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Evaluation of Loss of Spent Fuel Pool Cooling for the Shin-Kori unit 1 and 2

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1. Introduction

The nuclear safety regulation in Korea was revised that it should be necessary to develop the Accident Management Plan (AMP) including the evaluation of multiple failure accident. The multiple failure accidents mean postulated accident conditions that are not considered for DBA. Multiple failure accidents are analyzed with best estimate methodology, and in which release of radioactive material is kept within acceptable limits. The Loss of Spent Fuel Pool Cooling (LOSFPC) accident is included in the multiple failure accident that must be considered as shown in table I. In this paper, the evaluation of LOSFPC was performed for Shin-Kori unit 1 and 2.

Table I: Type of multiple failure accidents that must be considered

Classifications	Type of accident
Accidents that should be considered	AWTS
	SBO
	MSGTR
	TLOFW
	ISLOCA
	LOSCS
	LOUHS
	Loss of SI or recirculation with SBLOCA
	LOSFPC

2. Evaluation Methods and Results

2.1 Assumption of Accident Scenario

The assumption of operation mode at initiation of accident is also important to estimate the decay heat. Generally, it is considered that three operation modes are normal, abnormal and refueling modes to estimate the spent fuel pool accident.

In the normal operation mode, it was applied that the spent fuel pool was storing 944 spent fuel assemblies for 16 cycles and the 1/3 core from last cycle was discharged. The number of cycles is considered based on the SFP storage capacity for Shin-Kori unit 1. The time to finish the fuel transfer on last cycle and occur the LOSFPC is 150 hour after reactor shutdown.

In case of refueling mode, it was considered that the previous stored fuels were same as normal operation mode and the full core on last cycle was discharged. According to the NEI 12-06, it is considered that the refueling mode scenario is assumed for most conservative initial condition to evaluate cooling capacity of SFP [1]. The time to finish the fuel transfer on last cycle and occur the LOSFPC is also 150 hours after reactor shutdown.

In case of abnormal mode, the number of previous stored fuels and discharged fuels at last cycle are same as the refueling scenario. However, it was additionally considered that 1/3 core were discharged due to the abnormal situation at 480 hours before LOSFPC occurs.

The number of discharged fuel assemblies at each cycles is illustrated in table II.

Table II: The number of discharged fuel assemblies (FAs) on each assumed cases

Fuel group	Time after reactor shutdown	Normal	Refueling	Abnormal
1	150 hrs	59 FAs	177 FAs	177 FAs
2	480 hrs	-	-	59 FAs
1	1.5 yr	59 FAs	59 FAs	59 FAs
2	3	59 FAs	59 FAs	59 FAs
3	4.5 yr	59 FAs	59 FAs	59 FAs
4	6 yr	59 FAs	59 FAs	59 FAs
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15	22.5 yr	59 FAs	59 FAs	59 FAs
16	24 yr	59 FAs	59 FAs	59 FAs
Total # of FAs		1,003	1,121	1,180

2.2 Evaluation of initial temperature of SFP coolant

The initial coolant temperature at the LOSFPC occurs was calculated using the equation (1). The law of energy conservation is applied to this equation.

$$C \times m \times \frac{dT}{dt} = Q_{decay} - Q_{HX} - Q_{evap} \qquad (1)$$

Where, C is heat capacity of SFP coolant, m is mass of SFP coolant, Q_{decay} is total decay heat released, Q_{HX} is removed heat by SFP heat exchanger of SFP cooling system, and Q_{evap} is heat loss by evaporation on coolant surface.

$$Q_{HX} = W_c \times C_c \times \frac{T_{C,o} - T_{C,i}}{T - T_{C,i}} \times (T - T_c) \qquad (2)$$

$$Q_{evap} = M(T, T_A) \times h_{fg} \times A_S + h_c \times (T - T_A) \times A_S \qquad (3)$$

$$M(T, T_A) = -64.8 \times \left(\frac{C(T_A) \times D_{H_2O,air}(T)}{L}\right) ln\left(1 - y_{A,O}\right) \qquad (4)$$

Where, W_C is mass flow rate of SFP heat exchanger inlet, C_C is heat capacity of SFP Hx coolant, T is SFP initial temperature, T_C is initial temperature of SFP Hx coolant, and M is evaporation mass flow rate.

The design parameters of SFP are used to calculate above equations [2]. The calculation was performed using iteration method and initial temperature of coolant in SFP was calculated as shown in table III.

Table III: Type of multiple failure accidents that must be considered

Operation state	Operated Hx train	Maximum decay heat (MW_t)	Initial temperature (℃)
Normal	1	4.17	45.93
Refueling	1	9.73	60.5
Abnormal	2	11.6	50.21

2.3 Evaluation of event time and maximum evaporation rate

The water level is decreased due to the decay heat released from the stored spent fuel assemblies during the LOSFPC. For the accident mitigation, the evaluation of operator action time margin should be performed.

According to the INPO event report, the time to reach the temperature of 200 ℉ is important [3]. Therefore, the time to reach the degree of 200 ℉ was calculated using equation (5). Also, the time to reach the boiling point (212 ℉) and the top of SFP rack were calculated using as follows. Finally, the maximum evaporation rate of coolant was also calculated using the calculation results of event time and calculation results are shown in Table IV.

$$t_{200} = [V_{SFP} \times \rho_{SFP} \times C_P \times (200 - T_i)]/Q_{decay} \quad (5)$$

$$t_{boil} = [V_{SFP} \times \rho_{SFP} \times C_P \times (212 - T_i)]/Q_{decay} \quad (6)$$

$$t_{rack} = t_{boil} + \left(h_{fg} \times V_{rack} \times \rho_{SFP}\right)/Q_{decay} \quad (7)$$

$$\dot{V}_{evap} = V_{rack}/(t_{rack} - t_{boil}) \quad (8)$$

Where, ρ is density, C_p is heat capacity, T_i is initial temperature which is calculated in chap 2.2, h_{fg} is latent heat, and V_{rack} is free volume of coolant above the SFP rack.

Table IV: Type of multiple failure accidents that must be considered

Operational state	Time to reach the 200℉ (hr)	Time to reach the boiling point (hr)	Time to reach the top of rack (hr)	Maximum evaporation rate (gpm)
Normal	11.92	13.6	106.85	29.81
Refueling	3.54	4.26	44.22	69.58
Abnormal	3.9	4.5	38.0	82.98

3. Conclusions

In this paper, the event times which is considered during the LOSFPC are evaluated and maximum evaporation rate of SFP coolant is also calculated. As the result, the maximum evaporation rate is much lower than the designed flow rate of external SFP cooling injection for Shin-Kori unit 1 and 2. Therefore, it is concluded that the margin is sufficient to prevent the SFP integrity during the LOSFPC.

REFERENCES

[1] Nuclear Energy Institute, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide, NEI 12-06, Rev.B1, 2012.

[2] KOPEC co., Ltd., Evaluation report for coping with external cooling injection of SFP, 2012.

[3] Intitute of Nuclear Power Operations, Fukushima Daiichi Nuclear Station Spent Fuel Pool Loss of Cooling and Makeup, IER L1-11-2, 2011.