Analysis of Inherent Boron Dilution after SBLOCA in PWR

Kae Yeol Lew, Seoung-eun Chun, Sang Min Jung, Geol Woo Lee
KEPCO Nuclear Fuel, Daejeon, Korea
kylew@knfc.co.kr, sechun@knfc.co.kr, smjung@knfc.co.kr, gwlee@knfc.co.kr

1. Introduction

Inherent heterogeneous Boron dilution [1][2][3][4] in post-SBLOCA can be caused by injection of the slug of water in the reactor coolant loops due to condensed steam accumulated in Steam Generator (SG) tubes is . Boron-free water is collected in a region of the primary system forming a non-borated slug. If the subsequent natural circulation or RCP restart is established, the slug could be transported to the core. The entering of unborated slug to the core may cause a recriticality excursion. 3-Dimnsional analysis using the FLUENT [5] computational fluid dynamics code is performed to evaluate the mixing behavior of unborated water in the RCS after the initiation of natural circulation and RCP restart. In this study, a loopseal, a reactor coolant pump, a cold leg, a downcomer, a lower plenum and a core are modeled.

2. Analysis Method and Calculation Results

2.1 Analysis Method Description

A three-dimensional FLUENT model of the reactor vessel with RCP, suction loop, cold leg, lower plenum and active core is applied to model a turbulent chemical species mixing. This model begins at the outlet nozzle of steam generator and ends at the top of active core. The grid of the downcomer annulus is selected to be fine enough to allow the direct simulation of the annulus downflow pressure drop and radial jet mixing. In the lower head region, the grid structure is also fine enough for the prediction of turning losses and associated shear-generated turbulence and mixing. The inertial resistance factors of the porous media model are applied to the flow skirt, lower core support structure, and active core to represent flow resistances. The FLUENT nodalization for APR+ is shown in Figure 1 and 2.

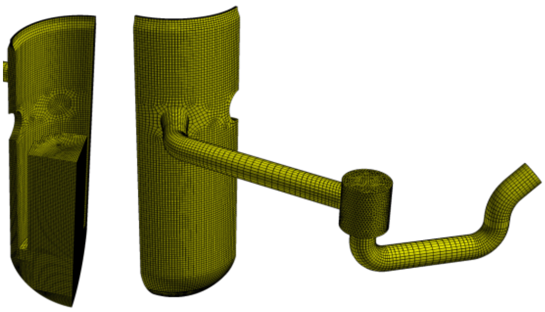

Fig. 1. Natural Circulation case Nodalization

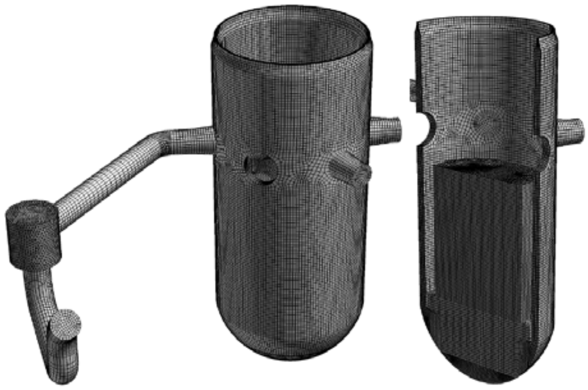

Fig. 2. RCP restart case Nodalization

2.2Initional Conditions

The initial condition of the reactor coolant system is assumed stagnant with a uniform 4,000 ppm boron concentration and 177℃ temperature in the condition of shutdown temperature and the boron concentration in safety injection systems. The actual boron concentration in the reactor coolant system is much higher, and the temperature would likely be higher than 177℃. It is assumed that 4,000 ppm of boric acid exist in the RCP, cold leg, downcomer, lower plenum and active core. The coolant mixing by temperature difference was not considered in spite of the mixing due to buoyancy force generated by density difference.

2.3 Boundary Conditions

The natural circulation velocity is assumed as the 3% of operation mass flow rate. [1] The natural circulation flow velocity is calculated 0.1695 m/s in each 4 cold leg region since the operating RCS mass flow rate is 10.59 m^3/s per each RCP. The largest possible volume of unborated water is assumed to be fully filled, as a conservative approach. The water immediately injected into the reactor vessel by the initiation of natural circulation is below the centerline of the entire cold leg from the reactor vessel nozzle to the steam generator outlet plenum. This is 7.419 m^3 which corresponds to the sum of volumes of a loop seal, a half of RCP and a half of cold leg. If this volume is assumed to be exceeded the level of centerline of cold leg, the highly borated water in the downcomer annulus will enter into the loop seals through the RCP and cold leg and then will mix with unborated water in the loop seal. It is conservatively assumed to begin the initiation of natural circulation at the same time in all loops. Since there are two RCP's connected to one steam generator and two loops in RCS, the total volume for all loops is 29.676 m^3. The boundary conditions of OPR1000 and APR1400 are also generated in the same manner as those of APR+. The analysis was performed with the k-epsilon turbulence model and standard wall functions.

2.4 Calculating Results

The Inherent Boron Dilution analysis for OPR1000, APR1400 and APR+ type nuclear power plants were performed using FLUENT CFD code. The initiation of natural circulation and restart of RCP were considered in this analysis. Figures 3 and 4 are shown the contour plotted results of boron concentration in APR+ at selected time steps. The results of Boron dilution analysis for three types of nuclear power plants are shown in the figures 5 and 6. The minimum boron concentration results are summarized in the Table I. According to the comparing result, the minimum boron concentration is likely to be increased as the volume of reactor is bigger.

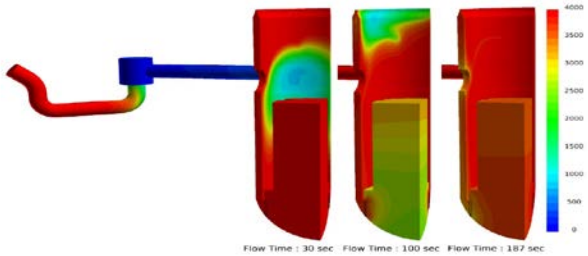

Fig. 3. Boron Concentration in the case of Natural Circulation for selected time steps

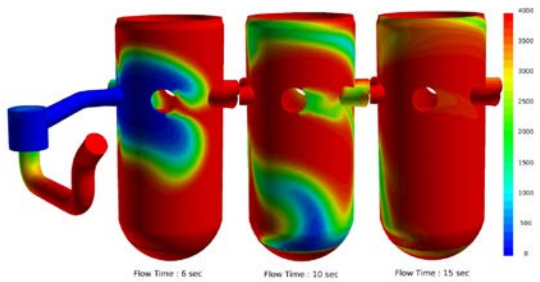

Fig. 4. Boron Concentration in the case of RCP restart for selected time steps

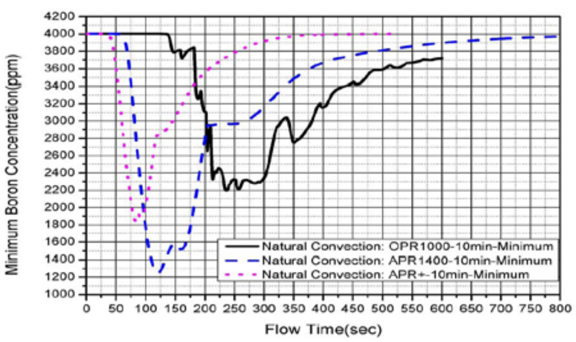

Fig. 5. Comparing Natural Circulation case result of Boron Concentration in the active core region for the three types of PWRs

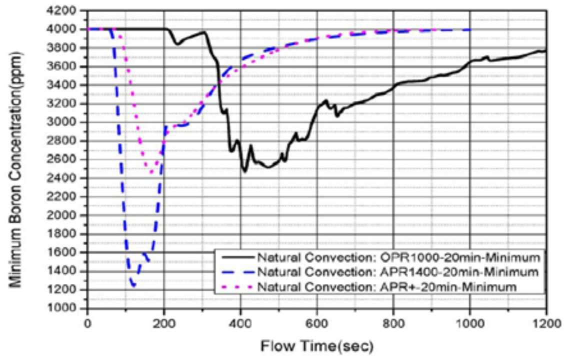

Fig. 6. Comparing RCP restart case result of Boron Concentration in the active core region for the three types of PWRs

Table I: Comparing Results of Minimum Boron Concentration in OPR1000, APR1400 and APR+ [ppm]

	Natural Circulation	RCP restart
OPR1000	2194	744
APR1400	1248	604
APR+	1843	1098

3. Conclusions

A FLUENT code is used to determine the boron concentration in the nuclear system after SBLOCA condition using FLUENT code. The RCP and natural circulation cases were analysed. A full reactor vessel including core was modeled to derive appropriate calculation. The result of boron concentration in the core region was shown and compared among three types of PWRs. This analysis is useful for estimating the reactivity in the core region due to the pouring of unborated water after SBLOCA and comparing the difference of hydraulic behavior between OPR1000, APR1400 and APR+ reactors.

REFERENCES

[1] Boron Reactivity Transients, NEA/SCNI/R(96)3, OECD, October, 1995.

[2] Evaluation of Potential Boron Dilution following Small Break Loss-Of-Coolant Accidents, 47-5006624-00, FRAMATOME.

[3] U.S. EPR Post-LOCA Boron Precipitation and Boron Dilution Technical Report, ANP-10288NP, AREVA NP Inc, 2007.

[4] Boron Mixing Experiments at the 2X4 UMCP Test Facility, M.Gavrilas, KTG Technical Expert Meeting, 2000

[5] ANSYS, ANSYS FLUENT Fluid Dynamics Verification Manual, 2011.