Application of Boron Credit Effect Methodology to Domestic Nuclear Power Plant

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1. Introduction

Spent fuel discharged after depletion in the reactor is stored in spent fuel pool (SFP) of domestic nuclear power plant (NPP). Since the reactivity of spent fuel increases when the gap between them approaches, soluble boron is mixed in the cooling water to prevent criticality. Soluble boron is generally injected and maintained at least 2,400 ppm according to the NPP technical specification. The methodology of securing sub-criticality by applying such soluble boron in the critical safety evaluation is called the boron credit effect. In the United States, the boron credit effect methodology is applied under normal and accident conditions in accordance with CFR 50.68(b)(4), but is not allowed in Korea [1, 2]. In this paper, we analyze the boron Credit effect methodology and describe the results of application to domestic nuclear power plants.

2. Methods and Results

2.1 Methodology

According to the US NRC "DSS-ISG-2010-01, Rev.0", and "NEI 12-16 and Rev.4", it is recommended to perform boron dilution accident evaluation to apply the Boron Credit effect. The boron dilution accident evaluation defines possible boron dilution accidents in the SFP, evaluates the dilution time to the target boron concentration, and proves that there is enough time for the operator to take follow-up action. [3, 4]. Therefore, in this paper, boron dilution accident evaluation was performed to apply the boron credit effect to domestic nuclear power plants. First, the minimum boron concentration applicable to the boron credit effect methodology was calculated, and then the time required to reach the minimum boron concentration due to the boron dilution accident was calculated. In order to calculate the minimum boron concentration, the spent fuel pool of domestic nuclear power plants was selected to calculate the critical safety margin secured according to the soluble boron concentration. Nuclear fuel was modeled on 17x17 WH type with 5.0 wt/o, and the boron credit effect methodology was applied under the same conditions as the existing critical safety evaluation methodology. The evaluation showed that the burnup ensured when the soluble boron concentration increased by 100 ppm was about 2,000-3,000 MWD/MTU, and when 500 ppm was applied, about 7,000-8,000 MWD/MTU. Therefore, the minimum boron concentration considered in the boron dilution accident evaluation was selected as 500 ppm. In addition, the input data applied to the boron dilution accident evaluation are as follows.

Table 1: Sources of Unborated Water into the SFP

Components	Flow Rate(gpm)
Spent Fuel Pool Cooling Heat Exchangers	7,000
Purification Pump	6,300
Demineralized Water Transfer Pumps	600
Fire Protection System	3,000

Table 2: Specifications of SFP

Factors	Value
Boron Density of SFP (C_0)	2,400 ppm
Volume of SFP (V)	460,000 gallons
High Level Alarm of SFP	93.4%

Based on the boron dilution source at the maximum inflow rate, the time required to reach the minimum boron concentration limit of 500 ppm was calculated. The assumptions and calculation formulas applied to the calculation are as follows.

- It was assumed that the unborated water inflowed from each boron dilution source was infinite.
- It is assumed that the volume of the SF reservoir is infinite.
- It is assumed that unborated water introduced into the SF storage tank is immediately homogeneously mixed with borated water present in the SFP.

$$C(t) = C_0 \times e^{-\left(\frac{t}{\tau_2}\right)}$$

Where:

- C(t) is the boron concentration at time t
- Co is the initial boron concentration
- τ is M/W
- M is the mass of the control volume (mass of borated water in the SFP in this case)
- W is the mass flow rate of the unborated water

2.2 Result

As a result of the evaluation, it was found that in the case of a heat exchanger accident with the largest inflow flow rate, it took about 103 minutes for the boron concentration to be diluted to 500 ppm. At this time, around 2 minutes after the accident, the water level of the SF reservoir reaches 93.4% and the high level alarm is operated, so the operator can recognize the boron dilution accident. Therefore, after the operator recognizes the boron dilution accident, the time required to dilute the boron concentration to 500 ppm was 101 minutes. In conclusion, it is judged that 101 minutes is enough time to stop the boron dilution accident for the driver.

Table 3: Boron Dilution Evaluation Results

Components	Time to 500ppm (min)	Time to SFP High Level Alarm (min)	500ppm after SFP High Level Alarm (min)
Spent Fuel Pool Cooling Heat Exchangers	103	2	101
Purification Pump	114	2	114
Demineralized Water Transfer Pumps	1,200	14	1186
Fire Protection System	240	3	237

3. Conclusions

In this paper, boron dilution accident evaluation was performed to apply the boron credit effect to domestic nuclear power plants. First, the minimum boron concentration applicable to the boron credit effect methodology was calculated, and then the time required to reach the minimum boron concentration due to the boron dilution accident was calculated. As a result of the evaluation, the minimum boron concentration applicable to the boron credit effect methodology was 500 ppm, and the time required for the boron concentration of the spent fuel pool to be diluted to 500 ppm after the boron dilution accident was 101 minutes. In conclusion, 101 minutes is enough time to stop the boron dilution accident, so it can be said that the critical safety of the spent fuel pool is secured.

REFERENCES

[1] NRC Code of Federal Regulations, Title 10, Part 50.68, "Criticality accident requirements", 2006

[2] 한국원자력안전기술원, “경수로형 원자력발전소 규제지침”, KINS/RG- 10.01, Rev. 1, 2015. 8.

[3] DSS-ISG-2010-01, Final Division Of Safety Systems Interim Staff Guidance, “Staff Guidance Regarding The Nuclear Criticality Safety Analysis For Spent Fuel Pools,” Revision 0.

[4] NEI 12-16, “Guidance for Performing Criticality Analyses of Fuel Storage at Light-Water Reactor Power Plants”, Revision 3, March 2018