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Numerical Analysis for the Accident at Spent Fuel Bay Cooling and Purification System of Wolsong NPP Unit 1

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1. Introduction

As a part of supporting LPSD (Low Power and Shutdown) PSA (Probabilistic Safety Assessment) of Wolsong Unit 1, numerical analysis for the accident at SFB (Spent Fuel Bay) cooling and purification system of Wolsong NPP Unit 1 was performed using RELAP5/MOD3.3 code[1]. The main purpose of SFB cooling and purification system is to remove decay heat of spent fuels and to maintain concentration of radioactivity (Fig. 1). Like Fukushima Daiichi nuclear disaster in 2011, loss of heat sink at SFB can lead to a critical situation. However it is also true that there is much more time available for operators to act responses to the accident at SFB compared with design basis accidents related to the reactor core occurring in the nuclear power plant. In this analysis, pipe rupture in the SFB cooling and purification system in Wolsong NPP Unit 1, the most severe accident at SFB, was analyzed to calculate the time of boiling and the time at which fuels are uncovered. The estimated times may be used for HRA (Human Reliability Analysis) of PSA.

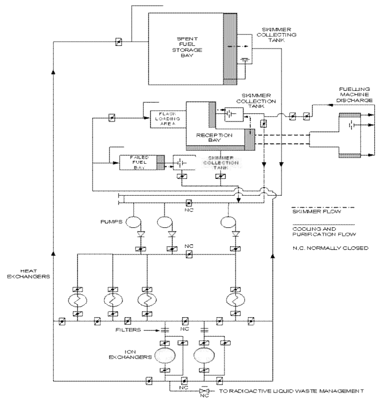

Fig. 1 Schematic diagram of SFB cooling and purification system

2. Methods and Results

2.1 Analytical Method

The RELAP5/MOD3.3 code was used for the SBLOCA in SFB cooling and purification system. Based on the configuration of the system and mode of operation, SFB system was modelled as shown in Fig 2. Spent Fuels are stacked along 19 trays and 24 bundles of fuel are stored in 1 tray. The two nodes (node 170 and 180) are constructed in the SFB since one node modelling gives almost stagnation flow in the SFB during the accident. This one node modelling in the SFB predicted unreasonable temperature distribution of SFB water during rupture of pipe.

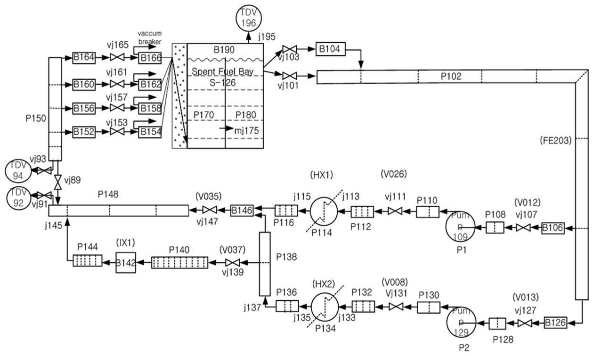

Fig. 2 Nodalization of SFB cooling and purification system

The two main functional requirements of SFB cooling and purification system are 1) to remove decay heat by 10 years accumulation of spent fuel at an 80 capacity factor refueling rate while maintain an operating temperature within the bay not exceeding 38°C (Normal operating condition) and 2) to remove decay heat from fuels at the normal operation condition plus one-half of reactor fuel discharged from the reactor 20 days after shutdown while maintain an operating temperature within the bay not exceeding 49°C (Abnormal operating condition). The heat loads in the SFB were conservatively assumed to be constant value of 2MWt and 4MWt at normal operation condition and abnormal operation condition respectively based on the design manual of the system. The postulated accidents which can be occurred in the SFB may be loss of SFB cooling (loss of pump, spurious valve closure, and loss of RSW etc.), loss of SFB inventory(rupture of piping or heat exchanger tubes) and loss of offsite power. Above all, loss of inventory is the most limiting accident. Therefore, pipe rupture downstream SFP pumps was chosen to be the target accident for analysis.

2.2 Analysis results

The Fig. 3 shows the results of steady state for normal operating condition of SFB. As shown in Fig. 4, following rupture of pipe in the system, the water level of the SFB decreases rapidly since SFB pumps still operates until the pumps stop automatically on SFB low level. The loss of pumps means loss of heat sink to SFB.

The temperature of water in the SFB increases gradually up to boiling point.

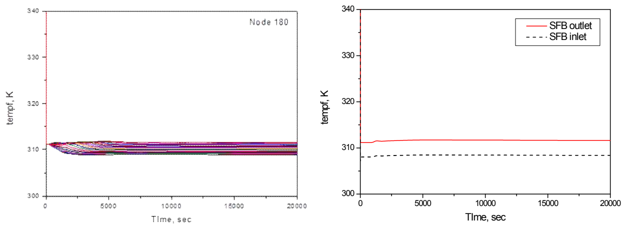

Fig. 3 Results of steady state for SFB normal operation

Upon reaching the saturation temperature, loss of SFB inventory occurs again due to vaporization of water in the SFB. Since total heat load of fuels are very low, there seems to be much time for operators to act measures against the accident. The time at which top of fuel was uncovered was calculated to be 240.5 hr after the accident.

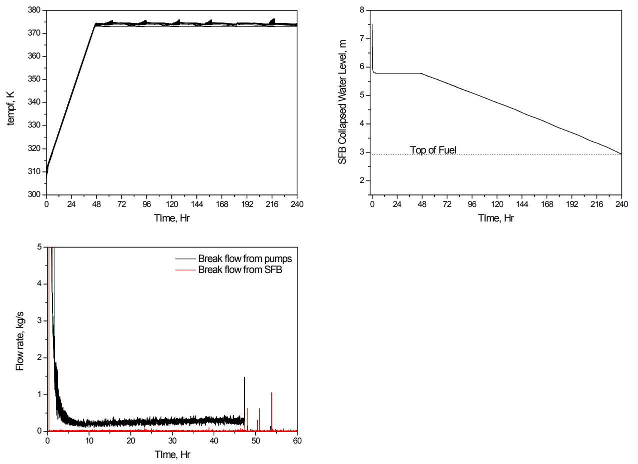

Fig. 4 Results of pipe rupture in the SFB for SFB normal operation

The results of steady state for SFB abnormal operation are shown in the Fig. 5.

The Fig. 6 shows the results of pipe rupture downstream SFB pumps in the abnormal operating condition. With higher initial temperature condition in the SFB and heat load of fuels, the boiling time is much shorter than that for SFB normal operation condition. The boiling begins at 19.72 hr and fuel uncover occurs at 117.6 hr following the accident.

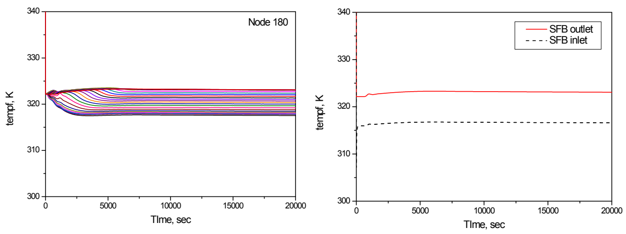

Fig. 5 Results of steady state for SFB normal operation

Although it is not easy to analyze the behavior of three dimensional effect using one dimensional code, the overall behavior like boiling and fuel uncovery time may be predicted reasonably for engineering purpose. Table 1 summarizes initial conditions and the major results.

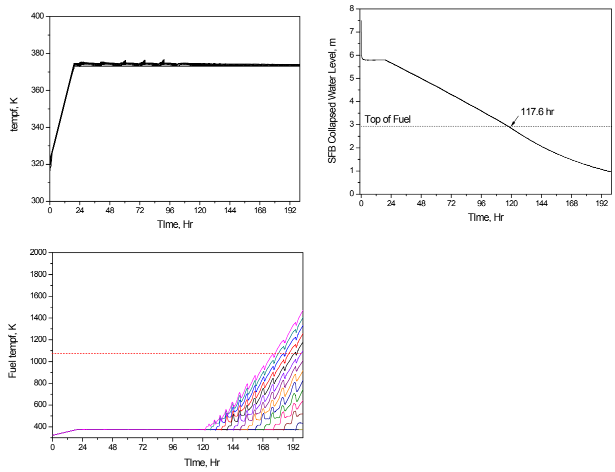

Fig. 6 Results of pipe rupture in the SFB for SFB abnormal operation

Table 1. Initial condition and summary of major results

	Normal operation	Abnormal operation
Heat loads of SFB	2 MWt	4 MWt
Initial temperature	38 ^{o}C	49 ^{o}C
Evaporation rate	0.88 kg/s	1.78 kg/s
Initial boiling	48 hr	19.72 hr
Uncovery of top of fuel	240.5 hr	117.6 hr

3. Conclusions

The accident in the SFB cooling and purification system of Wolsong NPP unit 1, specifically pipe rupture downstream SFB pumps, was analyzed using RELAP5/MOD3.3. The nodalization was developed based on the actual SFB cooling and purification system. The analysis of pipe rupture downstream SFB pumps for normal and abnormal conditions was performed to calculate major times, particularly the time of boiling and fuel uncovery. The predicted overall behaviors are reasonable. Thus the method developed in the analysis can be applied to support Wolsong NPP Unit LPSD PSA activities.

REFERENCES

[1] RELAP5/MOD3.3 Code Manual, Volume II, Appendix A Input Requirements, USNRC, Jan. 2002.
[2] Probabilistic Safety Assessment for Wolsong Unit 1. KHNP, 2011