Development of Methodology for Spent Fuel Pool Risk Assessment

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1. Introduction

Fukushima nuclear accident was not one of the accident scenarios which has preparedness plan, due to low frequency. But because the catastrophic accident was occurred in Fukushima, it became necessary changes in the nuclear safety framework. The major insight of Fukushima accident was necessity to prepare prevention and mitigation plan for beyond design basis accidents at multiple units. In addition, through the case of the incident of 4th unit of Fukushima, spent fuel is also important factor of the radiation release. Integrated risk assessment for whole site is necessary for developing preparedness plan for severe accident such as Fukushima event. The purpose of this paper is to acquire the Human Reliability Assessment(HRA) information for developing Spent Fuel Pool Probabilistic Safety Assessment (SFP PSA).

2. Methods and Results

2.1 RULEMAKING EFFORTS TO ENHANCE SAFETY

After the Fukushima Daiichi accident, Korean government became keenly aware of the necessity of systematic regulatory framework for severe accidents based on stipulated legislation, which can encompass not only the previous regulations on severe accidents but also the recent domestic responses and international efforts made to address lessons learned from the accident. The National Assembly made an amendment of the Nuclear Safety Act in 2015 to provide legal bases for regulatory control of severe accidents. The amendment of the Nuclear Safety Act requires that the applicant for operating license of a Nuclear Power Plant(NPP) shall provide, as one of application documents, an explanation on how the reactor facility and operation programs of the applicant satisfies the regulatory requirements on severe accidents stipulated in the Nuclear Safety Security Commission rules.

To prevent severe accidents, the new regulatory framework for severe accidents considers measures to control two categories of accident conditions, which are accidents associated with multiple failures and with beyond-design-basis extreme hazards. For regulatory control of accidents associated with multiple failures, various types of accidents are considered including conventional beyond-design-basis accidents e.g. anticipated transient without scram. Table 1 summarizes multiple failure accidents to be considered. The Loss of Spent Fuel Pool Cooling(LOSFPC) accident is included in the multiple failure accident that must be considered as shown in table 1.

Table 1. Accidents associated with multiple failures

Classification	**Type of accident**
List of accidents that shall be considered	- Anticipated transient without scram - Loss of AC power system - Loss of ultimate heat Sink - Multiple steam generator tube ruptures - Inter-system loss of coolant accident - SBLOCA with loss of safety injection - Loss of shutdown cooling **<u>- Loss of cooling function of spent fuel pool</u>**

2.2 ASSUMPTION OF ACCIDENT SCENARIO

The _ 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 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 APR1400. The time to finish the fuel transfer on last cycle and occur the LOSFPC is 100 hours 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 Final Safety Analysis Report(FSAR), 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 100 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.

It is generally assumed the spent fuel assemblies is stored for 16 cycle (20 year). However, since the some of them contain more than 30 cycles in Korea NPP, the calculation result of the maximum heat load is shown in Fig 1.

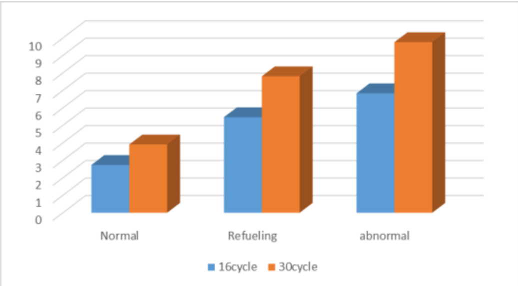

Fig. 1. Maximum Heat Load(Mw)

2.3 EVALUATION OF EVENT TIME IN SFP COOLING

One of the key issues in performing a PSA for the SFP is how much credit can be given to the operating staff to respond to an incident that impacts the SFP that would lead to a loss of cooling of the spent fuel. The times available for operator actions are based on calculations of the time it would take for bulk boiling to begin in the pool as appropriate to the definition of the corresponding human failure event [2]. The initial coolant temperature at the LOSFPC occurs was calculated using the equation (1). The law of energy conservation is applied to this equation.

$$C \times m \times dT/dt = Q \qquad (1)$$

Where, C is heat capacity of SFP coolant, m is mass of SFP coolant, Q is total decay heat released. The water level is decreased due to the decay heat released from the stored spent fuel assemblies during the LOSFPC [3].

For the accident mitigation, the evaluation of operator action time margin should be performed. The time to reach the boiling point (operator action time margin) is important. Therefore, the time to reach the degree of 212 °F was calculated using equation (2).

$$t_{boil}=[V_{SFP}\times\rho_{SFP}\times C_P\times(212-T_i)]\ /\ Q_{decay} \qquad (2)$$

Where, ρ_{SFP} is density, C_p is heat capacity, T_i is initial temperature, and V_{SFP} is free volume of the SFP. Figure 2 shows that the operator action time(margin) is a little reduced because the maximum heat load of 30 cycles is greater than that of 16 cycles.
And, the operator action time for recovery was substituted for Technique for Human Error Rate Prediction(THERP) and the probability of human error of operator was calculated [4]. The results can be found in Table 2 below.

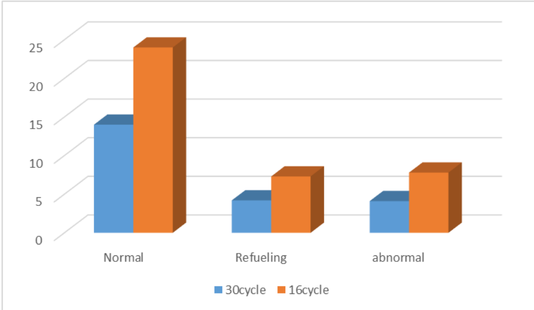

Fig. 2. Evaluation of Operator Action Time Margin(hr)

Table 2. HEP from THERP

Operational state	Normal	Refueling	Abnormal
16 cycle	8.59E-05	2.03E-04	1.95E-04
30 cycle	1.29E-04	3.04E-04	3.06E-04

3. Conclusions

In this study, the event times which is considered during the LOSFPC are evaluated and the probability of human error of operator at that time is also calculated. The study will provide input data needed to develop the SFP PSA. It will also be useful for the assessment of the loss of cooling function of spent fuel accidents, which is a multiple failure accident, in the accident management plan.

ACKNOWLEDGMENTS

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REFERENCES

[1] Korea Hydro & Nuclear Power, "Final Safety Analysis Report for Shin-Kori 3,4", 2011
[2] U.S. NRC, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants", NUREG-1738, 2001
[3] KOPEC co., Ltd., "Evaluation report for coping with external cooling injection of SFP", 2012
[4] U.S. NRC, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications", NUREG/CR-1278, 1983