RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**467-8394**
SRP Section:	**19 - Probabilistic Risk Assessment and Severe Accident Evaluation**
Application Section:	
Date of RAI Issue:	**04/22/2016**

Question No. 19-102

10 CFR 52.47(a)(23) states that a DC application for light-water reactor designs must contain an FSAR that includes a description and analysis of design features for the prevention and mitigation of severe accidents, e.g., challenges to containment integrity caused by core-concrete interaction, steam explosion, high-pressure core melt ejection, hydrogen combustion, and containment bypass. Revise the DCD to address the following.

A. APR1400 DCD Rev. 0 Section 19.2.3.2.1 states that the in-vessel core melt progression contains considerable uncertainty relating to the following:

   a. Potential for in-vessel steam explosion

   b. Interaction between core debris and internal vessel structures

   c. Time and mode of vessel failure

   d. Composition of the core debris released at vessel failure

   e. Amount of in-vessel hydrogen generation

   f. In-vessel fission-product release and transport

   g. Retention of fission products and other core materials in the RCS

   The DCD needs to describe how uncertainties relating to the above items were addressed.

B. APR1400 DCD Rev. 0 Section 19.2.3.2.2 Ex-Vessel Melt Progression does not list or describe uncertainty relating to the ex-vessel core melt progression. List and explain how uncertainty relating to the ex-vessel core melt progression was addressed.

Response

DCD Section 19.2.3.2.1 and 19.2.3.2.2 will be revised as shown in the Attachment associated with this response.

Impact on DCD

DCD Chapter 19 will be revised to reflect the response of this RAI, as shown in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

g. Retention of fission products and other core materials in the RCS

Insert the text from Description A at this location.

19.2.3.2.2 Ex-Vessel Melt Progression

Upon vessel failure, the melt progression moves to the containment (ex-vessel). The following conditions affect ex-vessel severe accident progression:

a. Mode and timing of the reactor vessel failure

b. Primary system pressure at reactor vessel failure

c. Composition, amount, and character of the molten core debris expelled

d. Type of concrete used in containment construction

e. Availability of water to the reactor cavity

The initial response of the containment from ex-vessel severe accident progression depends on RCS pressure at reactor vessel failure and the existence of water within the reactor cavity. If not prevented by design features, early containment failure mechanisms and bypass usually dominate risk consequences. Early containment failure mechanisms result from energetic severe accident phenomena, such as high-pressure melt ejection (HPME) with DCH and ex-vessel steam explosions. The long-term containment pressure and temperature response from ex-vessel severe accident progression is largely a function of an interaction between molten core and concrete, known as MCCI, and the availability of mechanisms to remove heat from the containment.

At high RCS pressures, ejection of the molten core debris from the reactor vessel could occur in jet form, causing fragmentation of the debris into small particles. The potential exists for the ejected debris to be swept out of the reactor cavity and into the upper containment. Finely fragmented and dispersed core debris could rapidly heat the containment atmosphere and lead to a large pressure spike. In addition, exothermic chemical reactions of the core debris particulate with oxygen and steam could add to the pressurization. Hydrogen, preexisting in the containment or produced during DCH, could ignite, further adding to the containment pressure load. These phenomena are together referred to as HPME with DCH.

Reactor vessel failure with discharge of core debris into a wet reactor cavity (i.e. the cavity contains water) induces interactions between fuel and water (coolant) with the potential for rapid steam generation or steam explosions. Rapid steam generation involves non-explosive steam generation that pressurizes containment compartments beyond their ability to withstand or relieve the pressure; thus, the containment fails because of local overpressurization. Steam explosions involve the rapid mixing of finely fragmented core debris with surrounding water, resulting in rapid vaporization and acceleration of surrounding water, creating substantial pressure and impact loads.

The eventual contact of molten core debris with concrete in the reactor cavity leads to MCCI. This interaction decomposes the concrete and can challenge the containment by various mechanisms, including:

a. Pressurization from evolved steam and non-condensable gases, which can cause overpressure failure of containment

b. Transport of high-temperature gases and aerosols into the containment, leading to high-temperatures and possibly failure at the containment seals and penetrations

c. Containment basemat melt-through

d. Reactor support structure melt-through leading to the relocation of the reactor vessel and tearing of containment penetrations

e. Production of combustible gases such as hydrogen and carbon monoxide

Many factors affect MCCI, including the availability of water in the reactor cavity, the containment geometry, the composition and amount of core debris, the core debris superheat, and the type of concrete involved.

Insert the text from Description B at this location.

19.2.3.3 <u>Severe Accident Mitigation Features</u>

Various APR1400 design features are intended to mitigate the effects of particular severe accident phenomena, as described in the following subsections.

Description A

In-vessel steam explosion leading to an alpha-mode containment failure is determined to be improbable in Subsection 19.2.3.3.5.1.1. Uncertainties in the interaction between core debris and internal vessel structures, vessel failure mode and timing, hydrogen generation, and fission product release and transport are partly addressed by the conservative assumption in the key phenomena; however, a full uncertainty study was not performed. For example, the cladding oxidation surface area was doubled to account for exposure on both sides after cladding rupture. All core channel steam flows were assumed to be available above the location of blocked nodes for oxidation and heat transfer. Also, the hydrogen generation rate was artificially extended until the hydrogen equivalent of 100% active fuel-cladding oxidation was achieved. Furthermore, a spectrum of sequences including dominant PRA sequences and bounding deterministic sequences were analyzed in order to address uncertainties in the phenomena and modeling.

Description B

The ex-vessel core melt progression contains considerable uncertainty. This uncertainty relates to the following:

a. Ex-vessel steam explosion

b. Direct containment heating (DCH)

c. Molten corium jet break up, oxidation and heat transfer as it falls through the water in containment

d. Critical heat flux from corium debris to the overlying water in the containment

e. Molten corium/concrete interaction (MCCI)

For the ex-vessel steam explosion evaluation, uncertainties associated with the pressure load calculation were assessed (Subsection 19.2.3.3.5.1.2). For the DCH evaluation, the uncertainties in input parameters such as the mass of UO_2 in the lower plenum at vessel breach, the fraction of Zr oxidized and the containment failure pressure were considered by using the Latin Hyper-Cube (LHS) sampling technique. The sampled inputs and other conservatively estimated inputs such as the RCS pressure at vessel breach, the fraction of corium dispersed from the cavity and the fraction of dispersed corium entering the subcompartment were used to calculate the conditional containment failure probability.

To address the uncertainties related to other ex-vessel core melt progression phenomena, conservative analysis inputs were selected. One set of input parameter values was selected to conservatively increase ablation depth due to MCCI. A second set of values was selected for the same input parameters in order to increase hydrogen generation and containment pressurization. A spectrum of sequences, including dominant PRA sequences and bounding deterministic sequences, was analyzed with the two sets of parameters and conservative results were selected.