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.:	**114-8041**
SRP Section:	**03.04.01 – Internal Flood Protection for Onsite Equipment Failures**
Application Section:	**3.4.1**
Date of RAI Issue:	**07/27/2015**

Question No. 03.04.01-3

DCD Tier 2, Sections 3.4.1.3 and 3.4.1.5 identify the in-containment flooding sources as coming from a loss of coolant accident (LOCA) or from a break in the fire protection system. The applicant states that the worst-case flooding event is a double-ended discharge leg LOCA with the minimum safety injection because it results in the most limiting flooding source for the reactor containment building.

The applicant is requested to provide the following information relating to the determination of the worst case:

a) Provide a comprehensive explanation of the calculation method for using “maximum break”, instead of “maximum flood water volume” to determine the worst case flooding event. In general, flood level is determined by the water volume. Provide design requirements (such as the drain capability) and the basis to support the method being used by APR1400.

b) Explain the basis for the determination of the worst case being LOCA with duration of 50 second. It should be noted that LOCA has higher peak flow but drops quickly lasting much longer than 50 second, while fire protection water could leak indefinitely without isolation resulting in larger volume of flood water. If isolation is used, provide the design basis and justifications.

c) Explain how other in-containment water sources (such as main feedwater line, main steam line, auxiliary feedwater system, shutdown cooling system, component cooling system, safety injection tank (SIT), and other water carrying piping) compare against the worst case LOCA?

Response – (Rev. 3)

a) Flood height at the bottom level of containment is determined by the maximum flood water volume and flood area; whereas, flood height of the containment upper level is determined by comparing inflow and outflow rates through openings and drainage paths. Flood height of the reactor containment building is based on the maximum flood water volume of a LOCA and is further described in Question 03.04.01-4. DCD Tier 2, Subsection 3.4.1.5.1 will be revised to change the term from ‘break flow’ to ‘flood water volume.’ Section 3.4.1.5 will be revised to describe the basis of determination of flood height in reactor containment building.

b) For a postulated LOCA event, most of the water is released into containment within the first 50 seconds based on analysis. For conservatism, the entire released volume during that time is taken to accumulate at El.100 ft of containment with no drainage to the HVT at a lower elevation. The total discharged water volume from a LOCA is assumed to be the volume of the reactor coolant system (RCS) and the four safety injection tanks described in DCD Tier 2, Table 6.2.1-20 and Table 6.2.1-21. The total assumed water volume is 19,482 ft^3. This volume corresponds to the maximum flood level in containment of 2 ft. Additional water used for safety injection and containment spray is taken from the IRWST (inside containment) which does not increase the maximum level due to the inflow and outflow rates through openings and drainage paths.

   Though flooding events from large water volumes such as the fire protection system could leak water at a lower rate, but for a substantially longer time, KHNP has determined this case is bounded by the LOCA flooding scenario. Adequate flood protection measures, including operator actions, can be taken to identify and isolate any indefinite flood source. The reactor containment is equipped with safety related level instruments at El.106 ft 3 in that can measure level from 100 ft 4 in to 102 ft 10 in and provides indication to the control room. Operating procedures will provide guidance based on abnormal indications and alarms to identify the source of the leakage. Actions can then be taken to isolate the leak.

   The fluid flow rate of fire protection system due to a through-wall crack is calculated to be 0.0116 m^3/sec (0.41 ft^3/sec). The postulated through-wall crack is based on a circular opening of area equal to that of a rectangle, one half pipe diameter in length, and one half pipe wall thickness in width. The time that it would take to flood containment up to 0.61 m (2 ft) height from the El.100 ft (e.g., that flood height calculated for the LOCA case) is 36.5 hours. This time is considered to be more than sufficient time for operators to identify and isolate the fire protection system in a flooding event.

   Since operator action is taken credit for in the identification and isolation of fire water sources, DCD Tier 2 Subsection 3.4.1.5.1 will be revised to describe the isolation of flood sources that could have a larger volume and where credit is taken for operator action.

c) Flooding sources inside the reactor containment building other than the reactor coolant system include: main feedwater, auxiliary feedwater, component cooling water, fire protection and the chemical and volume control systems. The LOCA case is the bounding source for the released water in containment compared to these other postulated piping system failures.

Water volumes of high and moderate piping systems inside the reactor containment building and assumed water volumes in the analysis are summarized in Table 1.

For an AF line break downstream of the check valve inside containment building, the flooding source of an AF Tank will not gravity discharge into the reactor containment building since the location of the piping, and therefore the break point, is higher than the top level of the AF Tank.

For the FW line break case, the runout flow rate for three main feedwater pumps is approximately 190 ft^3/sec. From DCD Tier 2, Table 15.2.8-2, the safety-related main feedwater isolation valves located outside containment will be closed in approximately 168 seconds into the feedwater line break event. The discharged water volume from the FW system during the 168 seconds is 31,920 ft^3. The AF flow to a faulted steam generator will be terminated manually by operator action 30 minutes after the initiation of the steam generator secondary side pipe rupture such as main feedwater line break. The volume of AF used to make up to a faulted SG is 3,552 ft^3 (26,577 gal) as described in DCD Tier 2, Section 10.4.9.3. Total discharged water volume is 35,472 ft^3 which is the summation of the discharged water volume from FW system and the water volume of AF makeup.

Table 1 Water sources inside reactor containment building

System	Water volume of source	Water volume for flood level determination	Piping failure flow rate	Energy line
RC (LOCA)	19,482 ft^3 (145,735 gal)	109,197 ft^3 [2)] (Recirculation Mode)	2,100 ft^3/sec	High-energy line
SD	11,396 ft^3 (85,246 gal)	11,396 ft^3	15 ft^3/sec	High-energy line
AF	81,763 ft^3 (611,627 gal)	0 ft^3	0 ft^3/sec	High-energy line
FW	65,301 ft^3 (488,477 gal)	35,472 ft^3 (Isolation)	190 ft^3/sec	High-energy line
CV	42,978 ft^3 (321,500 gal)	42,978 ft^3	28 ft^3/sec	High-energy line
CC	26,736 ft^3 (200,000 gal)	26,736 ft^3	<1 ft^3/sec	Moderate-energy line
FP	116,302 ft^3 (870,000 gal)	57,815 ft^3 (Isolation)[3)]	<1 ft^3/sec	Moderate-energy line
SI[1)]	N/A	N/A	N/A	High-energy line
SC[1)]	N/A	N/A	N/A	High-energy line

Note:

1) These systems are included in RCS boundary and therefore the water volume and flow rate are enveloped by the LOCA case.
2) RC (LOCA) is the largest water volume considering the recirculation mode with IRWST water volume (89,715 ft^3) plus LOCA induced water volume (19,482 ft^3).
3) The water volume of FP system will be isolated with flood protection measures including operator action and the discharged water volume is assumed to be 57,815 ft^3 under EL.102 ft of the RCB.

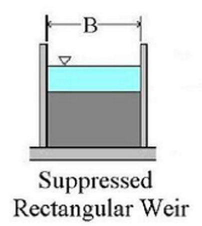
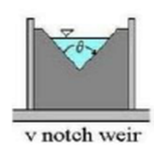
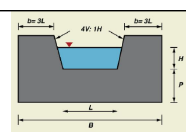
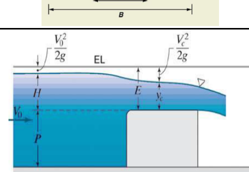
The analysis is modeled that for all of the break events in Table 1, except for the LOCA case, the water from the source will drain to the HVT through the floor openings on EL.100 ft and flow to the IRWST through two 24 inch spillways.

For the FW line break, the transient water level is evaluated using a time-history approach to determine the flood height and compare it to the 2 ft flood height of the LOCA case. The flow through the floor openings at EL.100 ft and the flow through the spillways are considered in this evaluation.

The flowrate through the opening is generally calculated by using the weir equations as depicted in Table 2 below. The shape of floor openings at EL.100 ft is similar to the sharp-crested rectangular and broad-crested rectangular weirs from Figures 1 through 3; thus, the associated equations are appropriate to use to calculate the flow rate in APR1400 DC.

The swirling effect is considered negligible since the floor opening width is sufficiently large and the flood source due to a FW line break would flow to EL.136 ft, down to EL.114 ft and finally to EL.100 ft of the containment building through gratings or stairwells. Thus, the flow rate will be decreasing such that the swirling effect is not significant.

Table 2 Type of weirs and applicability to APR1400 DC flooding model

Main Type of Weir		Simplified Figure	Applicability of APR1400 DC	Sensitivity Case
Sharp-crested	Rectangular		Applicable	Case 1
	Triangular		N/A	None
	Trapezoidal		N/A	None
Broad-crested	Rectangular		Applicable	Case 2

TS

Figure 1 Floor opening plan view on El.100ft

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Figure 2 Floor opening section view on El.100ft

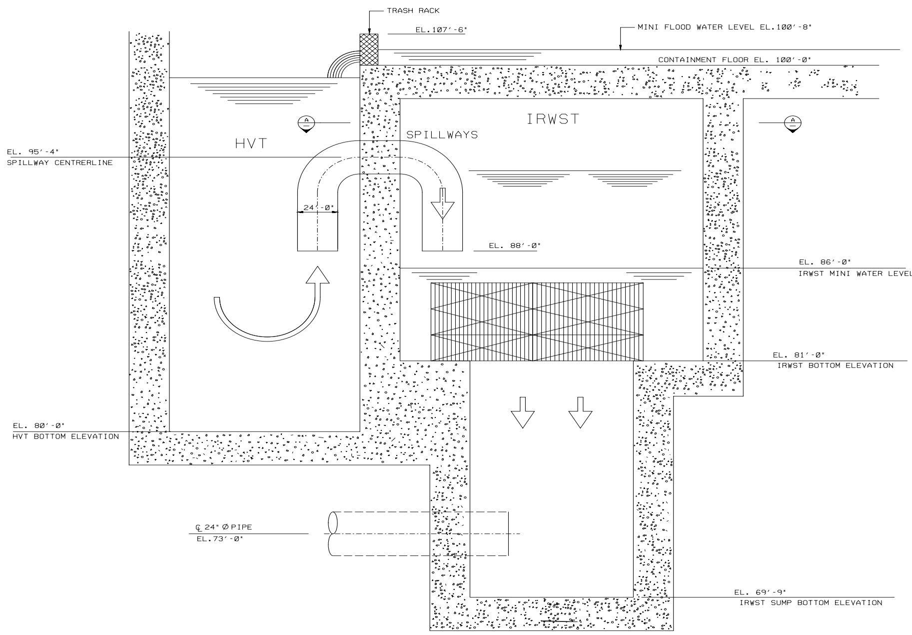

Figure 3 Flow Opening Schematic drawing on El.100 ft

The flood level for Case 1 is shown in Figures 4 and 5 and for Case 2 in Figures 6 and 7. Figure 8 shows the results of the sensitivity evaluation based on the weir equations.

Case 1

Flood level using the sharp-crested rectangular weir and pressure drop equation

- Flow into the HVT opening at EL.100 ft. is calculated by the sharp-crested rectangular weir equation and flow into the IRWST (through the spillway) is calculated by the pressure drop equation, Darcy's formula.
- Flood source is a FW line break flow (190 ft^3/sec) with AFW makeup flow (1.97 ft^3/sec).
- Sharp-crested weir equation: $\mathrm{Q} = \frac{2}{3} C_D \sqrt{2g} \mathrm{B} \mathrm{H}^{3/2}$

Where, Q: Volumetric flow rate

C_D: Discharge coefficient (usually ranging from 0.60 to 0.62)

B: Width of the weir

H: Height of the water

g: Acceleration of gravity (32.2 ft/sec^2)

The discharge coefficient (C_D) used is 0.60 and the blockage of the opening by trash rack is additionally considered to be 38% (0.62) for conservatism. The width of the weir (B) is 25.1 ft.

$$Q = (0.62) \times 2/3 \times (0.60) \times \mathrm{SQRT}(2 \times 32.2\ ft/s^2) \times (25.1\ ft) \times H^{3/2}$$

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Figure 4 Containment Water levels for FW break with sharp-crested weir equation (Case 1)

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Figure 5 Comparison of flow rate at EL.100 ft floor opening and flow rate of spillways (Case 1)

The flood water starts to flow to the IRWST through the spillways at 147.7 sec. The maximum flood level is approximately 100 ft at 200 sec. The water level gradually decreases after 200 sec so the flood level does not reach EL.102 ft as shown in Figure 4.

Figure 5 shows the flow rate into the HVT through the EL.100 ft floor openings and the flow rate through the spillways into the IRWST. The flow rate through the openings at EL.100 ft is greater than the flow rate through the spillways for a short time. The flow rate into the IRWST is greater than the flow rate into the HVT after 200 sec, thus the water in containment will be draining faster than it is building up.

Case 2

Flood level using the broad-crested weir and pressure drop equation

- Flow to the HVT through the openings at EL.100 ft is calculated by the broad-crested rectangular weir equation and flow into the IRWST (through the spillway) is calculated by the pressure drop equation, Darcy's formula.
- Flood source is a FW line break flow (190 ft^3/sec) with AFW makeup flow (1.97 ft^3/sec).
- Broad crested weir equation: $Q = b\sqrt{g}(\frac{2}{3}h)^{3/2}$

Where, Q: Volumetric flow rate

b: Length of weir

h: Height of the water

g: Acceleration of gravity (32.2 ft/sec^2)

The percent blockage of the openings by trash rack is additionally assumed to be 38%(0.62) for conservatism. The length of the weir (b) is taken to be 25.1 ft.

$$Q = (0.62) \times (25.1\ ft) \times SQRT(32.2\ ft/s^2) \times (2/3 \times h)^{3/2}$$

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Figure 6 Containment water levels for FW break case with broad-crested weir equation (Case 2)

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Figure 7 Comparison of flow rate at 100 ft floor opening and flow rate of spillways (Case2)

The flood water starts to flow to the IRWST through spillways after 134 sec. The maximum flood level is approximately 100.3 ft at 195 sec. The water level gradually decreases after 195 sec and remains below EL.102 ft as shown in Figure 6.

Figure 7 shows the flow rates into the HVT through the floor openings on EL.100 ft and the flow rate through the spillways into the IRWST. The flow rate through the floor opening on EL.100 ft is greater than the flow rate through the spillways for a short time. The flow rate into the IRWST is greater than flow rate into the HVT after 195 sec, thus the water in containment will be draining faster than it is building up.

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Figure 8 Water levels based on sensitive analysis

As a result of the flood evaluations from the two cases calculated, a sensitivity analysis shows that the broad crested weir equation results in slightly more conservative flood levels than the sharp crested weir equation. However, in either case, the flood level is well below EL.102 ft which was determined for the LOCA case.

Impact on DCD

DCD Tier 2, Subsection 3.4.1.5 and 3.4.1.5.1 will be revised as indicated in the attached markup.

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.

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b. Henry-Fauske model for subcooled liquid

~~HVT~~

A LOCA that results in the largest discharge volume to the reactor containment is assumed as a flooding source in the flooding analysis of reactor containment building. The flood level of the reactor containment building is determined by dividing the accumulated volume ~~of discharged water for 50 seconds~~ by the total floodable area at El. 100 ft 0 in. ~~No outflow to the lowest elevation for the early discharge period of 50 seconds is also assumed to result in conservative flood level~~, although fluid flow to the lower elevation will actually be established when broken flow arrives at the openings to the lower elevation.

Insert B

Insert A

~~Indoor hydrants~~ that could reach the area or zone where a fire occurs are contributed to internal flooding sources when a fire occurs. The discharge flow rate from ~~indoor hydrants~~ is assumed to be 0.044 m^3/s (700 gpm).

~~Most of the water is discharged during 50 seconds. The calculated outflow rate with water level height of 2 ft is greater than inflow rate at or after 50 seconds.~~

Fire hose stations

The lowest level of the auxiliary building is designed to function as an emergency sump to collect flooding sources when a flood event occurs. The flood level of the emergency sump is determined by dividing the maximum volume of flooding sources by the floodable area of the emergency sump. The flood level, except for the lowest elevation, is determined based on the level established by the difference between the inflow rate of the postulated flooding source and the outflow rate through drains or openings in steady-state condition.

Fluid flow rates through stairwells, floor openings, and under door gaps are determined in accordance with the formulae given in ANSI 56.11-1988 (Reference 5). The fluid flow rate through a stairwell or a floor opening is calculated using equation 5.2-1, and the flow rate under a door is calculated using equation 5.2-3 in Reference 5. ~~For each storage tank, it~~ is assumed that the total inventory of the ~~tank is~~ spilled out. No credit is taken for operation of sump pumps to mitigate the flooding consequences.

It

IRWST and SI tank are

The internal flooding analysis is performed on a floor-by-floor and room-by-room basis.

The total water volume in the IRWST is considered as a limiting flood source in auxiliary building only as a result of a pipe rupture.

Flooding analysis consists of the following steps:

a. Identification of safety-related SSCs

b. Identification of potential flooding sources

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A

For conservatism, the entire released volume is taken to accumulate at El. 100ft of containment with no drainage to the HVT at a lower elevation before recirculation mode

B

In the long term cooling period, during recirculation mode with containment spray from IRWST, the inflow of water onto EL.100 ft of containment consists of ECCS (SI and CS) injection flow from the IRWST with an outflow to the HVT and discharging back into the IRWST through spillways. The outflow to the IRWST through spillways is determined by using the general equation for pressure drop, Darcy's formula.

The worst-case flooding event is a ~~double-ended discharge leg~~ LOCA ~~with the minimum SIP flow~~, because it results in maximum ~~break flow~~ to the reactor containment building as a flooding source.

flood water volume

Insert C

in reactor containment building

~~maximum~~

Discharged water first fills up the volume below elevation El. 100 ft 0 in. and then spreads the volume above the grade level of the reactor containment building. Water released by a LOCA is collected in the IRWST through the ~~floor opening~~. It then flows back to the reactor coolant system or is sprayed into the containment and recirculated.

spillways between HVT and IRWST

551.67 m³ (19,482 ft³)

The total discharged volume of ~~double-ended discharge leg break of~~ a LOCA is ~~425.7 m³ (15,036 ft³)~~. The net floodable volume under El. 100 ft 0 in., including volume of air space of IRWST 753 m³ (26,592 ft³), holdup volume tank 242.3 m³ (8,557 ft³), and normal sump 6.7 m³ (237 ft³) is 1,002 m³ (35,385 ft³). The total discharged water volume due to LOCA is smaller than the total floodable volume.

which consists of volume for reactor coolant system and four safety injection tanks described in Table 6.2.1-20 and Table 6.2.1-21.

~~as described in Table 6.2.1-7.~~

~~The flood water level is determined as 0.61 m (2 ft) above El. 100 ft 0 in.~~ The maximum flood level of containment does not affect safety-related equipment. There are no submerged SSCs required for safe shutdown. Table 3.4-1 provides a list and the locations of SSCs inside the reactor containment building that require flood protection. These SSCs are located above the maximum internal flood level.

Insert D

It envelops all flood levels throughout the entire containment area at El. 100 ft 0 in. The flood levels in the separately compartmentalized areas located above the bottom and annulus area are independently determined by taking account of flows in and out of these areas.

3.4.1.5.2 <u>Auxiliary Building</u>

The auxiliary building is designed to provide physical separation to prevent spreading of fluids to the areas housing safety-related equipment and components.

Non-seismically designed pipes are excluded as flood sources because all piping inside the reactor containment building is seismically designed. Operator action is credited for identification and isolation of flood sources that could result in larger volumes to containment than a worst case LOCA.

<u>Elevation 55 ft 0 in</u>

The primary means of flood protection is the divisional or quadrant walls, which serve as flood barriers between redundant trains of safe shutdown systems and components. Flood barriers provide separation between the quadrants, while maintaining equipment removal capability.

The flood level of the bottom area of the reactor containment building with total water volume of LOCA is determined to be 0.61 m (2 ft) from the El. 100 ft 0 in.

On the divisional wall, penetrations are sealed and no doors are provided up to El. 64 ft 0 in., which is the potential flood level from the bottom elevation. Watertight doors are

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C

The water volume of bounding case is 109,197 ft^3 which is summation of total discharged water volume from a LOCA (19,482 ft^3) and the recirculation mode with IRWST water volume (89,715 ft^3). There are flooding sources inside the reactor containment building such as reactor coolant system, main feedwater, auxiliary feedwater, component cooling water, fire protection and chemical and volume control systems.

The flooding source of an AF tank does not gravity discharge into the reactor containment building since the location of the piping is higher than the top level of the AF Tank.
The discharged water volume from the FW system during the isolation time by safety-related main feedwater isolation valve and the volume of AF makeup flow to steam generator are less than the volume of water from a LOCA in recirculation mode. For the FW line break evaluation, the transient water level is evaluated using a time history approach to determine the flood height and takes a credit of the flow path from the floor opening at EL.100 ft of RCB. Based on the sensitivity analysis, the flood level resulting from a postulated FW line break remains below EL.102 ft.
The water volume of FP system is isolated with flood protection measures including operator action. It has sufficient time for operators to identify and isolate the fire protection system in a flooding event.

D

The maximum containment flood level is determined by dividing total LOCA volume by floodable area 11,215 ft^2 of ~~El~~EL.100 ft. For LOCA evaluation, the analysis conservatively assumes that the break volume is discharged to containment with no loss of volume through the floor openings at EL.100 ft of the RCB prior to recirculation. The resulting containment flood level has been determined to be an additional 0.61 m (2 ft) to EL.102 ft. In the long term period with the containment water level at EL. 102 ft, the outflow into the IRWST through two 24 inch spillways is greater than the inflow ~~with~~from SI and CS pumps ~~onto~~into containment. The flood height ~~is~~ ~~decreasing~~decreases during the recirculation period, and, therefore, the flood water level ~~does not higher than determined before recirculation period 0.61m (2 ft).~~ remains less than the determined level of 0.61 m (2 ft) established before recirculation period.