Evaluation of Boric Acid Precipitation Reflecting System Effects in Post LOCA Long-term Cooling

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1. Introduction

Post-LOCA long-term cooling has the objective of maintaining the core at safe temperature levels following any rupture in the primary system. To assure the core is maintained at acceptably low temperatures, precipitation of boric acid during the event must be avoided. The means of preventing boric acid precipitation has been to initiate simultaneous hot- and cold-side injections to terminate the build-up and flush the boric acid from the core. The timing of this operator's action is based on an evaluation of the build-up of boric acid in the vessel core and upper plenum regions.

Recently, the USNRC identified several non-conservative assumptions in the previously approved boric acid precipitation evaluation methodology and decided not to allow the use of the existing evaluation methodology until the NRC staff's safety concerns are sufficiently resolved [1]. The major concerns of the USNRC are that the assumptions about mixing volume are not conservative and the system effects such as time-varied mixing volume due to the variation of the core mixture level and void fraction cannot be addressed in the current boric acid precipitation evaluation. The Korean regulatory body also has requested the evaluation of the long-term cooling capability for domestic operating plants through the Periodic Safety Review (PSR). Therefore, a new evaluation methodology for boric acid precipitation reflecting system effects are developed to resolve the safety issues by modifying the current licensing code, BORON [2]. In this paper, the code modification and new analysis results for typical OPR-1000 (UCN 3&4) as a feasibility study are discussed. RELAP5/MOD3.1 is used to extract a time-varied mixing volume to implement system effects into the BORON code.

2. Analysis Methodology

The BORON[2] code calculates the boric acid concentration in the core and provides technical basis for the timing for simultaneous hot- and cold-side injections to terminate the build-up and flush the boric acid from the core using the following input; (a) initial boric acid water sources such as Refueling Water Tank, (b) injection pump characteristics such as safety injection flowrates, (c) mixing volume, (c) decay heat rates, (d) and net flushing flow with time, etc.

The current BORON code treats the core as one node with a constant mixing volume; therefore, it cannot reflect system effects such as time-varied mixing volume due to the variation of the core mixture level and void fraction. The mixing volume used in the current boric acid precipitation analysis consists of the volume from the core support plate to the bottom of the hot legs and the entire volume of the lower plenum. To address this safety concern, the mixing volume variation is extracted from the collapsed liquid level of the RELAP5/ MOD3.1 calculation results. For the lower plenum volume, two cases are considered: (a) the entire volume of lower plenum is credited and (b) only 50% of the volume of the lower plenum is credited. In Waterford Unit 3 power uprate licensing amendment, only 50% volume of the lower plenum was credited in the mixing volume from the test results [3].

Figure 1 shows the mixing volume variation calculated using RELAP5/MOD3.1 code considering system effects during the long-term cooling phase. The calculated mixing volumes are sufficiently lower than those of current boron code. This shows that the mixing volume in the current boric acid concentration calculation is not conservative as the USNRC identified it. The calculated mixing volumes increase until about 3,500sec and then are stabilized for both cases. In the modified BORON code, the curve-fitted mixing volume is used until 7,195sec, the time at which no core flushing flow exists. After this time the mixing volume is assumed to be constant.

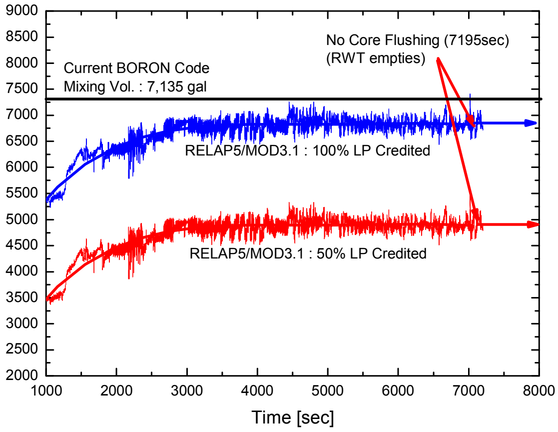

Fig.1 Mixing Volume Variation in the Reactor Vessel (OPR-1000, UCN 3&4).

The governing equations are modified to consider the time-varied mixing volume and density. The modified boric acid concentration equations are as follows:

- Injection phase

$$\omega_{core}^{n} = \omega_{core} + \frac{\rho_{RWT}\omega_{RWT}V_{in,boron}}{\rho_{core}V_{core} + 0.0035\rho_{water}\omega_{core}V_{core}} - \frac{\rho_{core}\omega_{core}}{\rho_{core}V_{core} + 0.0035\rho_{water}\omega_{core}V_{core}}(V_{core}^{n} - V_{core}) \quad (1)$$

- Recirculation phase

$$\omega_{core}^{n} = \omega_{core} + \frac{\rho_{sump}\omega_{sump}V_{in} - \rho_{core}\omega_{core}V_{flushing}}{\rho_{core}V_{core} + 0.0035\rho_{water}\omega_{core}V_{core}} - \frac{\rho_{core}\omega_{core}}{\rho_{core}V_{core} + 0.0035\rho_{water}\omega_{core}V_{core}}(V_{core}^{n} - V_{core}) \quad (2)$$

$$\omega_{sump}^{n} = \omega_{sump} + \frac{\rho_{core}\omega_{core}V_{flushing} - \rho_{sump}\omega_{sump}V_{in}}{\rho_{sump}V_{sump} + 0.0035\rho_{water}\omega_{sump}V_{sump}} - \frac{\rho_{sump}\omega_{sump}}{\rho_{sump}V_{sump} + 0.0035\rho_{water}\omega_{sump}V_{sump}}(V_{sump}^{n} - V_{sump}) \quad (3)$$

where

$$V_{in} = Boil + (V_{core}^{n} - V_{core}) + V_{flushing}$$

In the injection phase, the boric acid concentration is calculated using Eq. (1), assuming that the boil-off flow by decay heat plus the mixing volume variation are compensated by the core flushing flow from RWT until RWT is 90% empty. After RWT is empty, the boric acid concentration is calculated using Eqs. (2) and (3). It is assumed that there is no core flushing flow with a constant mixing volume in this phase.

3. Results and Discussion

Boric acid precipitation analysis uses conservative assumptions to yield the most unfavorable performance predictions. The major assumptions for the analysis are as follows: (a) core power is 102% of the nominal full power, (b) the decay heat model based on the 1973 ANS Standard 5.1, (c) maximum boric acid source concentrations, (d) RCS saturation conditions based on the atmospheric pressure, (e) and one HPSI pump is assumed to be operable. The detailed evaluation methodology including major assumptions is described in Reference 2.

Figure 2 shows the comparison of boric acid concentration variation in the reactor vessel between the current and modified BORON code. For the first 1,000 seconds, all cases assume a constant mixing volume and the nominal decay power is multiplied by 1.2. This results in the same boric acid concentration for this time interval. After 1,000 seconds, the boric acid concentration increases most rapidly when 50 % of the lower plenum volume is credited. The lower mixing volume contributes to a more rapid increase in the boric acid concentration. Even though the mixing volume in the current BORON code is more than the case at which the entire volume of lower plenum is credited, boric acid concentration is lower than that of the current BORON code. That is why the mixing volume in the current BORON code is conservatively recalculated for density changes as the boric acid builds up.

In OPR-1000, High Pressure Safety Injection pumps discharge is realigned so that the total injection flow is divided approximately equally between the hot and cold legs between two and three hours post LOCA. The concentration for boric acid precipitation is 29 wt%. This is the precipitation limit at 16.2 psia (1.12bar), 217°F (103°C). These conditions were calculated using a conservative ECCS model for containment pressure [4]. When the entire lower plenum is credited as the mixing volume the current simultaneous injection timing is effective. It is found that earlier initiation of the simultaneous injection is needed to prevent the boric acid precipitation for cases at which 50% of lower plenum volume is credited. However, the present results are so preliminary that this fact will be confirmed through the detailed analysis in the plant application to verify the long-term cooling capability of domestic operating plants.

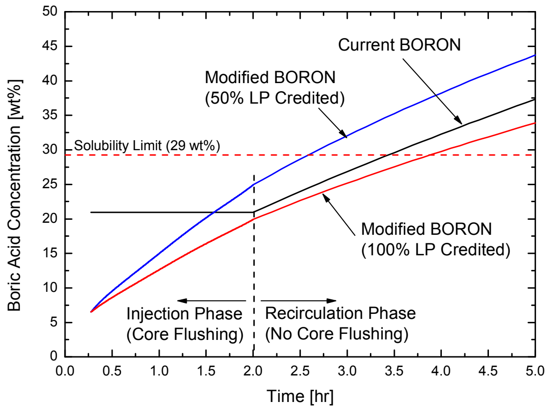

Fig. 2. Boric Acid Concentration in the Reactor Vessel (OPR-1000, UCN 3&4)

3. Conclusions

A new evaluation methodology for boric acid precipitation in post LOCA long-term cooling are developed, reflecting system effects by modifying the current licensing code, BORON. The system effects, such as the time-varied mixing volume due to the variation of the core mixture level and the void fraction, are implemented using RELAP5/MOD3.1. Through the present study, it is concluded that the developed methodology can meet the regulatory position on boric acid precipitation analysis. This methodology will be applied to verify the long-term cooling capability of domestic operating plants.

REFERENCES

[1] NRC Letter "Suspension of NRC Approval for Use of Westinghouse Topical Report CENPD-254-P, Post-LOCA Long-Term Cooling Model, Due to Discovery of Non-conservative Modeling Assumptions during Calculation Audit" dated August 1, 2005.

[2] WEC, CENPD-254-P-A, Revision 1-P, "Post-LOCA Long Term Cooling Evaluation Model," Revision 1-P, June 1980.

[3] Westinghouse Letter LTR-LIS-05-56, Revision 0, "Waterford 3 Update RAIs, Transmittal of Summary of MHI BACCHUS Tests," dated 02-03-05. MHI Tests.

[4] Korea Hydro & Nuclear Power Co., Ltd., “Final Safety Analysis Report,” UCN 3&4.