RESPONSE TO AUDIT ISSUES

APR1400 Topical Reports

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

Docket No. PROJ0782

Review Section	**TR Realistic Evaluation Methodology for LBLOCA of the APR1400**
Application Section	**Topical Report: APR1400-F-A-TR-12004 Realistic Evaluation Methodology for Large-Break LOCA of the APR1400**
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Audit Issues No. 17

NUREG/CR-5429, Section 2.1 establishes an acceptable approach for the documentation of the PIRT. The following concerns are related to Table 3-2 of the topical report:

a. A more detailed explanation of the phenomena [ ]TS along with a justification for their respective importance rankings is needed. This needs to include a discussion of how these phenomena (ranked 4 or higher) are modeled and how the uncertainty in these parameters is determined and included in the analysis.

b. According to the Table 3-1 of the topical report, the end of blowdown period is defined as the initiation of SITs-FD injection. As a result, the process or phenomena associated with SIT-FD are not present during the blowdown period. However, some of phenomena for the SIT-FD are ranked during the blowdown period in Table 3-2 of the topical report. The basis for the importance rankings assigned to the SIT-FD phenomena during the blowdown period is needed.

c. Section 3.1.2.3 of the topical report provides the phenomena descriptions during the early reflood period. [ ]TS Based on the accident period definition, the gas discharge should be initiated after the SIT-FD water has depleted at the end of the early reflood period. The same comment also holds for the ranking of the [ ]TS The basis for the stated importance rankings is needed.

d. [ ]TS According to the accident period definition, SIT-FD do not inject until the beginning of period 2. Therefore, provide the rationale for the rank of 3 for period 2 and the rank of 5 for period 1, for both the above mentioned phenomena. The ranking for these phenomena is important because they are treated with a bias during the accident.

e. [

]TS

f. Provide an explanation for not considering downcomer boiling during the refill period.

g. [

]TS

h. According to Table 3-2 of the topical report, non-condensable gas is only expected to be influential in the reactor vessel downcomer component during the early reflood period. However, a relatively large amount of non-condensable gas is transferred from SIT to the downcomer after the depletion of SIT water inventory, the late reflood period. Provide an explanation of the current ranking for the cited phenomenon.

i. [

]TS Table 5-1 the topical report shows that this parameter is part of the uncertainty analysis. Provide the rationale for not including the form loss through the RCPs.

Response

a) ~ h)

The APR1400 PIRT has some mistakes in the PIRT modification process based on the KNGR PIRT, especially with regard to the change in time period definitions. The APR1400 PIRT will be revised to the attached documents of audit issue no. 15. The audit issues a) through h) include the issues related to the nitrogen gas injection phenomenon and its effectiveness in time period, therefore those issues can be cleared up following the modification of the APR1400 PIRT in association with the response to audit issue no. 15.

i)

[

]TS The limiting break determination process is described in Section 3.1.1 and 5.2.1.1 of the topical report. The additional information is available in the response to the audit issue no. 61 (b)~(f) as well.

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 Report

Topical report will be revised as discussed in this response. Revised PIRT is described in the attachment for the response of Audit Issue No. 14.

There is no impact on Technical or Environmental Report.

As the primary system depressurizes, flashing occurs first in the hot regions of the system, such as the upper plenum, hot leg, pressurizer, and core, and then proceeds to the relatively cold regions, such as the lower plenum, downcomer, and cold legs. Extensive voiding occurs in all areas of the reactor pressure vessel. Nucleate boiling develops in the core. Fission power, which is calculated by the kinetics model, drops to the level of decay heat due to the voiding in the core. The flashing also reduces the primary system depressurization rate.

When the critical heat flux (CHF) condition is reached in the core, heat transfer mode changes from nucleate boiling to post-CHF heat transfer regimes (i.e., transition boiling, film boiling, and forced convection to vapor). Fuel rod cladding temperatures increase rapidly due to the degrading rod-to-fluid heat transfer. The increase of the rod cladding temperatures during the early blowdown period is terminated by following reasons:

- The core power decreases rapidly due to the insertion of negative reactivity resulting from the voiding of the core.
- Rod-to-fluid heat transfer enhances due to the downward flow in the core after the flow stagnation.
- The large coolant inventory in the upper guide structures (UGS) and the upper head moves toward the top of the core by two paths; through the UGS drainage holes in the UGS bottom plate that is between the UGS and the upper plenum, and through the guide tube pipes that terminate in the upper inactive core.

As the low pressurizer pressure set-point is reached, the reactor is tripped. Reactor coolant pumps (RCPs) are modeled to trip and coast down from the beginning of the accident assuming loss-of-offsite-power. As the primary system pressure continues to decrease, flashing develops in the cold regions of the system. Resultant voiding in the RCP degrades its pumping performance. Break flow rate decreases rapidly as the flow regime changes from subcooled to saturated critical flow at the break.

Four SIT-FDs begin to deliver flow into the four DVI lines when the primary system pressure falls below their actuation set-point. The coolant flows through the DVI nozzles into the upper annulus and then begins to refill the reactor pressure vessel. Because the reactor coolant system is still depressurizing, some of the coolant entering the upper annulus is swept out to the break along with entrained liquid from the lower plenum and the downcomer. Although the break flow remains high, sufficient flow in the excess of the bypass is delivered downward into the downcomer and increases the downcomer water level. Then the coolant injected by the SIT-FDs eventually reaches the lower plenum.

3.1.2.2 Refill

The refill period begins when SIT-FD injection flow is initiated and ends when the water level in the lower plenum reaches the ~~core inlet~~ bottom of the active core. Refill begins at around 15 s and ends at around 38 s.

~~ECC water in the reactor vessel downcomer can flow down by gravity or be swept out to the break by the pressure differential and the upward-escaping steam flow that levitates the liquid.~~ Reactor vessel walls and internals are large metal structures at temperatures above saturation. When subcooled ECC water comes into contact with the metal structures in the downcomer, steam is generated by nucleate boiling. This reduces the gravitational head of the fluid in the downcomer. The process of liquid penetration and sweep-out repeats in the downcomer and direct-contact condensation of steam on the subcooled ECC water continues in the upper annulus. Figure 3-5 gives a schematic of the two-phase primary coolant system 25 s after the break opens.

The depressurization of the system wanes as the differential pressure between the reactor coolant

system (RCS) and the containment reduces. Owing to the gradual reduction of flashing and break flow, the rate of liquid penetration into the lower plenum increases. With the decreasing steam flow rate, ECCW bypass is insignificant and most of it flows downward to fill the downcomer and the lower plenum. At this stage, ~~water~~ levels in the downcomer and the lower plenum increase rapidly.

mixture

Heatup, which is almost adiabatic, continues in the core during this period because there is no inventory to cool the core.

mixture

The refill period ends when the ~~liquid~~ level in the lower plenum reaches the bottom of the active core.

and remains full thereafter and conditions are established for continuously reflooding the core with coolant.

3.1.2.3 Early R[illegible]

The early reflood period begins when the lower plenum ~~is completely filled with water~~ and ends when the SIT-FD water is depleted. This period begins at around 38 s [illegible]

the mixture level in

reaches the bottom of the active core

The early reflooding process is shown in [illegible] 7, and Figure 3-8. These figures respectively provide schematics of coolant distributions at 62 s when “high flow” is injected from the SIT-FDs, at 92 s when “low flow” is injected from SIT-FDs, and at 150 s when the entire core is quenched. Modeling of SIT-FD is explained in Section 4.2.1. The “high flow” and the “low flow” of SIT-FD are exemplified in Figure 5-14 and further described in Section 5.2.1. Around the beginning of the early reflood period, SIPs begin to inject water.

Initially, the core reflood is quite rapid because:

- the downcomer remains filled with water by the ECC injection,
- the high flow injection of SIT-FD continues,
- loop steam flow rate is low and therefore the hydraulic resistance in the loop is low, and
- there is no severe steam binding.

after the break

Maximum SIT-FD injection flow is reached ~~during this period~~ at around 30 s. High flow injection of the SIT-FD continues until around 66 s, then the flow through the stand-pipe becomes unavailable and only the flow through the fluidic-device is possible. During the high flow injection, downcomer and core liquid levels increase rapidly. As the downcomer liquid level approaches the level of the cold legs, much of the coolant spills out of the break and the vessel side break flow tends to increase. When the water level in the SIT-FD decreases to below the top of the stand pipe, the low flow injection begins. Water levels in the downcomer and core decrease slightly but the levels increase again within around 10 s, maintaining downcomer water level above the level of the cold legs. It appears that the combined SIP and SIT-FD flows are sufficient to maintain the water level in the downcomer and to retard core heatup.

In the core, heat transfer regimes encompass the entire spectrum, such as single phase liquid convection, nucleate boiling, transition boiling, film boiling, and single phase vapor convection.

Due to droplet de-entrainment at the fuel alignment plate and spacer grids, local quenching could occur. Vapor velocities and liquid entrainment in the central region of the core are higher due to the higher power of this region. The entrained liquid could have a cooling effect on the upper region of the core. Some of the entrained liquid is de-entrained at the fuel alignment plate and the remainder is carried into the upper plenum forming a two-phase pool. Liquid from the pool can reenter the low powered regions of the core through the fuel alignment plate due to the lower vapor velocities in those regions. Therefore, a three-dimensional flow pattern can occur: water flows from low to high powered regions in the core, while the flow is in the opposite direction in the upper plenum. Liquid from the upper plenum pool may be further entrained and carried over into the hot legs and steam

generators.

As reflooding progresses upward from the lower core region, more liquid is entrained to the upper plenum and the level of the two-phase mixture in the pool can reach the hot leg. When the entrained liquid reaches the U-tubes of the steam generators, it is vaporized by reverse heat transfer from the secondary side to the primary side. Due to the vaporization in the U-tubes, hot side pressure increases and this causes steam binding which deteriorates the reflooding of the core. Because the steam generation rate in the core decreases due to the lower reflood rate, liquid entrainment and the steam binding effect decrease, causing the reflood rate to increase again. Through this cyclical process, the entire core eventually becomes reflooded. The increase of core pressure due to the steam binding causes manometric oscillations between levels in the downcomer and the core.

The early reflood period ends when SIT-FDs are emptied.

3.1.2.4 Late Reflood

The late reflood period begins when SIT-FDs are emptied. ECC water is supplied only by SIPs during this period.

The water level in the downcomer decreases somewhat as the SIT flow stops at the beginning of this late reflood, and falls below the level of the cold legs. Then, the core water level becomes stabilized. Liquid levels in the downcomer and core become balanced ~~within around 20 s~~ during this period as shown in Figure 3-2. Due to the decreased flow of coolant into the downcomer, liquid temperature in the downcomer can increase to near saturation temperature due to the residual heat structures, that is, vessel walls in the downcomer. Boiling can occur on the surface of the walls depending on the conditions. As enough ECCW is provided by two SIPs, the possibility of the downcomer boiling is successfully suppressed and the core is found to remain amenable to cooling.

Because the entire core remains in a quenched state during this period, the steam generation in the core is not significant enough to cause any severe ECCW bypass. The core is found to be kept in a coolable condition as shown in Figure 3-9.

3.2 Nuclear Power Plant Selection (Step 2)

SKN 3 and 4 were selected as a reference. The main features are described in Chapter 1.

3.3 Phenomena Identification and Ranking Table (Step 3)

Phenomena identification and ranking table (PIRT) is used to identify the major phenomena or processes that occur during the accident and to prioritize them according to their effects on primary safety concern.

The PIRT of APR1400 LBLOCA is based on “KNGR PIRT.” KNGR is initialism for “Korea Next Generation Reactor;” and it was ARP1400’s name during its developmental stage. The PIRT was prepared by INEEL in 2001[5] for KINS. Four characteristic time periods of blowdown, refill, early reflood, and late reflood are summarized in Table 3-1. A numeric value is assigned to each phase as shown below:

1: Blowdown

2: Refill

3: Early reflood

4: Late reflood

Table 3-1 Definition of Time Periods

Period (Number)*)	Starts at	Ends at
Blowdown (1)	Break initiation	Initiation of SIT injection
Refill (2)	End of blowdown	Initiation of core recovery (~~liquid~~ mixture level at the bottom of the fuel rods)
Early Reflood (3)	End of refill	End of SIT injection
Late Reflood (4)	End of SIT injection	Stable core quench

*) The numbers indicated in parentheses are used as indices in the PIRT table to denote each phase in that table.