done to prove that practically the entire core inventory will be collected in the cavity prior to spreading and stabilization? What is the effect of jet impingement on the substrate in the cavity pit under both metallic and oxidic melts?

RAI-34 Section 5.2.5:
It is possible that some core material could relocate from the reactor vessel at a time following failure of the reactor cavity melt plug. What implications would such late-failing debris have on discharge to and cooling or MCCI inside of the spreading chamber?

RAI-35 Section 5.4.1.2:
It is stated that "In traditional severe accident space, single failure is not a consideration in system design; however, the U.S. EPR severe accident systems can accommodate such a failure and still perform their function," Please elaborate if this is true for all severe accident mitigation systems in U. S. EPR.

RAI-36 Section 6.1:
Please provide more details on the flow of data among the MAAP4, MELTSPREAD, and WALTER codes that is sketched out in Figure 6-1 of the topical report. Specifically, what MAAP4 input parameters are impacted by the results of the MELTSPREAD and WALTER calculations?

RAI-37 Section 6.1.1:
Please provide subroutine descriptions for all new models added to MAAP to analyze the US EPR design. Describe the status of peer review for MAAP4.07 models as part of the present U. S. EPR submission process). Also discuss any MAAP4 model validation for the new core barrel, melt relocation, and the impact of the heavy reflector.

RAI-38 Section 6.1.1:
Has the second order Runge-Kutta integration method been used for this analysis? If so, what are the major differences between these results and those obtained using the first-order Euler method?

RAI-39 Section 6.1.1.7:
Is oxidation of the molten steel between the crust and the solid part of the core barrel calculated? If so, how much additional hydrogen is produced?

RAI-40 Section 6.1.2:
Please discuss the applicability of 1D MELTSPREAD code to the spreading compartment that is clearly 2D? Were other codes (e.g., THEMA) considered?

RAI-41 Section 6.2.1.12:
What criteria do users need to use to select the Kutateladze Number for the containment heat sinks? What are the ranges of uncertainty for any model parameters varied?

RAI-42 Section 6.3:
When will the validation work with MAAP 4.0.7 and MELCOR 1.8.6 be completed? Will the results be presented after design certification begins?

RAI-43 Section 6.3.1.1:
The comparison of MAAP with CC2 test (limestone/concrete sand basemat) is satisfactory, while the MAAP ablation predictions of CC3 test (siliceous basemat) showed discrepancies between factors of 2-3. The reason for the differences between the predictions for the two tests is not explained in the topical report. This could impact the MAAP predictions for EPR severe accident calculations. Please explain.

RAI-44 Section 6.3.1.1.3, Figure 6-14:
It is not clear which curve represents the MAAP 4.0.7 results. There are several red curves shown. Please provide a more clear delineation of the various curves.

RAI-45 Section 6.5.1, Table 6-9:
Regarding the RCS depressurization issue, what would happen if PDS fails to actuate? What is the probability of failure of the PDS to actuate?

RAI-46 Section 6.5.1, Table 6-9:
What is the reason for not including (in Table 6-9) induced SGTR (Steam Generator Tube Rupture) scenarios that may be relevant under the "RCS [Reactor Coolant System] Depressurization" issue?

RAI-47 Section 6.5.1:
It is recognized that simultaneous release of corium and water from the RPV is one of the bounding scenarios that will be considered (Table 6-9). How would the presence of any water inside the cavity and melt discharge channel (e.g., from injection sources to the failed RPV) affect the melt discharge from the cavity, and its subsequent relocation into the spreading compartment?

RAI-48 Section 6.5.2:
Please address uncertainties in determining the recombination rate in the recombiners.

RAI-49 Section 7.0:
From among the scenarios selected for a bounding analysis of accidents with MAAP4, why was no scenario chosen involving high reactor vessel pressure up until the moment of vessel breach? Would high pressure alter substantially any of the findings with respect to parameters such as time to vessel failure, quantity of hydrogen generated, etc.?

RAI-50 Section 7.0:
A SBLOCA scenario with EFW (Emergency Feed Water) was selected as the limiting case with respect to hydrogen production. Would the limiting case not be better represented by a scenario involving some recovery of injection capability after the start of core degradation, so as to maximize the amount of steam available?

RAI-51 Section 7.3.1:
Please provide more information on the LBLOCA scenario, namely:

a) The initiator for the LBLOCA scenario was taken to be a severance of the pressurizer surge line. Since the rationale for this scenario was as a bounding case with respect to melt stabilization and early containment pressurization, why was a larger break not analyzed?

b) Following lower plenum dryout at 2 hours (Figure 7-8), there is still about 20 tons of water in the RCS. Where is this water coming from?

c) Is the fraction of the core/reflector in the lower plenum at the time vessel breach (see also Figure 7-11 and 7-12) a conservative estimate for melt spreading and stabilization.

d) The MAAP analysis shows extremely efficient melt quenching evidenced by the corium temperature (Figure 7-25), and rapid containment pressurization (Figure 7-14) in about one hour. What is the modeling assumption in MAAP? Is the bottom cooling modeled?

e) In the period between about 10 and 20 hours, total containment pressure (Figure 7-14) is about 2.5 to 3.5 bar, and the average air mole fraction (Figure 7-16) is about 0.15 to 0.20, implying that the average partial pressure of air is only about 0.5 bar. Since no failure of containment was mentioned in the calculation results, where has the rest of the air gone (approximately 1.0 bar at the beginning of the scenario)?

f) How much time is required for the melt in the reactor cavity to reach the stabilized melt conditions that are desired prior to melt transfer? Does an adequate margin of time exist within which to guarantee these melt conditions?

RAI-52 Section 7.3.2, Figure 7-38:
What causes the reductions in hydrogen mole fractions? Burns? PAR operation? What causes the increase following vessel failure? Core debris/concrete interactions? Please provide a plot of CO mole fraction.

RAI-53 Appendix C:
Have any calculations been performed using the MELCOR 1.8.6 input deck described in Appendix C for U. S. EPR?