REVISED 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.:	**432-8377**
SRP Section:	**19 – Probabilistic Risk Assessment and Severe Accident Evaluation Section: 19**
Application Section:	**19**
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Question No. 19-63

10 CFR 52.47(a)(23) states that a design certification (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.

Provide the following regarding the discussion on in-vessel steam explosion as provided in APR1400-E-P-NR-14003-P, “Severe Accident Analysis Report,” Rev. 0, Appendix D, “Severe Accident Analysis Report for FCI” and revise the design control document (DCD) to incorporate them:

a. Figure 3-1 shows one-dimensional nodalization of TEXAS-V for the in-vessel steam explosion in the APR1400 RPV. Explain and justify using one-dimensional analysis.

b. Section 3.4.1 states that “The penetration velocity profile [in Figure 3-2(a)] shows the typical corium penetration behavior in TEXAS where the corium jet is injected with the initial velocity and rapidly decelerated where the initial jet break-up occurs and start accelerating again.” Explain the reasons for a second deceleration and subsequent acceleration of the jet.

c. Provide the initial void fraction assumed for the melt jet.

d. Explosion energy generated depends on melt fraction and void fraction before triggering an explosion, which are functions of time after the initiation of premixing. Provide the timing and justify the time at which triggering was assumed.

Response – (Rev. 4)

a. The TEXAS-V code is a transient, one-dimensional model capable of simulating fuel-coolant interactions. And to maximize the fuel mass participates in the explosion, the external trigger when the jet touches the bottom of the lower head. Thus the constant cross-sectional area nodes system for the lower head zone is employed in IVSE analysis rather than considering the hemi-spherical shape of the lower head. TEXAS-V, therefore, can provide more conservative estimation of IVSE loading at the given initial conditions by selecting optimal cross-section area based on energy index, as addressed in response to RAI 432-8377 Question 19-64 Rev.3. For IVSE analysis, various cross-sectional area of coolant (ARIY) is employed for TEXAS-V to find the optimal energy index and consequently, the peak pressure and impulse.

The ARIY of [ ]TS m^2 is selected based on the optimal energy index, which corresponds [ ]TS of energy index as below:

TS

where, M is mass and e is specific energy. Subscript m and c represents melt and coolant, respectively: ρ_m=[ ]TS kg/m^3 (density of melt), $A_m=\pi D_j^2/4=0.071$ m^2 (melt jet area), u_m = 3 m/s (melt release speed), t_{mix} = 0.72 sec (mixing time predicted from TEXAS-V), $c_{p,m}$ = [ ]TS J/kgK (specific heat of melt), T_m = 3000 K (initial melt temperature), T_w=[ ]TS K (water temperature), $h_{fg,m}$=[ ]TS J/kgK (heat of fusion of melt), ρ_c=[ ]TS kg/m^3, H_c= 2.4 m (water pool height), $c_{p,c}$ = [ ]TS J/kgK,T_{sat} = 424.98 K (saturation temperature of water at in-vessel pressure, 5 bar), $h_{fg,c}$=[ ]TS J/kgK. Using given properties, ε= [ ]TS %. The following figure shows the peak pressure and maximum impulse according to the ARIY and, in consequence, energy index. As seen in the figure ARIY is selected to create the conservative result.

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b. TEXAS-V models LaGrangian particle filed for the melt as discrete material volumes or ‘master particles’ within Eulerian control volume for coolant vapor and liquid. The

LaGrangian treatment for the fuel makes it quite straightforward to track the fuel particle movement and thus eliminates the numerical diffusion difficulties encountered in pure Eulerian codes.

For a given initial velocity and radius of melt jet, how much of the fuel first enters the water pool as discrete fuel masses can be specified. In TEXAS-V code only discrete fuel masses and the leading edge may undergo hydrodynamic fragmentation. In addition, the TEXAS-V models the fuel jet as a collection of master particles and the jet breakup is attributed to Rayleigh-Taylor instabilities at the jet leading edge. As an approximation of the actual coherent jet, this jet is taken to be composed of a series of discrete ‘blobs’ or master particles that enter the coolant sequentially with the jet leading edge found by the relative position of the first unfragmented master particle ‘blob’ compared to the position of the master particles preceding it.

Therefore, for the velocity profile given in Figure 3-2(a), the deceleration zone represents the influence of the fragmentation of the first leading master particle. After the completion of the first master particle fragmentation, the preceding (or the second) master particle then has a leading position and will have the hydrodynamic fragmentation which leads to the second deceleration.

c. For melt jet, the initial void fraction is set to be zero.

Regarding the multi jet calculation conditions, APR1400-E-P-NR-14003-P/NP Rev.0 Appendix D Table 3-2 and section 3.2.1 will be revised as shown in Attachment.

d. The steam explosion energetics depends largely upon the corium mass participated in the interaction. Therefore, it is assumed that the artificial trigger is provided by the corium jet contact at the bottom of RPV. The less conservative results will be obtained if the corium jet is triggered before or after the bottom contact of corium leading edge to the RPV wall.

Impact on DCD

There is no impact on the DCD.

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

Technical Report APR1400-E-P-NR-14003-P “Severe Accident Analysis Report.” Rev.0 Appendix D “Severe Accident Analysis Report for FCI” Table 3-2 and Section 3.2.1 is revised as shown in Attachment.

3. IN-VESSEL STEAM EXPLOSION ANALYSIS RESULTS FOR APR1400

3.1. Introduction

In this chapter, the APR1400 design specific analysis for the evaluation of in-vessel steam explosion risk will be discussed. The analysis consists of determination of initial and boundary conditions for the in-vessel steam explosions, the structure analysis for the APR1400 RPV against the explosion loading, sensitivity analysis for key parameters that vary with the consideration of severe accident scenarios, measures and progression. Finally, the analysis results will be discussed to evaluate the IVSE risk in the APR1400 design.

3.2. Initial and Boundary Conditions

In the IVSE analysis, the complex internal structure of RPV is not considered and assumed to be divided by two regions; the molten corium region in the core region and the residual water filled in the lower plenum. This assumption is considered conservative since the complex internal structure disrupts a corium flow path and provides steam explosion triggering source, causing pre-mature steam explosion. In addition, it is assumed that corium jet is introduced at the center of the RPV and steam explosion is triggered by the bottom contact of the corium jet. This assumption also provides additional conservatism on the analysis of IVSE. The summary of the initial and boundary conditions for the TEXAS-V analysis is shown in Table 3-2. The following sub-sections describe the rationales for the selection of the quantities of the key parameters.

3.2.1. Corium Characteristics

Corium composition and thermal properties: The reference corium composition 90%UO_2-10%ZrO_2 with its thermal and transport properties as shown in Table 3-1 is chosen. Table 3-1 indicates also the properties of corium composition of 80%UO_2-20%ZrO_2 that often used in experiments that most of thermo-physical properties are similar and no significant effects of those difference on the steam explosion energetics.

Corium temperature: The base case corium temperature of 3000 K is selected. This corium temperature corresponds to the superheat of 150 K. The corium temperatures at the vessel failure are estimated by considering the results of the MAAP analysis [Reference 32], the SCDAP/RELAP 5 analysis [Reference 31] and compared with other reactor case analyses such as SERENA-I reactor application [Reference 5], AP1000 analysis [Reference 19], Japanese LWR application [Reference 15, 21].

For the oxidic layer of the corium, most of reactor case analyses used the corium temperature considering the melt superheat of 150 K. Since the oxidic layer corium temperature of 3150 K was used in AP1000 as a conservatively bounding case, sensitivity analyses for the corium temperature up to 3150 K is performed.

Corium jet diameter: The base case corium jet diameter of 0.3 m was chosen. In the in-vessel conditions, it is not feasible to consider the large diameter expected in the ex-vessel case where the RPV failure may create a major release of melt that accounts a large corium jet diameter such as 0.5m or more. In addition, it has a possibility to have multiple jets relocated from the core locations to the lower plenum. In this situation, each jet could be much thinner than one for the single jet case. ~~For the multi-jet case, a total of 24 jets with a diameter of 0.05 m was considered for testing the effect of multi-jet on the IVSE energetics.~~

Corium jet velocity: The corium jet velocity of 3 m/s is selected for the base case analysis. For the in-vessel scenario, it is not expected that corium jet is accelerated by any additional forces but by gravity.

For the multi-jet cases, a total of 36 with a diameter of 0.05 m, 9 jets with a diameter 0.1 m, and 24 jets with a diameter 0.08 m were considered for testing the effect of multi-jet on the IVSE energetics.

Table 3-2

Initial and Boundary Conditions for the IVSE analysis with TEXAS-V

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