Studies on the extended loss of AC power event concurrent with loss of ultimate heat sink

Seyun Kim*, Bongsik Chu, Junkyu Song, Chang Hyun Kim
KHNP Central Research Institute, 70, Yuseong-daero, 1312-gil, Yuseong-gu, Daejeon, 34101, KOREA
**Corresponding author: seyun.kim@khnp.co.kr*

1. Introduction

The extended loss of AC electric power (ELAP) event concurrent with loss of ultimate heat sink (LOUHS) is one of the consequent scenarios initiated by a natural disaster. In the accident scenario, the passive accident coping measures, such as the turbine-driven auxiliary feed water (TDAFW) system, play essential role and the functions, operational range and capacity of passive system could be significant factors to the transient and strategy [1]. In the first phase of the FLEX strategy, accident mitigation actions are applied with the present plant equipment [2]. This study is focused on the transient phenomena in early stage of accident (~ 8 hours). The thermal-hydraulic transient analysis using SPACE (Safety & Performance Analysis Code for Nuclear Power Plants) code was performed to provide technical basis for development of coping strategies. SPACE code has been developed and applied to the safety analysis for design basis events and beyond-design-basis events. SPACE code solves two-fluid, three-field governing equations [3]. For preliminary study, the total feed water demand to remove decay heat was calculated in simplified conditions. And the plant transient simulation was performed to analyze the allowable time limit for the auxiliary feed water pump initiation in the coping strategy.

2. Analysis

2.1 Coolant inventory demand

In the emergency conditions, the decay heat of reactor core is most significant factor. To provide the appropriate heat removal measure is the primary objective of accident coping measure. The decay heat table suggested by ANS 2014 is fitted with a power function and applied in calculations. The feed water temperature is 108.9[C] and the steam generator dome average pressure of 5.0[MPa] is assumed. The heat removal capacity of the steam generator is function of the sensible heat and latent heat transfer of unit feed water mass as described below. The feed water demand to remove the instant decay heat and average decay heat are depicted Fig. 1. If the whole decay heat for 72 hours is removed through steam generator, the total required feed water volume is about 505,000[gal].

$$\dot{\upsilon} = \frac{q_{decay}}{\rho\left(\Delta h_s + h_{fg}\right)}$$

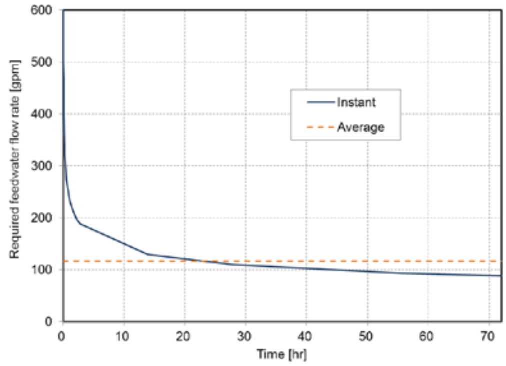

Fig. 1 Required feedwater flow rate

The effective water volume of condensate storage tank of OPR1000 is sufficient to supply the required feed water for 72 hours [4]. In the transient condition of plant, the decay heat is removed by the consumption of SG inventory before SG dryout. According to the coping strategy, the influx and efflux of heat could vary the heat balance of nuclear steam supply system. However, in the simplified calculation the SG inventory and the accumulated heat of RCS are ignored, and after 2 hours the instant feed water demand decreases below 200[gpm]. In the design of capacity of the mobile pump to supply auxiliary feed to SG, the simplified calculation could be utilized.

2.2 Coping time analysis

2.2.1 Analysis method

To analyze the coping time for the given scenario, Hanul Units 3&4 were selected as a representative plant for OPR1000 design [4]. The SPACE nodalization diagram for Hanul 3&4 is shown in Fig. 2.

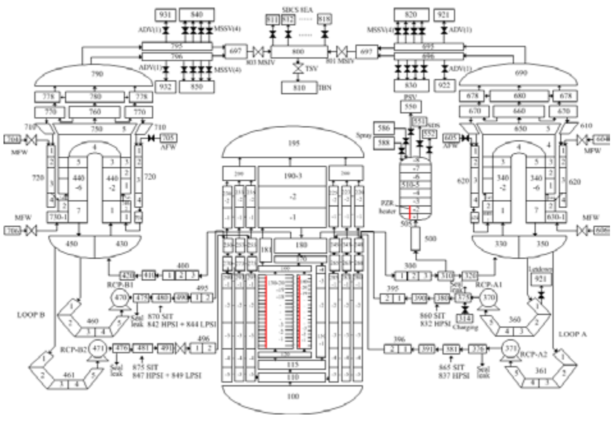

Fig. 2 Nodalization diagram of Hanul 3&4

The nodalization model was developed based on the previous LOCA analysis nodalization model. The hydraulic component models such as charging, letdown, pressurizer spray, auxiliary feed water system and atmospheric dump valve were added. The 3.12 version of SPACE code is used in this analysis [3]. The plant is modeled with 243 fluid cells, 378 faces between cells and 497 heat structures. The default critical flow model, Ransom-Trapp model, is applied to simulate the choking phenomena in the safety valves and seal leakages.

2.2.2 Analysis results

At the ELAP event condition concurrent with LOUHS, the plant subsequently depends on the passive TDAFW system for the decay heat removal in early phase of event without a supply of any other mobile accident mitigating measure. In this study, an assumption of unavailability of the TDAFW pump was adopted to analyze the coping time. A calculation to attain steady state condition was carried out for 3000 seconds and the major plant parameters are tabulated in Table 1.

Table 1 Major parameters of plant

Parameter		Target	SPACE	Error
PZR press. [MPa]		15.51	15.56	0.4%
Hot leg temp. [K]		600.48	602.14	0.3%
Cold leg temp. [K]		568.98	571.40	0.4%
Core flow [kg/s]		14848	14883	0.2%
PZR level [%]		52.6	52.7	0.2%
SG press. [MPa]	A	7.38	7.39	0.1%
	B	7.38	7.39	0.1%
Feed water flow [kg/s]	A	801.3	801.5	0.02%
	B	801.3	801.5	0.02%
SG level (NR) [%]	A	44.0	46.2	5.1%
	B	44.0	46.2	5.1%

The major sequence of event of the given scenario is presented in Table 2. The passive accident mitigation components, those are the main steam safety valve (MSSV) and the pressurizer safety valve (PSV), open at 45 seconds and 1.6 hours respectively. And core uncovery occurs at 2.2 hours consequently.

Table 2 Major sequence of event

Time [s]	Events
0.0	SBO occur, TBN trip, RCP trip, Rx trip, MFIS, MSIS, RCP seal leakage occur
45	MSSV first open
600 (10 min)	AAC fail to start
2130 (36 min)	SG depleted
5684 (1.6 hr)	PSV first open RCS saturation
7891 (2.2 hr)	Core uncovery

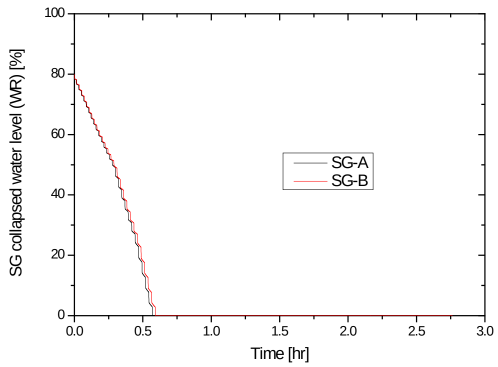

Fig. 3 SG collapsed water level

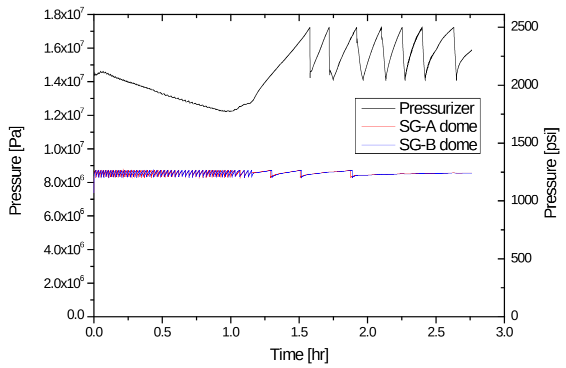

Fig. 4 Primary and secondary pressure

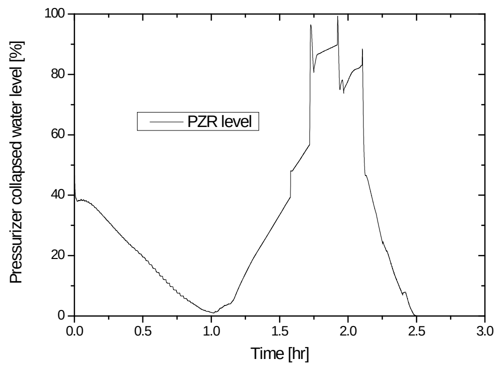

Fig. 5 Pressurizer collapsed water level

Without a supply of auxiliary feed water, the steam generators become depleted before 36 minutes as presented in Fig. 3. The pressure behavior of the primary and the secondary system is shown in Fig. 4. The pressure buildup in pressurizer occurs about 1 hour following the RCS heatup. The complete depletion of SG is delayed by inventory below the lower level tap. After the complete depletion of SG, MSSV open frequency and the heat transfer through SG tube wall decreases. The swelling of RCS and the insurge in pressurizer can be observed in Fig. 5. The level drop in reactor vessel is depicted in Fig. 6 after PSV opening.

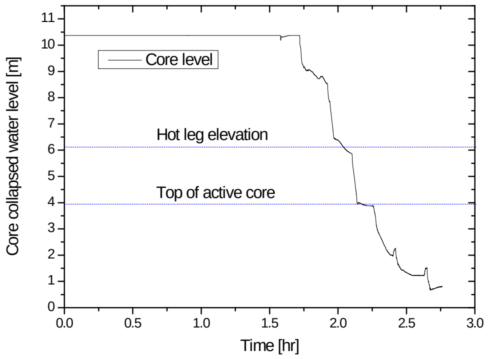

Fig. 6 Core collapsed water level

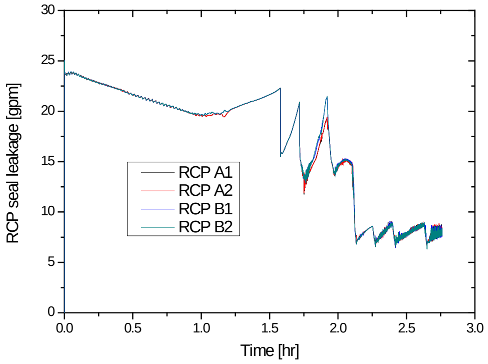

Fig. 7 RCP seal leakage flow rate

After the loss of heat removal function of SG, the inventory of primary RCS gradually decreases. The flow rates of leakages through the RCP seals are oscillatory generally according to intermittent PSV opening as shown in Fig. 7. At about 2 hours, the RCP seal leakage flow abruptly drop because the upstream of RCP seal become two phases and the core level pass the cold leg elevation.

3. Conclusions

The studies on transient phenomena in early stage of ELAP event concurrent with LOUHS were performed. With a simplified calculation, the total demand of feed water to SGs was calculated as 1×10^6 gallons for 3 days which can be accommodated in present condensate storage tank of OPR1000. To analyze the coping time, the unavailability of the TDAFW pump was assumed. In the numerical simulation with SPACE code, steam generators are depleted completely at about 1 hour and the heatup and the pressure buildup of RCS occur. As a result, there is 2.2 hours to take accident mitigation actions to prevent core uncovery. The hydraulic behaviors, such as swelling of pressurizer water volume and RCP seal leakage decrease due to level drop, are observed in the calculation results. In the future, the sensitivity studies on various circumstances will be carried out for development of appropriate coping strategies for postulated beyond-design-basis events.

REFERENCES

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