SUPPLEMENTAL 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.:	**290-8336**
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:	**11/03/2015**

Question No. 06.02.01.03-1

Break Spectrum Analysis for Hot Leg Break LOCA

General Design Criterion 50, “Containment design basis” and Appendix K to 10 CFR Part 50, “ECCS Evaluation Models” require 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. 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, identifies the double-ended discharge leg slot break (DEDLSB) with maximum safety injection (SI) flow to be the most severe LOCA. The staff is concerned that the APR1400 methodology does not satisfy the required break spectrum analysis (small, medium, and large breaks) to identify the most limiting LOCA. This requirement appears to have been interpreted only in terms of hot leg and cold leg breaks as opposed to the break flow areas ranging from small slot to double-ended (DE) guillotine break. In this regard, the applicant is requested to address the following two questions and update the APR1400 DCD and TeR accordingly.

(1) This analysis follows the traditional assumption of a hot leg piping slot break of the same flow area as that of a double-ended guillotine piping rupture. However, the TeR does not report any double-ended (DE) guillotine break analysis results. The applicant is requested to demonstrate that a limiting double-ended (DE) guillotine break would result in less severe thermal-hydraulic conditions in the containment than in the limiting DEDLSB with maximum SI flow, or justify why such an analysis is not warranted.

(2) Table 3-1 in the TeR shows that the double-ended hot leg slot break (DEHLSB) results in

the lowest peak pressure compared to all four cold leg breaks. It is not documented in the DCD or the TeR whether the DEHLSB was assumed to be the limiting break size for a hot leg LOCA or it was obtained from a break spectrum analysis. The applicant is requested to demonstrate that the mass and energy release and subsequent containment thermal-hydraulic response analyses for DEHLSB are most conservative across the possible hot break spectrum, including smaller slot break sizes.

Response

(1) The hot leg guillotine break case is newly analyzed with the assumption of the double-ended break area. The blowdown mass and energy (M/E) release data of the guillotine break case is calculated and compared with those of the hot leg slot break case of APR1400 DCD Section 6.2.1.3. The comparison is presented in Figure 1 and Table 1 and shows that the hot leg guillotine break case has slightly more severe results than the hot leg slot break case. Even though the DEHLGB case is more severe than the DEHLSB case, the peak pressure of the DEHLGB is less than that of the limiting LOCA case (DEDLSB) in the APR1400 DCD Table 6.2.1-19.

In order to justify the limiting LOCA case, the blowdown M/E data of the double-ended discharge leg guillotine break (DEDLGB) case is newly calculated and compared with the DEDLSB case of APR1400 DCD Section 6.2.1.3 in Figure 2 and Table 2. This comparison of M/E data shows that the DEDLSB case of APR1400 DCD Section 6.2.1.3 is clearly more severe than the DEDLGB case even though the containment peak pressures are not compared. Thus, the DEDLSB case in APR1400 DCD is still valid as the limiting LOCA case.

Table 1. Comparison of M/E results of DEHLSB and DEHLGB

TS

Table 2. Comparison of M/E results of DEDLSB and DEDLGB

TS

TS

Figure 1. Comparison of M/E results of DEHLSB and DEHLGB

TS

Figure 2. Comparison of M/E results of DEHLSB and DEHLGB

(2) For the break area spectrum analysis of the double-ended hot leg slot break (DEHLSB), two cases with 0.8 DEHLSB area and 0.6 DEHLSB area are analyzed. The calculated mass and energy releases are compared with those of the DEHLSB case in the APR1400 DCD and presented in Figure 3. The subsequent containment thermal-hydraulic responses are presented in Table 3. The comparison of the results shows that the double-ended hot leg break case as in the APR1400 DCD is most conservative in the break spectrum analysis.

Table 3. Containment Peak P/T Results of Hot Leg Slot Break Area Spectrum Analysis

TS

TS

Figure 3 Comparison of M/E Results of Hot Leg Slot Break Area Spectrum Analysis

Supplemental Questions

Public Teleconference (July 7, 2016)

The RAI essentially asked for a demonstration that the M&E release and subsequent containment thermal-hydraulic response analyses for DEHLSB are most conservative across the possible hot break spectrum including smaller slot break sizes. In order to meet the break spectrum analysis requirement to identify the most limiting LOCA, APR1400 methodology needs to demonstrate that a limiting DE guillotine break would result in less severe thermal-hydraulic conditions in the containment than resulted by the limiting DBA, i.e., DEDLSB with maximum SI flow. However, the applicant chose to run 60% and 80% of the double–ended area to address the staff's question. The staff would like to understand applicant's reasons for not analyzing smaller breaks even further below 60% in order to support their conclusion.

Public Teleconference (August 9, 2016)

The RAI essentially asked for a demonstration that the M&E release and subsequent containment thermal-hydraulic response analyses for DEHLSB are most conservative across the possible hot break spectrum including smaller slot break sizes. In order to meet the break spectrum analysis requirement to identify the most limiting LOCA, APR1400 methodology needs to demonstrate that a limiting DE guillotine break would result in less severe thermal-hydraulic conditions in the containment than resulted by the limiting DBA, i.e., DEDLSB with maximum SI flow. However, KHNP chose to run 60% and 80% of the double–ended area to address the staff's question. The staff would like to understand applicant's reasons for not analyzing smaller breaks even further below 60% in order to support their conclusion.

As mentioned during the call, the staff is aware of at least one CE power plant that has a limiting small break hot leg LOCA (10% of Double-Ended Slot Break) resulting in higher peak pressure than the double-ended hot leg LOCA. During the previous conference call with KHNP, the applicant requested that the NRC staff provide a citation. The staff would like to point to the following citation in this regard: Calvert Cliffs UFSAR (Updated Final Safety Analysis Report), Revision 39, Chapter 14.20, Section 14.20.2, Page 14.20-2. The staff found that the calculation packages supporting the FSAR are not available publically. However, NUREG-0800, Section 6.2.1.3 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."

Public Teleconference (September 22, 2016)

The staff noted that the applicant analyzed only two smaller break sizes that are 60% and 80% of the DEHLSB. Small break LOCAs allow time for the primary coolant to absorb energy from the secondary side of the SGs as opposed to the DE breaks, which result in rapid blow down and an insufficient time period for any reverse heat transfer from the SGs. During the July 7, 2016, public teleconference, the staff emphasized the need to further analyze smaller HLSBs below 60% of the DE area, per NUREG-0800, Section 6.2.1.3, to ensure that no limiting LOCA exists for a smaller break. During the August 9, 2016, public teleconference, the applicant showed the M&E release and peak containment pressure results for six cases with 0.8 DEHLSB area through 0.05 DEHLSB area. The results showed a monotonous decrease in the predicted containment peak pressure with the reduction in the break area. Therefore, the DEHLSB case in the APR1400 DCD is most conservative in the double-ended hot leg slot break spectrum. The staff would accept the revised response to RAI 8336, Question 28416 (06.02.01.03-1) when it is submitted on the docket, assuming it is consistent with the information presented during the public teleconference. It is currently tracked as an open item.

Supplemental Response

Public Teleconference (July 7, 2016)

Based on the analysis results for the 100%, 80% and 60% DEHLSB cases, a trend was observed - the containment peak pressure becomes smaller as the break area becomes smaller, as shown in Table 3 above. Based on these results, KHNP extrapolated that the same trend of the containment peak pressure versus break area was applicable to smaller break cases (below 60% DEHLSB) based on the fact that there were not any reasons to increase the peak pressure in the smaller break cases. Therefore, the three cases analyzed (i.e., 100%, 80% and 60% DEHLSB) were considered to be sufficient in identifying the limiting hot leg break size.

Public Teleconference (August 9, 2016)

For the break area spectrum analysis of the double-ended hot leg slot break (DEHLSB), six cases (0.8 DEHLSB through 0.05 DEHLSB areas) area are analyzed. The calculated mass and energy releases are compared with those of the DEHLSB base case in the APR1400 DCD, and presented in Figures 1 through 4 below. The subsequent containment thermal-hydraulic responses are presented in Table 1. The comparison of the results shows that the double-ended hot leg break case from the APR1400 DCD is most conservative case in the break spectrum analysis.

Table 1. Containment Peak P/T Results of Hot Leg Slot Break Area Spectrum Analysis **TS**

TS

Figure 1. Comparison of Mass Release Rate

TS

Figure 2. Comparison of Break Enthalpy

TS

Figure 3. Comparison of Integrated Mass Release

TS

Figure 4. Comparison of Integrated Energy Release

Public Teleconference (September 22, 2016)

This supplemental response to RAI 8336, Question 28416 (06.02.01.03-1) provides answers to NRC staff questions based on the July 7, 2016 and August 9, 2016 public teleconferences.

Impact on DCD

DCD Tier 2, Section 6.2.1.3.1 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, Re.0, “LOCA Mass and Energy Release Methodology,”) Section 3.3 and associated tables and figures will be revised, as indicated in Attachment 2, 3 and 4 to this response.

a. Double-ended suction leg slot break (DESLSB) in the suction leg of the RCP

b. Double-ended discharge leg slot break (DEDLSB) in the discharge leg of the RCP

c. Double-ended hot leg slot break (DEHLSB) in the hot leg of the RCS

The break type is assumed to be a slot break that has the break area equivalent to the double-ended break. The largest break area (i.e., double-ended break area) is limiting in a large break LOCA.

Detailed descriptions on the effect of the break type and the spectrum of the break area are provided in Reference 3.

M&E release data for the suction leg, discharge leg, and hot leg break cases are given in Part A of Tables 6.2.1-4 through 6.2.1-8. For cold leg breaks (pump suction and discharge), some of the post-blowdown SIS water is postulated to spill directly to the containment floor whenever the reactor vessel annulus is full. The vessel spillage data associated with these breaks are also given in Part A of Tables 6.2.1-4 through 6.2.1-8.

6.2.1.3.2 Energy Sources

The following sources of generated and stored energy in the RCS and secondary coolant system are considered:

a. Primary coolant

b. Secondary coolant

c. Primary walls (including reactor internals)

d. Secondary walls

e. Safety injection water

f. Core power

g. Decay heat

c. The second post-blowdown period is the reflood period. During reflood, SIS water floods the core. Reflood is assumed to end when the liquid level in the core is [ ]$^{\text{TS}}$ below the top of the active core. During reflood, a significant amount of the SIS water entering the core is postulated to be carried out of the core by the steaming action of the core-to-coolant heat transfer process. This fluid then passes through a steam generator where reverse (i.e., secondary to primary) heat transfer heats it before it reaches the containment. The residual steam generator secondary energy is sufficient to convert all of this fluid to superheated steam during the initial part of the reflood period. Subsequently, as the steam generators are cooled by this process, there is not enough heat transfer to boil all of the fluid passing through the tubes. This causes the break flow to change from pure steam to two-phase.

   As the entire NSSS cools, the flow to the containment eventually becomes subcooled because the safety injection water is subcooled. The onset of the two-phase release to the containment may or may not occur before the end of reflood; typically, it occurs close to the end of reflood. The potential release of subcooled fluid to the containment does not occur during reflood when conservative system parameters are used.

d. The third post-blowdown period is the post-reflood period. During this period, the dominant process is the continued cooling of the steam generators by the SIS water leaving the core. The release to the containment during this period becomes generally two-phase in the earlier stage of this period as the cooling of the steam generators continues. The post-reflood ends when the affected steam generator has essentially reached the containment temperature.

e. The final post-blowdown period is the decay heat period, which begins at the end of post-reflood. During the decay heat period, the dominant mechanisms for release rates are the generation of the decay heat and the cooling of all NSSS metal. The decay heat period ends when the containment pressure and the environmental pressure are essentially equal.

LOCA mass and energy releases are analyzed using the computer codes, CEFLASH-4A and FLOOD3 for the categorized phases. The CEFLASH-4A computer code is used for analysis of the blowdown period and the FLOOD3 computer code is used for analysis of the reflood period. The detailed descriptions of the codes are presented in References 2 and 3, respectively.

The M/E calculated by CEFLASH-4A and FLOOD3 is supplied as input to the GOTHIC computer program (References G-5, G-6 and G-7 in Appendix G) for the containment analysis. Mass and energy release during the decay heat period is calculated directly by GOTHIC and is integrated with the containment analysis. Detailed descriptions of the codes are presented in Appendix A.

3.3 Mass and Energy Release Data

Pipe breaks and locations are assumed to be as follows:

- Double-ended suction leg slot break (DESLSB) in the RCP suction leg.
- Double-ended discharge leg slot break (DEDLSB) in the RCP discharge leg.
- Double-ended hot leg slot break (DEHLSB) in the RCP hot leg.

Replace this paragraph with the paragraph "A" and "B" in the following pages.

~~The break type is assumed to be a slot break that has the break area equivalent to the double-ended break. The largest break area, i.e. the double-ended break area is limiting for a large break LOCA.~~

c. The second post-blowdown period is the reflood period. During reflood, SIS water floods the core. Reflood is assumed to end when the liquid level in the core is 0.6096 m (2 ft) below the top of the active core. During reflood, a significant amount of the SIS water entering the core is postulated to be carried out of the core by the steaming action of the core-to-coolant heat transfer process. This fluid then passes through a steam generator where reverse (i.e., secondary to primary) heat transfer heats it before it reaches the containment. The residual steam generator secondary energy is sufficient to convert all of this fluid to superheated steam during the initial part of the reflood period. Subsequently, as the steam generators are cooled by this process, there is not enough heat transfer to boil all of the fluid passing through the tubes. This causes the break flow to change from pure steam to two-phase.

As the entire NSSS cools, the flow to the containment eventually becomes subcooled because the safety injection water is subcooled. The onset of the two-phase release to the containment may or may not occur before the end of reflood; typically, it occurs close to the end of reflood. The potential release of subcooled fluid to the containment does not occur during reflood when conservative system parameters are used.

d. The third post-blowdown period is the post-reflood period. During this period, the dominant process is the continued cooling of the steam generators by the SIS water leaving the core. The release to the containment during this period becomes generally two-phase in the earlier stage of this period as the cooling of the steam generators continues. The post-reflood ends when the affected steam generator has essentially reached the containment temperature.

e. The final post-blowdown period is the decay heat period, which begins at the end of post-reflood. During the decay heat period, the dominant mechanisms for release rates are the generation of the decay heat and the cooling of all NSSS metal. The decay heat period ends when the containment pressure and the environmental pressure are essentially equal.

LOCA mass and energy releases are analyzed using the computer codes, CEFLASH-4A and FLOOD3 for the categorized phases. The CEFLASH-4A computer code is used for analysis of the blowdown period and the FLOOD3 computer code is used for analysis of the reflood period. The detailed descriptions of the codes are presented in References 2 and 3, respectively.

The M/E calculated by CEFLASH-4A and FLOOD3 is supplied as input to the GOTHIC computer program (References G-5, G-6 and G-7 in Appendix G) for the containment analysis. Mass and energy release during the decay heat period is calculated directly by GOTHIC and is integrated with the containment analysis. Detailed descriptions of the codes are presented in Appendix A.

3.1.3 LOCA Mass and Energy Release Data

Pipe breaks and locations are assumed to be as follows:

- Double-ended suction leg slot break (DESLSB) in the RCP suction leg.
- Double-ended discharge leg slot break (DEDLSB) in the RCP discharge leg.
- Double-ended hot leg slot break (DEHLSB) in the RCP hot leg.

"A"

The break type is assumed to be a slot break and the break areas are equivalent to the double-ended break. The effect analyses are performed for the break types, the slot break and the guillotine break. The blowdown M/E release of the double-ended hot leg slot break (DEHLSB) and the double-ended hot leg guillotine break (DEHLGB) are calculated and compared with each other. The comparison is presented in Figure 3-1 and Table 3-1 and shows that the DEHLGB has slightly more severe results than the DEHLSB. Even though the DEHLGB case is more severe than the DEHLSB case, the peak pressure of the DEHLGB

Replace the deleted paragraph with this paragraph.

Replace the deleted paragraph with this paragraph.

"B"

is less than that of the limiting LOCA case (DEDLSB).

The blowdown M/E release of the double-ended discharge leg slot break (DEDLSB) and the double-ended discharge leg guillotine break (DEDLGB) are calculated and compared with each other. The comparison is presented in Figure 3-2 and Table 3-2 and shows that the DEDLSB is more severe than the DEDLGB. Thus, the DEDLSB is the limiting LOCA case in APR1400 DCD and the break type is assumed to be a slot break.

The limiting break area is determined to be the double-ended break area based on the area spectrum analysis. For the break area spectrum analysis of the hot leg slot break, six cases with 0.8 DEHLSB area through 0.05 DEHLSB area are analyzed. The calculated mass and energy releases are compared with those of the DEHLSB case and the behaviors of the M/E are presented in Figure 3-3 though Figure 3-6. The subsequent containment thermal-hydraulic responses are presented in Table 3-3. The comparison of the results shows that the double-ended hot leg break area is most conservative in the break spectrum analysis.

There are five analysis cases for LOCA M/E analysis: for the suction leg break with maximum and minimum SI flow, discharge leg break with maximum and minimum SI flow, and hot leg break cases. Those cases are summarized in Table 4-1. In this report, the analysis result of the limiting case is provided. The limiting case is determined based on the containment peak pressure. Mass and energy release data for the limiting case are provided in Tables 4-2. For cold leg breaks (pump suction and discharge), some of the post-blowdown SIS water is postulated to spill to the containment floor whenever the reactor vessel annulus is full. The vessel spillage data associated with these breaks are also given in Part A of Table 4-2.

3.1.4 Energy Sources

The following sources of generated and stored energy in the reactor coolant system and secondary coolant system are considered:

- Primary coolant
- Secondary coolant
- Primary walls (including reactor internals)
- Secondary walls
- Safety injection water
- Core power
- Decay heat

For the conservative analysis, the assumptions of energy sources are biased to maximize stored energy.

For considering the stored energy in the coolant, the initial reactor coolant system water volumes are conservatively calculated based on maximum manufacturing tolerances for the reactor vessel and steam generator tubes. Expansion of the loop components from cold to hot operating conditions is also considered for the coolant stored energy. The initial water volume of the pressurizer includes an allowance for level instrumentation error. This maximizes the pressurizer water volume containing the maximized stored energy.

For considering the stored energy in the walls, the large specific heat and heat conductivity of carbon steel are conservatively assumed for all walls in the RCS.

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.

Insert Table 3-1 through 3-3 in the following two pages after this page. The subsequent Table numbers should be readjusted.

Insert this page.

Table 3-1. Comparison of M/E results of DEHLSB and DEHLGB

TS

Table 3-2. Comparison of M/E results of DEDLSB and DEDLGB

TS

Insert this page.

Table 3-3. Containment Peak P/T Results of Hot Leg Slot Break Area Spectrum Analysis

TS

TS

Figure 3-7

~~Figure 3-1~~ **CEFLASH-4A Node Diagram for LOCA Discharge Leg Break**

Insert Figure 3-1 through 3-6 in the following four pages before this page. The subsequent Table numbers should be readjusted.

Insert this page.

TS

Figure 3-1 Comparison of M/E results of DEHLSB and DEHLGB

Insert this page.

TS

Figure 3-2 Comparison of M/E results of DEDLSB and DEDLGB

Insert this page.

TS

Figure 3-3 Comparison of Hot Leg Mass Release Rate

TS

Figure 3-4 Comparison of Hot Leg Break Enthalpy

Insert this page.

TS

Figure 3-5 Comparison of Hot Leg Integrated Mass Release

TS

Figure 3-6 Comparison of Hot Leg Integrated Energy Release