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.:	**322-8393**
SRP Section:	**06.02.01.03 – Mass and Energy Release Analysis for Postulated Loss-of-Coolant Accidents (LOCAs)**
Application Section:	**6.2.1.3**
Date of RAI Issue:	**11/30/2015**

Question No. 06.02.01.03-2

Modeling Fluidic Device and Direct Vessel Injection for the Limiting LOCA

General Design Criterion (GDC) 50, "Containment design basis," and Appendix K to 10 CFR Part 50, "ECCS Evaluation Models" require, in part, that the selected combination of power distribution shape and peaking factor should be the one that results in the most severe calculated consequences for the spectrum of postulated breaks and single failures that are analyzed. NUREG-0800, SRP Section 6.2.1.3, "Mass and Energy Release Analysis for Postulated Loss-of-Coolant Accidents (LOCAs)" suggests that containment design basis calculations should be performed for a spectrum of possible pipe break sizes and locations to assure that the worst case has been identified. APR-1400 methodology identifies a double-ended discharge leg slot break (DEDLSB) with maximum safety injection (SI) flow to be the most limiting LOCA, as documented in Table 3-1, "Containment P/T with 1 Percent Metal-Water Reaction", in the Technical Report (TeR) APR1400-Z-A-NR-14007-P, Rev.0, "LOCA Mass and Energy Release Methodology".

It can be postulated that a higher safety injection rate and flow enthalpy would result in a higher mass and energy release and subsequently higher peak containment pressure and temperature. In this regard, the staff seeks the following information to address safety concerns about the CEFLASH-4A treatment of the fluidic device (FD) flow as a reactor coolant system (RCS) boundary condition for the limiting LOCA analysis for the containment. The applicant is also requested to update the APR1400 DCD and the TeR to document the respective explanations.

Table 3-1 in the TeR shows that, for the limiting cold leg LOCA, it takes 324.1 seconds from the start of the accident until the containment peak pressure is reached. TeR Table 4-2 shows that it takes 49.35 seconds for the safety injection tank (SIT) flow to be turned down to the low-flow rate by the FD. This leaves 324.1– 49.35 = 274.75 seconds for the remaining SIT flow to contribute to the containment peak pressure. However, it is argued in TeR Section 3.11.1 that the effect of the FD flow rate on steam condensation in the downcomer of the intact loop is conservatively ignored considering the FD flow rate to be small. Clarification is sought regarding the treatment of the SIT water below the top of the stand pipe. The following two questions inquire about whether or not the SIT water inventory is credited in the analysis to enter the RCS after the SIT water level drops below the top of the FD stand pipe.

(a) If no SIT water inventory is credited in the analysis, the extent of conservatism by ignoring steam condensation is reduced, as the SIT water below the top of stand pipe does not enter the core to pick up heat and transfer to containment for pressurization. In that case, please justify using a less than 100% SIT flow as the limiting cold leg break LOCA uses maximum safety injection.

(b) On the contrary, if the entire SIT water inventory is credited in the analysis, please justify the capability of the CEFLASH-4A code for modeling the FD to account for its contribution to containment peak pressure.

Response

(a) The SIT flow is not turned down to low flow during the blowdown phase, as shown in Table 1 below, but is turned down to low flow during the post-blowdown phase. After the FD is turned down, the SIT water inventory below the top of the fluidic device (FD) stand pipe does enter the RCS in the LOCA analysis, as shown in Table 4-2 (pages 18 through 20 of 21) and Figure 4-2 in the TeR.

As described in Section 3.9 of the TeR, the limiting cold leg break LOCA case assumes maximum safety injection pump flow during the post-blowdown phase. The assumed flow is not dependent upon the SIT water inventory below the top of the FD stand pipe.

(b) The SIT water inventory below the top of the FD stand pipe is credited to enter the RCS after the FD turndown in the analysis even though the SIT-FD low flow is not credited to condense steam flows in the downcomer. This is a conservative assumption since the steam flow in the RCS is not decreased by the SIT-FD low flow and the M/E release rate is maximized. DCD Tier 2, Section 6.2.1.3.4 and TeR APR1400-Z-A-NR-14007, “LOCA Mass and Energy Release Methodology,” Sections 3.6 and 3.11.1 will be revised to clarify SIT-FD low flow enters the RCS, as indicated in the attachments associated with this response.

The CEFLASH-4A code is capable of modeling the FD simply by adding the K-factor value of the FD to that of the SI line. Since the FD turndown does not occur during the blowdown phase, the SIT-FD high flow is maintained throughout the blowdown phase. Therefore, the SIT-FD high flow is calculated using the input of the K-factor of the FD and the SI line in the CEFLASH-4A code.

Table 1. SIT Water Volume at EOB vs. FD Turndown for LOCA Cases

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Impact on DCD

DCD Tier 2, Section 6.2.1.3.4 will be revised, as indicated in Attachment 1 to this response.

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-Z-A-NR-14007, “LOCA Mass and Energy Release Methodology,” Section 3.6 will be revised, as indicated in Attachment 2 to this response and Section 3.11.1 will be revised, as indicated in Attachment 3 to this response..

e. The thermal resistance corresponding to the steam generator tubes is 0.000077 $(kcal/m^2\text{-}hr\text{-}°C)^{-1}$ $(0.000376\ (Btu/hr\text{-}ft^2\text{-}°F)^{-1})$. This value is also used in calculating secondary-to-primary heat transfer.

f. The carryout rate fraction (CRF) used during the reflood is based on the guideline in NUREG-0800, Section 6.2.1.3 (Reference 14).

g. Reflood is assumed to terminate when the 3.2 m (10.5 ft) quench level in the core is reached.

h. As conservatism for the available energy sources, 120 percent of the standard decay heat curve in Figure 6.2.1-32 is used up to 1,000 seconds, and 110 percent is used after 1,000 seconds.

i. For the suction leg and discharge leg cases, credit is taken for the condensation of approximately 42 percent of the total steam flow when the annulus is full and the high safety injection tank (SIT) flow is injected. No credit is taken for the condensation after the SITs empty or the turndown to low SIT flow by the fluidic device.

, even though the low SIT flow enters the RCS

6.2.1.3.5 Description of Post Reflood Model

The post-reflood model is identical to the reflood model except that at the end of the reflood, the CRF is changed from 0.8 to 1.0. The change conservatively increases the system flow rates due to the increased CRF. The flow rates are further enhanced by the fact that the core liquid height is now constrained at the 3.2 m (10.5 ft) level, which maximizes the available driving head between the annulus level and the core in the flooding equation. All of the heat transfer coefficients are kept at the values used for the reflood analysis. Condensation is analyzed as previously described; however, there is insufficient spillage for complete thermodynamic condensation of the steam so that credit for condensation is not taken.

active core. Other variables, such as core inlet temperature, pressure, flow rate, linear heat rate, or other experimental data are not used to determine the CRF.

g. Reflood is assumed to terminate when the 3.2 m (10.5 ft) quench level in the core is reached.

h. [ ]TS of the standard decay heat (Figure 4-1) curve is used as a conservatism for the available energy sources.

i. During reflood, credit is taken for the condensation of steam in the annulus by the cold ~~SIS~~ SIT water. As a conservatism, credit is not taken unless the reactor vessel annulus is full since the SI flow is injected directly into the annulus. Also, as an additional conservatism, credit is not taken when the SI flow rate is too low to thermodynamically condense all of the steam in the annulus. Thus, credit is not taken for the condensation after the SITs empty or the turndown to low SIT flow by the fluidic device, even though the low SIT flow enters the RCS. The percentage of the total steam flow condensed varies slightly with time for each case. For suction leg and discharge leg cases, credit is taken for the condensation of approximately [ ]TS of the total steam flow when the annulus is full and the thermodynamic criteria are simultaneously met.

3.7 Description of Post-Reflood Model

The post-reflood model is identical to the reflood model except that, at the end of reflood, the CRF is changed from [ ]TS to [ ]TS. This conservatively increases the system flow rates due to the increased CRF. The flow rates are further enhanced by the fact that the core liquid height is now constrained at the [ ]TS level, which maximizes the available driving head between the annulus level and the core in the flooding equation. All heat transfer coefficients are kept at the values used for the reflood analysis. Condensation is analyzed as previously described; however, there is insufficient spillage for complete thermodynamic condensation of the steam so that credit for condensation is not taken.

3.8 Description of Decay Heat Phase Model

The final phase of the large break LOCA is a relatively stable period characterized by decay heat release and it extends from the end of the post-reflood phase. The analysis method used to determine the mass and energy released during this period is described in Appendix A.2.4, "Decay Heat Phase M/E Analysis Model."

3.9 Single Active Failure Analysis

Two possible failures are considered as single failure in LOCA mass and energy analysis, the failure of one SI pump and the failure of one emergency diesel generator (EDG). Both failures would degrade SI flow and eventually degrade emergency core cooling system (ECCS) performance to cool down the core. In LOCA mass and energy analysis, the single failure is assumed for minimum SI flow and no failure is assumed for maximum SI flow.

Another failure in the containment system is considered as a single failure, the failure of one train of containment spray. The failure reduces the capability to suppress containment pressure, which results in higher containment pressure during the LOCA transient. In the case with maximum SI, the failure of one train of containment spray system (CSS) is assumed. In the case with minimum SI, the failure of one train of containment spray system is assumed also, due to the failure of one emergency diesel generator.

The limiting case is determined by the case analyses with the maximum and minimum safety injection flow. This case analysis with the maximum and minimum safety injection flow is performed at the three break locations.

Low flow : Due to the sustained SIT injection, the SIT water level decreases below the entrance of the stand pipe. The inventory supply into the main port is lost. The inventory is supplied only into the four control ports, thus, the SIT fluidic device produces low-flow, which is about one third of the high-flow. This delays the SIT empty time and minimizes the spillage of the injected flow. The condensing fraction is assumed to be [ ]TS during the period of low-flow injection.

The fluidic device is considered in this analysis. The function of flow control is implemented in the computer code, FLOOD3 as in the flow diagram, Figure 3-4.

Although the fluidic device will improve the LOCA thermal margin for fuel performance, it may have an adverse impact on the mass and energy release during a LOCA. In a conventional LOCA M/E analysis where the fluidic device is not considered, the SIT injection flow is high enough to condense the steam flows in the intact side from the time that the reactor downcomer is full until the SIT is empty. In the APR1400, the SIT-FD low-flow is so small that the flow is not credited to condense the steam flows in reactor vessel annulus. Thus the steam mass and energy release through the break is increased by the amount of the non-condensed steam. The increased mass and energy release can have a considerable impact on the peak pressure and temperature of the containment.

3.11.2 Effect of IRWST Water Temperature on Mass and Energy Release

The released mass through the break during a LOCA is accumulated on the floor inside containment in a hot liquid condition. This liquid flows into the IRWST via the holdup tank and is mixed with the IRWST water inventory, which is the source water for safety injection pumps. Mixing with the hot liquid results in a temperature increase in the IRWST inventory and this yields a temperature increase in the SI water into the RCS. Therefore, the energy of the break flow may be higher due to the deteriorating circulation of the released mass.

In the LOCA M/E analysis, the effect of the IRWST water temperature was considered. The containment analysis based on the initial M/E data can provide the data of the sump water temperature. Taking the data of the sump water temperature as the input of SI water temperature during the reflood stage, reanalysis of LOCA M/E is performed for more conservative M/E data.

3.12 Description of Containment Pressure and Temperature Analysis

The methodology for the containment response analyses to LOCA and MSLB accidents is addressed in detail in Appendix A.

, even though the SIT-FD low flow enters the RCS

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Question No. 06.02.01.03-3

Figure 2-2 in the TeR shows the unique APR1400 feature of direct vessel injection (DVI), delivering safety injection flow to the downcomer during a LOCA. According to Figure 2-2 of the TeR and Figure 5.3-8 of the DCD, the DVI nozzle elevation is well above the cold leg. In this backdrop, the applicant is requested to address the following questions.

(a) The traditional PWR cold leg injection credits the emergency coolant injection only into three out of the four cold legs for core cooling, with the broken leg coolant added to the containment as spillage flow. The spillage flow rates for APR1400 design are given in Table 4-2 of the TeR. Please state the fraction of the coolant flow that spills out of the break into the containment. In other words, how does the spillage flow as a percentage of total safety injection compare with the 25% for the traditional PWR cold leg injection?

(b) The safety injection into the RCS by the SITs and the safety injection pumps (SIPs) during the blowdown, refill, and the reflood phases of a LOCA are modeled by using the CEFLASH-4A and FLOOD-3 codes. Have these modeling codes been validated and approved to model DVI type injection?

Response

(a) The spillage data for the APR1400 LOCA are given in the Table 4-2 (page 7 of 21) of TeR APR1400-Z-A-NR-14007, “LOCA Mass and Energy Release Methodology.” The spillage data includes:

- the condensed steam portions,
- the primary liquid inventory which has not passed through the core and steam generators (SGs) but through the reactor vessel (RV) annulus, and
- the primary liquid inventory which has passed through the core and SGs that has not

evaporated into steam.

The direct spillage of one out of four safety injection (SI) lines for the traditional PWR cold leg injection is not included in the spillage data since all the safety injection tank (SIT) water of the APR1400 is injected directly into the reactor vessel through the direct vessel injection (DVI) nozzles.

The integrated SI flows in Table 1 below are calculated based on the SI flow data in Table 4-2 (pages 17 through 20 of 21) of the TeR.

The fractions of spillage flows as a percentage of total safety injection are presented in the right column of Table 1.

Table 1. The Fraction of the Spillage Flow

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(b) The DVI type injection in the LOCA blowdown analysis is modeled in the user input of the CEFLASH-4A code by arranging the nodes and paths as presented in Figure 3-1 of the TeR. The effect of the DVI type injection during the LOCA blowdown phase is similar to that of the cold leg injection (CLI) type with the except that there is no loss of one train of SI for DVI type injection. Regardless of the safety injection type, most of the injected SIT water during the blowdown period bypasses the core support barrel and is released to the containment through the break. Both of the blowdown transients, DVI and CLI, are analyzed using the CEFLASH-4A code without any code model change.

In the FLOOD3 code, the safety injection flow is modeled as a direct input to the reactor vessel annulus. This model is the same as that of the FLOODMOD2 which is the NRC approved version. For this reason, no additional code validation and approval to model DVI type injection is necessary.

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

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