Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang Korea, October 30-31, 2014

The Loss of Spent Fuel Pool Cooling Analysis during Plant Outage for OPR1000

Cheol Woo Kim* and Jae Young Huh

KEPCO E&C, Inc., Safety Analysis Dept.,
989-113 Daeduk-Daero, Yuseong-gu, Daejeon, KOREA 305-353,
*Corresponding author: cwkim@kepco-enc.com

1. Introduction

Recently, spent fuels stored in the spent fuel pool (SFP) with a loss of cooling during the refueling of plant outage have been required to maintain their integrity especially after the Fukushima disaster. A thermal-hydraulic analysis of the loss of SFP cooling (LOSFPC) during the plant operating state 8 (POS 8) or refueling period is performed to establish the success criteria for the probabilistic safety assessment (PSA).

This paper is to investigate the incipient boiling time in the spent fuel region, time to uncover in the SFP and the time of fuel cladding failure for the Hanul Nuclear Power Plant Units 3 and 4 (HUN 3&4) which is the typical optimized power reactor 1000 (OPR1000).

The results show that the sufficient time for operator action is available for the LOSFPC during the refueling period for the OPR1000.

2. Analysis Method of LOSFC

A realistic and best estimate analysis method is applied and reasonable operating conditions are assumed for the realistic PSA model.

RELAP5/MOD3.3-patch 4 [1] is used for the analysis of the thermal-hydraulic behavior in the SFP. The analysis is performed for the HUN 3&4 with 20 years of spent fuels stored in the SFP and the full core discharge. The used fuel racks are the high density storage rack of HUN 3&4.

The RELAP5 node diagram for the LOSFPC is provided in Figure 1.

3. Major Assumptions and Initial Conditions

Major assumptions and initial conditions for the LOSFPC analysis are based on the realistic and normal operation status of the average outage duration.

A limiting situation of the LOSFPC such as the full core is discharged to the SFP during refueling with all gates closed is considered. Other major assumptions used in the LOSFPC analysis are as follows:

- Newly discharged full core fuels at 200 hrs after reactor shutdown simultaneously
- The decay powers of all spent fuel assemblies based on the burn up of 54,000 MWD/MTU or 54 months (3 cycles of 18-month fuel)
- ANS2005 standard decay heat curve [2] considering 2-sigma (8%) uncertainty with the nuclides of U^{235}, U^{238}, Pu^{239}, Pu^{241} for the equilibrium cycle of Plus7 fuel
- The maximum fuel assembly (FA) of 68 for each batch
- New fuels ready for insert (stored in Region-I) without heat source to minimize water inventory
- No heat transfer through the metals except fuels
- No heat & mass transfer through water surface
- Constant heat generation of stored spent fuels in SFP racks
- No cross flow between racks

Conservative initial conditions for the LOSFPC analysis are assumed as Table 1.

Table 1 Initial Conditions of SFP

Parameters	Values	Remark
SFP Surface Pressure	101,325 Pa (1 atm)	-
SFP Surface Temperature	60 °C (333.15 K)	Max
Elevation of SFP Bottom	100.5 ft	-
Elevation of SFP Water Surface	142 ft	Nom
Decay Heat from SFs for 20 years	1.3547 MWt	-
Decay Heat from Full Core Discharge	9.167 MWt	
SFPC HX Flow Rate	2850 gpm	Min

4. Analysis Results

Using the modified RELAP5/MOD3.3-patch 4, the LOSFPC for the HUN 3&4 is analyzed using the high density storage rack.

4.1 Results of Pressure and Temperature Behavior

The pressure behaviors of the SFP are provided in Figure 2. As shown in this figure, the pool pressure is increased up to the time of boiling and SFP bottom pressure is maintained before boiling and then decreased due to the depletion of pool water. The spool water starts to boil at about 17,000 seconds (4.7 hrs) after event initiation and then the water inventory is decreased as shown in Figure 3.

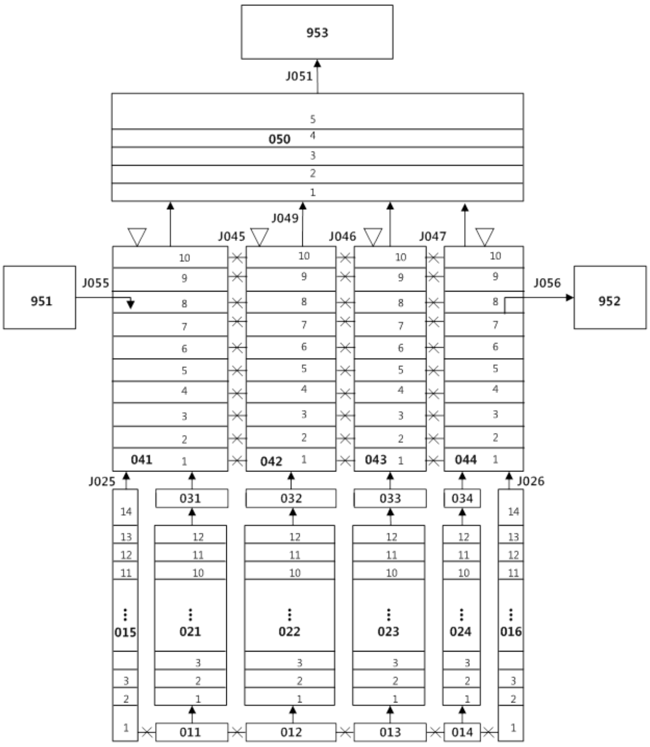

Figure 1 Node Diagram for LOSFPC

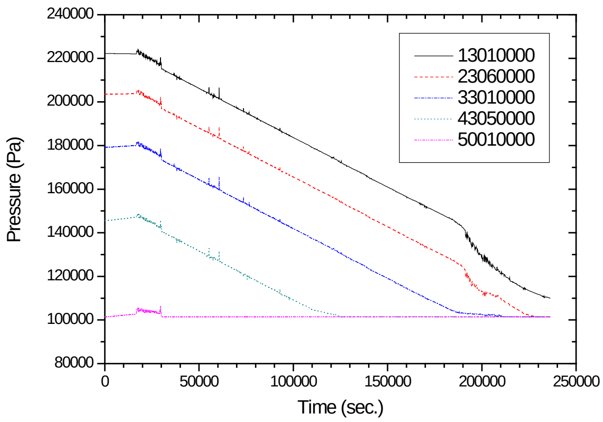

Figure 2 Pressure Distribution of SFP

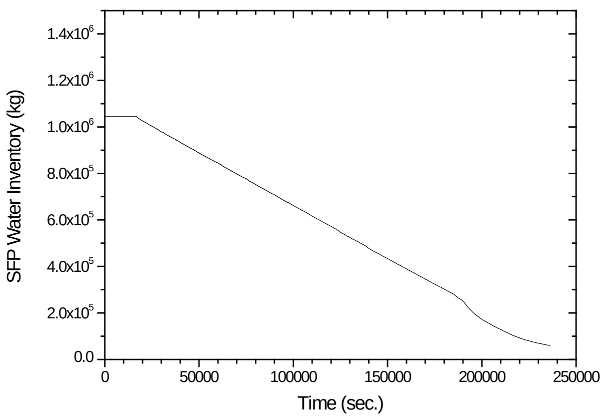

Figure 3 Water Inventory in SFP

Pool water temperature is increased up to the boiling and then maintained at the saturated temperature of the pressure (Figure 4). The maximum temperature is observed as 387 K.

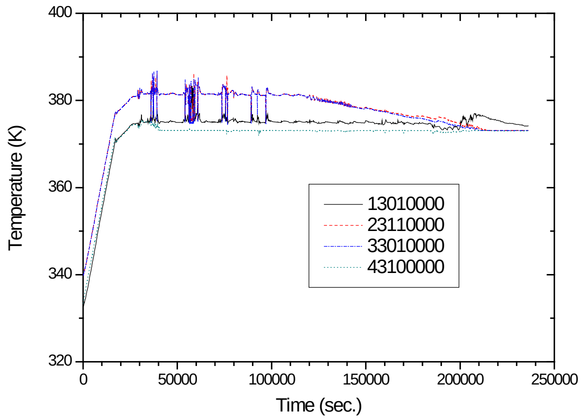

Figure 4 Temperature Distribution of SFP

4.2 Spent Fuel Pool Water Level

After boiling, the pool water level starts to decrease and empty at 186,000 seconds (51.7 hrs) as in Figure 5. The water levels of spent fuel racks as shown in Figure 6 start to decrease after depletion of pool.

Figure 7 compares the void fraction at the top of active core in the spent fuel racks. At the top of the active fuel, the water in the hottest assembly channel starts boiling at about 153,300 seconds (42.6 hrs) and the water in average FAs starts to boil at 166,800 seconds (46.3 hrs) whereas the spent FAs channel starts at 189,800 seconds (52.7 hrs).

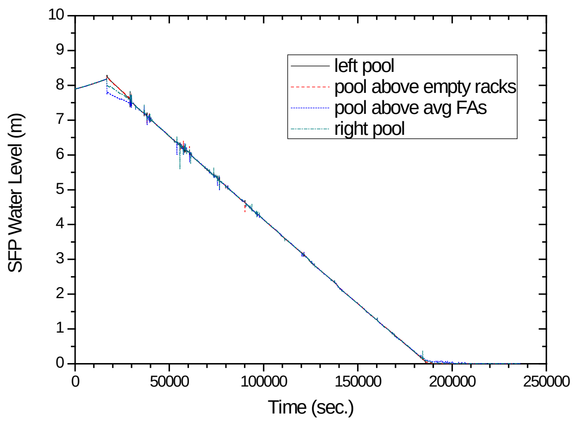

Figure 5 Water Level of Pool above Racks

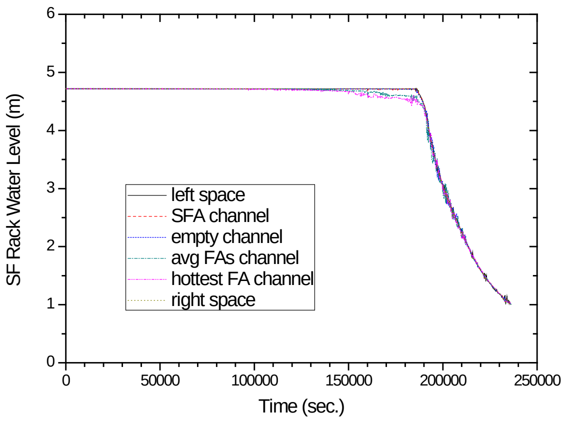

Figure 6 Water Level of SF Racks

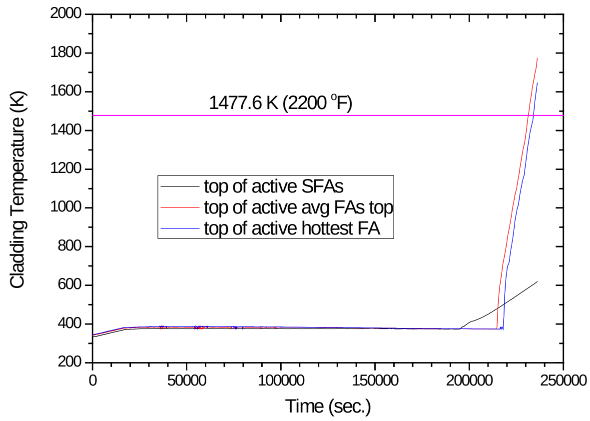

Figure 8 Distribution of Fuel Cladding Temperatures

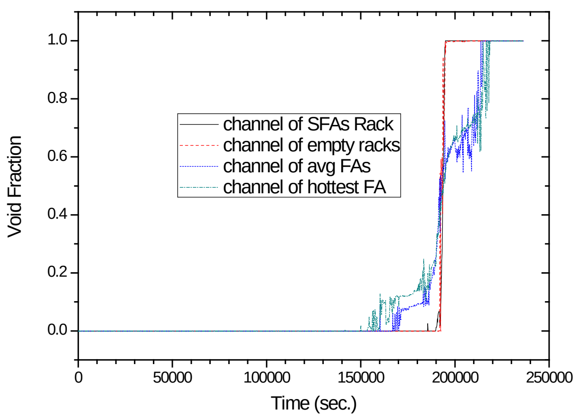

Figure 7 Comparison of Void Fraction in Fuel Racks

4.3 Peak Cladding Temperatures

The sequence of the major thermal-hydraulic phenomena is summarized in Table 2.

The uncover time of active fuel is determined as the time of sharp increase in void or cladding temperature. The uncover time is observed as 218,000 seconds (60.6 hrs) at the hottest assembly whereas 214,600 seconds (59.6 hrs) at the average FAs as in Figure 8. The time of cladding failure, which is the time of the peak cladding temperature exceeds 1477.6 K (2200 °F), is observed as 234,100 seconds (65 hrs) at the hottest assembly whereas 231,400 seconds (64.3 hrs) at the average FAs which is 4.7 hours after time to uncover.

Table 2 Results of Analysis

Time to	**Description**	**Time (sec./hr)**
SFP Boiling	Time of boiling at top surface of pool	17,000 (4.7)
Empty of Pool Water	Time of pool level less than 0.1 m (at pool above hottest FA)	185,600 (51.6)
Incipient Boiling at Top of Active Core	Based on continuous void formation at hottest FA channel	153,300 (**42.6**)
	At average FAs channel (newly discharged)	166,800 (46.3)
Fuel Uncover	Time to sharp increase of fuel cladding temperature (hottest FA)	218,000 (60.6)
	At channel of average FAs (newly discharged)	214,600 (**59.6**)
Fuel Damage	Time to PCT > 1477 K, at hottest FA	234,100 (65.0)
	At average FAs (newly discharged)	231,400 (**64.3**)

5. Conclusion

From a loss of SFP cooling analysis for HUN 3&4, RELAP5/MOD3.3 shows reasonable thermal-hydraulic behaviors and is acceptable to establish the success criteria of operator action for the PSA.

The results show that the incipient boiling occurs in the SFP at 42.6 hrs into the accident, the fuel uncover starts at 59.6 hrs, and the fuel cladding fails at 64.3 hrs. In conclusion, there is sufficient time for operator action to mitigate the LOSFPC during the refueling period for the OPR1000.

REFERENCES

[1] NUREG/CR-5355, Rev. P4, "RELAP5/MOD3.3 Code Manual," Nuclear Systems Analysis Operations, Information Systems Laboratory Inc., October 2010.

[2] ANSI/ANS-5.1-2005, "Decay Heat Power in Light Water Reactors," ANS, April 2005.