Proceedings of the Korea Nuclear Society Spring Meeting
Cheju, Korea, May 1996

Analysis of the Boron Concentration Behavior Using LTC code During Power Maneuvering

Jong Soo Kwon, Sung Goo Chi, Hae Yun Choi, Seong Hoon Park, Gi Won Lee
Korea Atomic Energy Research Institute

Abstract

The main purpose of this paper is to develop the modified LTC code for accurate analysis of the boron concentration behavior of all components in the Nuclear Steam Supply System (NSSS). This is achieved by adapting a multi-cell model to the existing Long Term Cooling (LTC) code. To verify the modified LTC, the simulated results were compared with the actual test results measured during YGN 4 initial criticality test. It was shown that the simulated results of this modified LTC were in good agreement with the actual test results. Also, the boron concentration behavior analysis were performed using the modified LTC code for both direct and indirect dilution/boration mode using YGN 3,4 design data.

This modified LTC code can provide a valuable information in predicting boron concentration behavior during power maneuvering such as startup operation, shutdown operation and load follow operation. It is expected that the modified LTC can be applied to both on-line and off-line mode using Plant Computer System (PCS).

1. Introduction

Control rods and soluble boron are used to compensate for the reactivity change resulting from changes in reactor coolant temperature, fuel burnup and xenon concentration. However, the use of control rod is restricted during power maneuvering due to the limitations on rod insertion and axial power distribution. Adjustments of the Reactor Coolant System (RCS) boron concentration must be made periodically over the course of core life to compensate for xenon concentration changes and fuel burnup. Additionally, it is used to compensate for some or all of the reactivity effects resulting from power maneuvering situations such as startup operation, shutdown operation and load following operation. In addition, changes to the boron concentration provide the necessary shutdown margin for refueling operations.

Boron concentration adjustments are accomplished by the addition of boric acid and/or demineralized water to the Volume Control Tank (VCT) or directly to the charging pump suction line within the Chemical and Volume Control System (CVCS). The total volume of the makeup water is calculated using the boration/dilution table which is based on one-cell model. However, because of time lags in the pipes and diffusion effects in the control volume, it is difficult to predict the boron concentration behaviors at each subsystems - RCS, pressurizer and CVCS.

Several models have been proposed to investigate the behavior of the RCS boron concentration during nuclear power plant operation in a pressurized water reactor. One-cell model treats the RCS including CVCS as a single diffusion cell. This model is appropriate for calculation of the required total makeup water to change the RCS boron concentration. Mathieu and Distexhe[1] presented a multi-cell model which predicts the required makeup flowrate as a function of time to achieve the primary loop boron concentration predicted by neutronic code. Integrated Boration and Dilution Model (INBAD)[2] which utilized one-cell model to predict the required makeup flowrate and multi-cell model to analyze the boron concentration behavior at each subsystem within RCS was proposed. However, in this model, a simple pressurizer model is employed and the RCS loop is modeled as a single instantaneous diffusion cell. Also, this model did not provide realistic responses of the NSSS in analyzing the behavior of the boron concentration at each components in the NSSS during boration or dilution operation.

In this paper, to accurately and realistically analyze the behavior of boron concentration at all components in the NSSS, the multi-cell model was adapted to Long Term Cooling (LTC) code[3]. LTC code is used to analyze the thermal-hydraulic response of the NSSS to a wide variety of plant transients. To verify this modified LTC, the results were compared between the simulation and the chemical sample during the YGN 4 initial criticality test. The behavior of the boron concentration was analyzed for both direct and indirect mode using the modified LTC. Also, the effect of pressurizer heater output on the boron concentration was investigated.

2. Boration/Dilution Model

2.1 Multi-Cell model

The one-cell model is used to determine the total amount of boric acid (in the case of boration) or demineralized water (in the case of dilution) that must be added to the VCT within the CVCS for the purpose of changing the RCS boron concentration. This model assumes the RCS including CVCS as a single control volume.

In the multi-cell model, the reactor vessel, the pressurizer and the VCT are modeled as a separate diffusion cell. The surge line, two spray lines and connecting lines are modeled by a single time lag line with constant water mass. In the time lag line, if the boron concentration at the inlet of the line is known, the boron concentration at the outlet can be determined by the following relationship ;

$$Cout = Cin(t - \Upsilon(t)) \quad \text{with} \quad \Upsilon(t) = M(t)/D(t) \qquad (1)$$

where, M : mass in the line

D : flowrate in the line

Υ : time lag in the line

C : boron concentration of the line

In the diffusion cell, the mass balance equation and the boron balance equation around the control volume can be written as follows:

$$\frac{dM(t)}{dt} = Din(t) - Dout(t) \qquad (2)$$

$$\frac{d(M(t)C(t))}{dt} = Din(t)Cin(t) - Dout(t)Cout(t) \qquad (3)$$

2.2 Modified LTC Model for Boron Concentration Behavior Analysis

LTC code is used to analyze the thermal-hydraulic response of the NSSS to a wide variety of plant transients. To analyze the behavior of boron concentration at each subsystem and each component in the NSSS more realitically, the makeup lines and multi-cell model were added to the existing LTC code as shown in Figure 1. The reactor vessel, the pressurizer and the VCT are modeled as an instantaneous diffusion cell containing the water mass (Mrv(t), Mpzr(t) and Mvct) and boron concentration (Crv(t), Cpzr(t) and Cvct(t)). The cold-leg lines, hot-leg lines and the steam generator lines including the U-tubes are modeled as time lag lines with variable water mass. The charging line, the letdown line, the spray line and surge line are modeled as time lag lines with constant water mass. The volume, mass and flowrate are calculated using the existing LTC code and used to simulate the behavior of boron concentration at each components in the NSSS. Total makeup volume for changing boron concentration of the RCS was calculated using one-cell model.

3.0 Simulation Results

3.1 Verification

In order to verify the modified LTC, the simulated boron concentrations were compared with the test results measured using chemical sample during YGN 4 initial criticality test[4] as shown in Figure 2. The initial condition of the RCS is 296.1°C, 158.2kg/cm^{2}A, 1800 ppm boron and 4 RCS pumps operating. The comparison showed that the simulated result coincided with the actual test result within maximum deviation of 2%.

3.2 Indirect Mode

As an initial condition, critical boron concentration at 80% power (790 ppm) are selected. The total makeup volume required for dilution and boration of 20 ppm were 5748.11 and 1374.97 liter, respectively. When the demineralized water (or boric acid) was injected through the VCT at a rate of 1.597 l/sec for dilution (0.382 l/sec for boration) for 1 hour, Figures 3 and 4 show the behavior of the boron concentration at each subsystem. As shown in Figures 3, the boron concentration at the VCT rapidly decreases to 663.5 ppm during makeup. After completion of makeup, it is increasing due to the higher borated flow returning from letdown line and seal injection return line. The boron concentration of reactor vessel decreases and reaches an equilibrium condition. After reaching equilibrium condition, the boron concentrations of the reactor vessel and the VCT are 769.7 ppm and 769.1 ppm, respectively. For the case of boration, after reaching equilibrium condition, the boron concentrations of the reactor vessel and the VCT are 809.2 ppm and 810.4 ppm as shown in Figure 4. It correlates well with the anticipated boron concentration from one-cell model.

3.3 Direct Mode

With the same initial condition as indirect mode, direct boration and dilution were performed. As shown in Figures 5, the boron concentration at reactor vessel increases very rapidly during makeup. After completion of makeup, the boron concentrations increases slightly due to the effect of the lower borated flow from the VCT. After reaching equilibrium condition, the boron concentrations of the reactor vessel and the VCT are 810.3 ppm and 810.2 ppm. In the dilution mode, the boron concentrations of the reactor vessel and the VCT are reached to 769.1 ppm and 769.2 ppm at equilibrium condition as shown in Figure 6.

3.4 Effects of Pressurizer Heater Output

The difference in the boron concentration between the reactor vessel and the pressurizer after the completion of boration or dilution operation leads to a power transient due to out-surge flow from the pressurizer. It creates an additional burden to the reactor operator to maintain the constant power.Therefore, it is important to minimize the difference of the boron concentration between them. Figure 7 shows that the difference of the boron concentration between the reactor vessel and pressurizer depend on the pressurizer heater output. Consequently, the difference of the boron concentration can be reduced by a sufficient recirculation between them. For this purpose, all the heaters of the pressurizer should be turned on during the adjustment operation of the RCS boron concentration.

4. Conclusions

To accurately analyze the behavior of boron concentration at each component in the RCS including pressurizer and VCT, the multi-cell model was adapted to the existing LTC code. The simulated results were in a good agreement with the actual test results measured during YGN 4 initial criticality test.. It can be concluded that this modified LTC code provide an accurate information for predicting the behavior of boron concentration at each components in the NSSS during various boration and dilution operation. Especially, this modified LTC code can provide a valuable information in predicting boron concentration behavior during power maneuvering such as startup operation, shutdown operation and load follow operation. It is expected that the modified LTC can be applied to both on-line and off-line mode using Plant Computer System (PCS) such that operator can monitor and predict the boron concentration behavior during power maneuvering.

References

[1] P. Mathieu and E. Distexhe, "Modeling of Boron Control During Power Transients in a PWR", Nuclear Technology, Vol.72, pp 135, 1986.

[2] S.G. Chi, H.K. Choi and J.E. Kuh, "Development of Integrated Boration and Dilution Model for Boron Concentration Behavior Analysis", Journal of KNS, Vol. 24, No. 1, Mar. 1992.

[3] ABB/CE "LTC User's Manual", Dec. 1986.

[4] KEPCO, "Initial Criticality Test Results for YGN 4", 4S-I-000-01.

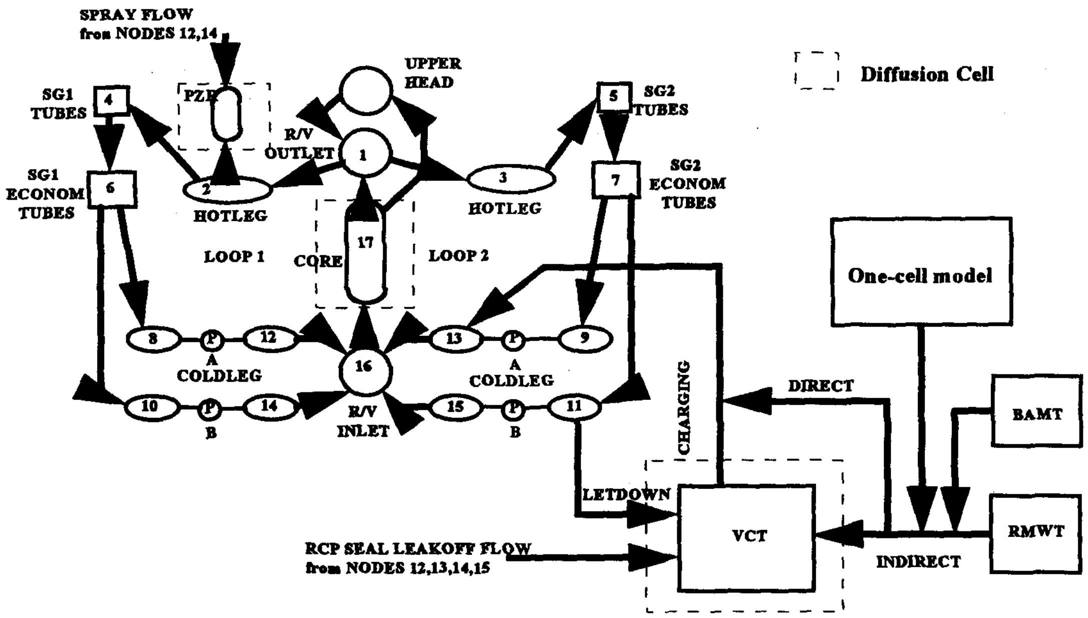

Figure 1. Modified LTC Model

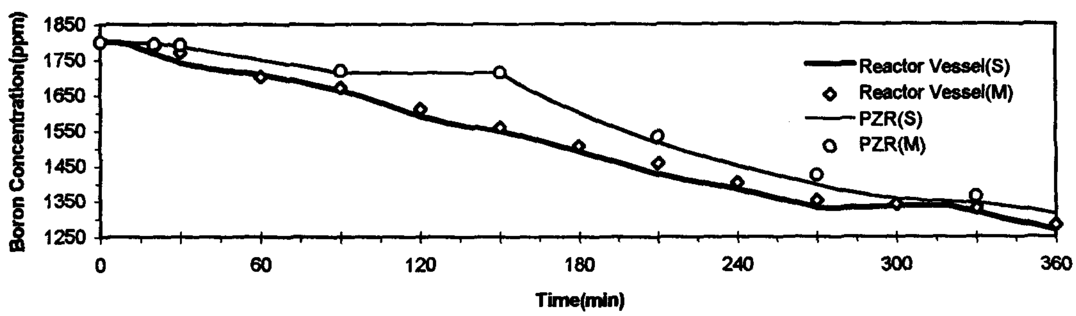

Figure 2. Simulation of Initial Criticality Test

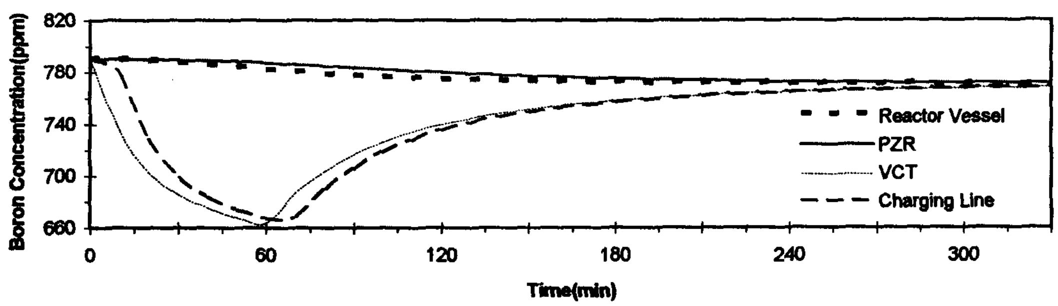

Figure 3. Indirect Dilution (20ppm)

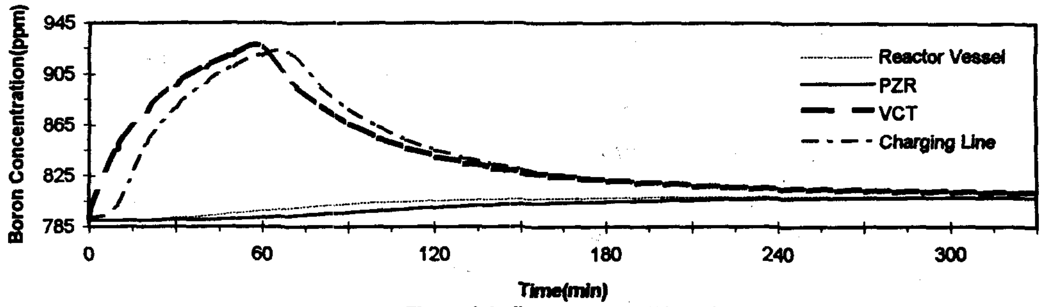

Figure 4. Indirect Boration (20ppm)

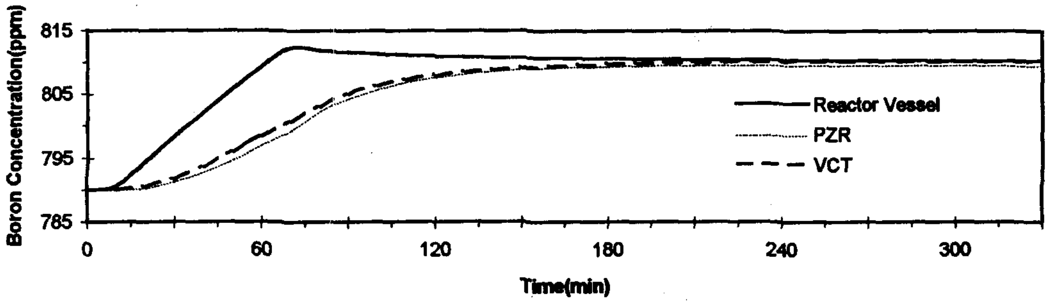

Figure 5. Direct Boration (20ppm)

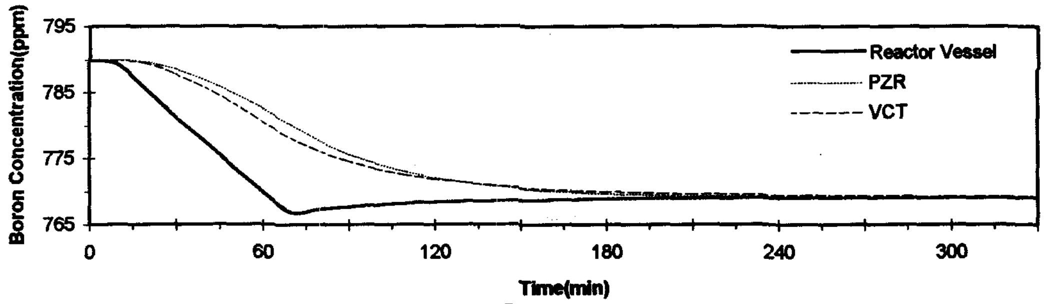

Figure 6. Direct Dilution (20ppm)

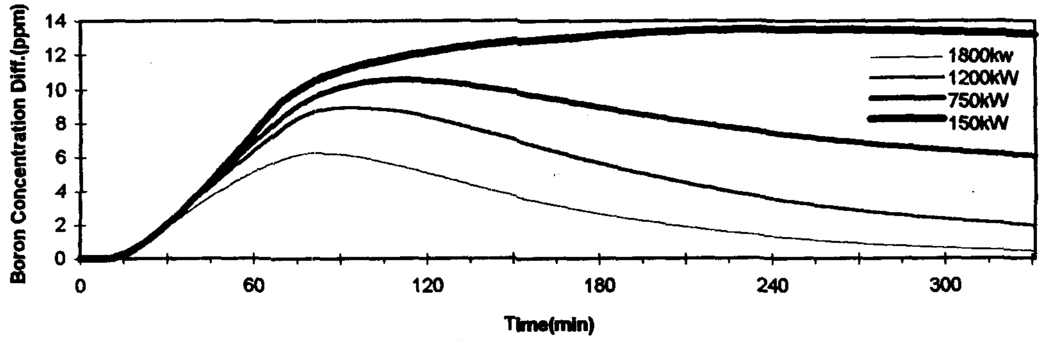

Figure 7. Boron Concentration Difference Between Reactor Vessel and Pressurizer as a Function of Pressurizer Heater Output