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Development of a Boron Transport Model in SPACE Code

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1. Introduction

KOPEC has been developing a system thermal hydraulics solver of SPACE, which is a safety analysis code of nuclear power plants, using two-fluid, three-field governing equations for two phase flow [1]. Several numerical schemes, such as collocated, staggered, semi-implicit, and implicit schemes, have been tried so far and a lot of effort has been made to verify the applicability of the SPACE code. In this paper, boron transport model was developed. And the boron precipitation and dilution test was performed using the SPACE code. The test results showed that the SPACE is applicable to the post LOCA long term cooling evaluation, especially on the USNRC safety issues addressed in the USNRC letter[2].

2. Analysis methodology

2.1 General description

Emergency Core Cooling System (ECCS) should have sufficient capability to maintain core temperature at acceptably low level during the Long Term Cooling (LTC) phase of a LOCA to demonstrate compliance with the 10 CFR 50.46 requirements. Until now, a simple but conservative evaluation methodology has been applied to the post-LOCA boric acid precipitation evaluation by licensing code, BORON. The USNRC identified several non-conservative assumptions in the previously approved analysis methodology regarding the build-up of boric acid in the reactor vessel and requested that the licensees respond to the safety concerns addressed in the USNRC letter[2]. These modeling assumptions and concerns, mainly discussed for thermal hydraulic phenomena, are briefly summarized bellows: (1) mixing volume reflected void fraction and system effects (2) boric acid carry-over and plate-out (3) impact of the back pressure due to loop conditions (4) decay heat and the impact of additional heat source. Now, a new evaluation methodology for boric acid precipitation has been developed to resolve the safety issues above by modifying simply the current licensing code, but it cannot resolve the NRC staff's all safety concerns.

The SPACE system code, using two-fluid, three-field governing equations, has an ability to simulate the transport of a dissolved component in the liquid phase and droplet phase, and treat various system effects. Therefore, the SPACE boron transport model is expected to resolve most of current issues regarding modeling assumptions and concerns for thermal hydraulic phenomena.

2.2 Discretized boron conservation equations

Only an additional field equation for the conservation of solute is required to model boron transport phenomena in SPACE. Since the continuous and dispersed liquid fields both carry boron, mass conservation equations for both phases are written;

- Continuous liquid mass conservation equation

$$\varepsilon V \frac{\alpha_l^n \rho_l^n \omega_l^n - \alpha_l \rho_l \omega_l}{\Delta t} + \sum_E \varepsilon^E \mathbf{A}^E \cdot \left(\alpha_l^E \rho_l^E \omega_l^E\right)\left(\mathbf{U}_l^E\right)^n = \varepsilon V \left(S_D \omega_d - S_E \omega_l\right)$$

- Dispersed liquid mass conservation equation

$$\varepsilon V \frac{\alpha_d^n \rho_d^n \omega_d^n - \alpha_d \rho_d \omega_d}{\Delta t} + \sum_E \varepsilon^E \mathbf{A}^E \cdot \left(\alpha_d^E \rho_d^E \omega_d^E\right)\left(\mathbf{U}_d^E\right)^n = \varepsilon V \left(-S_D \omega_d + S_E \omega_l\right)$$

$(l = liquid, d = droplet)$

3. Analysis Result

3.1 Test problem

For the boric acid precipitation and dilution test, the SPACE is applied to multi-dimensional two phase flow problem. The test domain, as shown in Fig.1, consists of 207 hexahedrons filled with vapor. The inlet flow boundary conditions are given at the cold leg beyond and at the hot leg. The pressure boundary conditions are given 10 bar at faces of the other cold leg. For the test, two cases are considered: (a) For the first 200 seconds, subcooled liquid inlet flow velocity of cold leg and hot leg is 1 m/s and 0 m/s with the initial 25wt % boric acid concentration and (b) the simultaneous cold leg and hot leg SI dilution flow, 0.5m/s with the 0wt% boric acid concentration, are initiated to prevent boric acid precipitation after 200 seconds. Both tests assume that solubility limit is 30wt%.

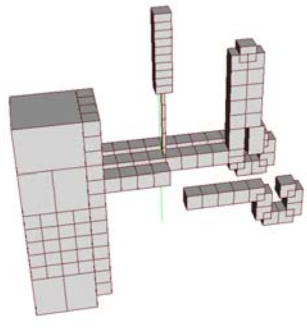

Fig.1. Geometry of the test problem

3.2 results

Fig. 2 shows void fraction and precipitation born mass[kg] in reactor vessel for boric acid precipitation test. The RCS refills since the cold leg injection and water continuously boils off in the core. Steam flows from the upper plenum through the hot leg, steam generator, suction side piping and reactor coolant pump before reaching the break. It will transport the boric acid in steam and in droplet to another location. That is, the boric acid is accumulated in steam generator as well as in the core since water boils off in the core. In some cases, increased upper plenum pressure doesn't allow water injection to reactor vessel and water is filled in the loop seal pipe. It is also found that the boric acid precipitation is mainly accumulated along the right wall and upper left wall in core region.

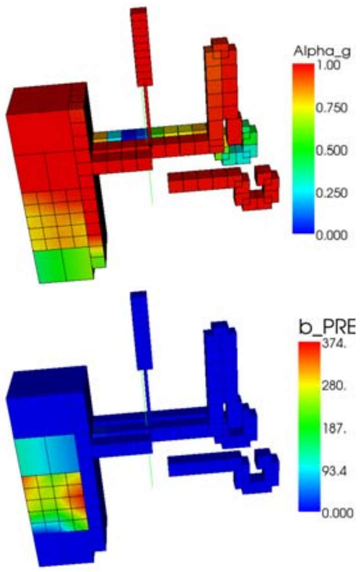

Fig. 2. Void fraction & Boron precipitation mass in RV(at 200 seconds)

Fig. 3 shows void fraction and precipitation boron mass[kg] in reactor vessel for boric acid dilution test. Even though unrealistic, it assumed that the boric acid, deposited in system, was diluted below the solubility limit, 30wt%. After the switch to hot and cold leg injection, water continuously boils off in the core. It is also found that water cannot easily be injected due to upper head pressure. Boric acid concentration and precipitation born mass in vessel starts to gradually decrease as dilution of core region. Precipitation boron mass remains at the lower right corner, and at the upper left corner of the core for the longest time. Boric acid dilution is the fastest at the center of the core,

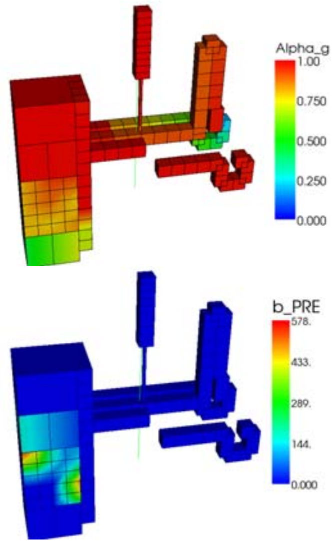

Fig. 3. Void fraction & Boron precipitation mass in RV (at 400 seconds)

4. Conclusions

As an effort to verify the code applicability, the boric acid tests are simulated using the SPACE code. The analysis results show that boron transport equation properly works for two-phase flow phenomena and are reasonable in the qualitative. Also it identifies that the SPACE code has an ability to resolve various issues regarding long term cooling analysis methodology.

Based on these results, it is concluded that the SPACE is applicable to the analysis of a boric acid precipitation and dilution.

REFERENCES

[1] S. Y. Lee, Development of a Hydraulic Solver for the Safety Analysis Codes for Nuclear Power Plants(I), Korean Nuclear Society Spring Meeting, 2007.

[2] 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.