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TRAC-M/F77 Code Assessment for the Direct Vessel Injection Test During LBLOCA Reflood Phase

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Abstract

Introducing Direct Vessel Injection (DVI) to KNGR ECCS, it is more necessary to assess the capability and limit of codes could be utilized in audit calculation. Tests and data related to DVI are limited to several UPTF tests for LBLOCA reflood. In this study, The capability of TRAC-M/F77 code in predicting phenomena related ECC entrainment under downcomer injection condition during reflood phase is evaluated using the experiment data of the UPTF Test 21D. The facility is modeled in detail, and the test condition is simulated. The calculation result is compared with the applicable measurement data and discussed in terms of the pressure response, and water level in downcomer and core. It is found that TRAC code could predict the pressure and water level responses of the test system simulating LBLOCA reflood phase relatively good and that the predicted value of TRAC calculation shows conservatism at sensitivity study.

1. Introduction

Analytical and experimental justification of the core cooling performance of the direct vessel injection (DVI)-typed Emergency Core Cooling System (ECCS) design during a postulated large break loss-of-coolant-accident (LBLOCA) has been requested by the introduction of the ECCS having DVI nozzle into reactor vessel downcomer to the Korea Next Generation Reactor (KNGR) design [1]. In analytical approach, it is evident that the reliability as well as validity of the used analysis tool should be verified for the thermal-hydraulic phenomena induced solely by the DVI-typed ECCS. And the major parameter including peak cladding temperature important to the plant safety during LBLOCA should be determined by the proven analytical tool.

Generally, it is expected that thermal-hydraulic phenomena during refill and reflood phases of LBLOCA under DVI condition may bring about different characteristics from those under the existing cold leg injection (CLI)-type ECCS. The ECC bypass and lower plenum delivery in refill phase can be drastically changed and the extended refill duration may be needed when compared to those in the existing CLI-type ECCS design. Some of the test result of Upper Plenum Test Facility (UPTF) revealed such a change in lower plenum delivery rate [2]. In reflood phase, direct bypass of ECC water and sweepout of ECC water induced by the steam jet impingement from the cold leg may be DVI-specific thermal-hydraulic phenomena. And its effect on the degradation of core reflooding rate may be significant [3].

The basic feature of those complex phenomena can be regarded as three-dimensional two-phase steam-water interaction in downcomer(DC). Therefore, the analytical tool for the DVI performance evaluation should be assessed with a relevant experiment simulating three-dimensional steam-water interaction under DVI. And some thermal-hydraulic models specific to DVI condition might be further developed if necessary.

In former study, the predictability of the TRAC code during refill phase was discussed and several findings were presented.[4] in terms of steam-water interaction and the related ECC delivery to lower plenum under DVI condition during refill phase.

The present study aims at evaluating the capability of thermal-hydraulic analysis tool for TRAC code [5] in predicting the relatively important global parameters such as pressure and water level of vessel under DVI condition during reflood phase. For this purpose, the code was assessed using the experiment data of the UPTF Test 21D [2]. The test is a unique one simulating the reflood phase of LBLOCA of pressurized water reactor (PWR) under the downcomer injection. Although the geometric configuration of the UPTF downcomer injection was not the same as the KNGR one, the basic two-phase interaction could be similar to the KNGR one. The code capability identified from the present assessment can be applied to the real plant calculation without any scalability concern, since the UPTF 21A was full-scale separate effect test.

2. UPTF Test Description

The Upper Plenum Test Facility (UPTF) is a full-scale separate effect test (SET) facility of a four-loop 1300 MWe pressurized water reactor (PWR). It is composed of full-size reactor vessel including the downcomer, lower plenum, core simulator, upper plenum and upper head and four loops with pump and steam generator simulator. The test vessel, core barrel and internals are also a full-size representation a PWR. The height and the outer diameter of the test vessel are 13.49 m of 5.03 m, respectively. The gap width of vessel downcomer is 21~25 cm. The major thermal hydraulic phenomena with multidimensional nature during end-of-blowdown to reflood phase of LBLOCA have been investigated in the UPTF. In UPTF both cold leg and hot leg breaks have been investigated including emergency core cooling system (ECCS) injected into the intact and broken cold legs and/or hot legs and into the downcomer. The steam produced in a real core and the water entrained by the steam flow was simulated by steam and water injection through core simulator. For testing the downcomer injection, two ECC injection nozzles having inner diameter of 0.308 m were located at 0.35 m above from the cold leg center. Two nozzles are connected to the downcomer annulus at the center between the cold leg 1 nozzle and the broken cold leg nozzle (0°) and at the center of cold legs 2 nozzle and cold legs 3 nozzle (180°).

The Test 21, quasi-steady state experiment, was carried out to obtained full-scale data on downcomer/lower plenum refill and reflood behavior for downcomer ECC injection. The test was subdivided into four phases simulating the refill phase (21A and 21B) and reflood phase (21C and 21 D) of the real plant event.

The Test 21D was performed to determine the downcomer water level/entrainment relationship during reflood with downcomer ECC injection. The intact loops were partly open and the hot leg of broken loop was closed. Steam was injected only into the steam generator simulators.

In the test, the test vessel was initially filled with steam at 250 KPa and 400 K while water level of vessel was 4.1 m. At the beginning of the test, the cold leg break valve was open to the containment simulator and to the water separator connected with drainage tank. The containment pressure was kept to be about 250 KPa. At 32 sec of the transient, steam was injected from three steam generator simulators at 33 kg/sec each. The steam injection rate was changed to 29, 25 and 20 kg/s at 166, 296 and 426 sec. respectively. At 41 sec, the ECC water was entered into the downcomer through two ECC injection nozzles (0° and 180°) at 120 kg/sec each. The ECC injection and the steam injection were terminated at 560 sec. At 52.5 sec, vessel water started to drain at 120kg/s. Core simulator water injection system was actuated at 298sec. Saturated water was injected into core at 298 and 436 sec during 20 and 25 sec each. Hot water injection rate of these periods were 270 and 725kg/s respectively.

3. Code and Modeling Description

In former study, TRAC code input deck was prepared for the simulation of the UPTF Test 21A which was modified from that of UPTF Test 6 run 133 included in TRAC code developmental assessment manual particularly on upper downcomer region volume and flow area, ECC injection pipe and nozzles, lower plenum nodding and broken cold leg pipe to water separator. Three intact loops with hot leg, steam generator simulator, crossover leg, pump simulator, and cold leg and a broken loop were separately modeled. The loop nodalization is identical to the base input deck. For broken loop hot leg is connected with steam generator simulator to pump simulator and cold log is connected to water separator that separate water and steam out of break flow. Separated steam in water separator is sent to containment simulator and separated water to KTA water collecting tank via drainage vessel. In TRAC modeling broken cold leg pipe to water separator is modeled and connected to BREAK component as a pressure boundary. Test vessel was modeled in 8-azimuthal cells, 3-radial rings and 14 axial cells. Downcomer region is modeled with stacked 10 axial levels with outer radial ring and bounded from axial level 4 to 13. Cold leg (CL)s and Hot leg(HL)s were connected at level 12, ECC injection nozzles at level 13. Azimuthal ECC nozzle connection is somewhat different from real configuration. The Nozzle connection point was modeled 22.5° shifted in azimuthal direction and 80cm higher in z-direction than actual location.

For UPTF test 21D, UPTF test 21A input deck described above was used and adjusted as the test 21D initial and boundary condition such and pump simulator friction, system pressure and temperature and injection of ECC water and steam generator simulator steam etc.

4. Calculation Results

Pressure Response

System pressure is on of the key parameters in predicting overall system response. Figures 1 and 2 show a comparison of pressure at the reactor vessel downcomer top and upper plenum (UP) between the experiment data and the calculated one by TRAC code. In experiment, DC and UP pressure was sharply increase due to the steam injection from three steam generator simulators and decreased and stabilized as SG simulator steam injection rate decrease to 33, 29, 25 and 20kg/s. Downcomer and Upper plenum pressure responses showed similar pattern though the pressure value were different.

TRAC code calculated the pressure response relatively well except that the calculated pressure draws more unstable pressure peaks. The size of these pressure peaks was decreased as the steam injection rate was decreased. This was more severe in DC. There are probable several causes of pressure oscillation. One could be found in modeling scheme in the input deck in which DVI nozzle is located above the cell the broken cold leg was connected due to the limitation of the code-modeling scheme. However, actual DVI nozzle is located in the middle of the broken cold leg and cold leg 1. This modeling scheme could affect the flow of the injected ECC water near the broken cold leg and lead to plug formation in the entrance of broken cold leg. The other cause of pressure oscillation could be found from the calculation method of the code related to 3D and 1D component junction. If the momentum and pressure calculation in the interface of 3D and 1D component is different from the actual situation in which water and steam have combined and fluid velocity is relatively high, then pressure oscillation could be present.

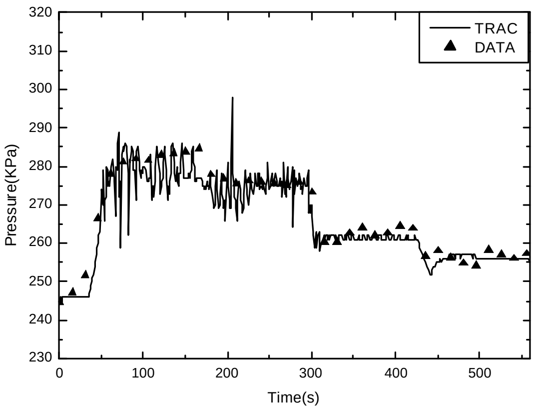

Figure1. Downcomer Pressure

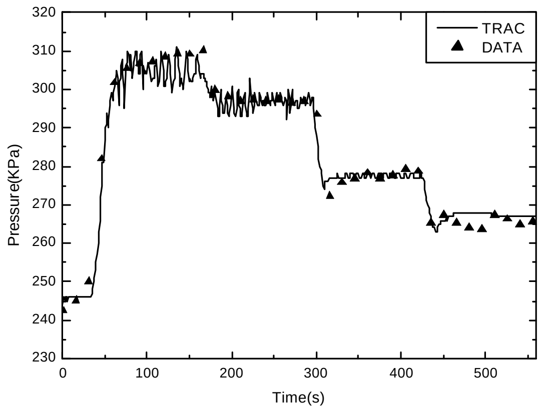

Figure2. Upper Plenum Pressure

Differential Pressure

General Pressure response calculation was relatively good. In addition to the pressure response, differential pressure will be discussed in this paragraph because the water level was measured from the differential pressure between two points to be measured the water level. And the pressure difference between upper plenum and downcomer is depends on the loops pressure drop, mainly on the pump simulator friction factor. Loop modeling and response could be checked using the comparison of the calculated and data UP to DC pressure difference.

Figure 3 shows a comparison of the differential pressure of LP to UP between the experiment data and the calculated by TRAC code. The experimental data and the calculated value have the difference in value about 5 KPa over the entire test. But the overall trend of the differential pressure was predicted well. In TRAC modeling, lower plenum was modeled with cell about 1m height. Calculated pressure of this cell was not the cell bottom value but cell-averaged value. This made above difference.

Pressure difference between upper plenum and downcomer was predicted well as shown in Figure 4. However, the calculated differential pressure oscilated before 300 sec as a system pressure case.

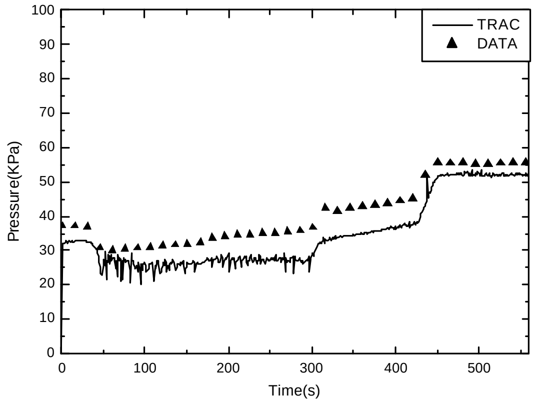

Figure 3 Differential Pressure between LP and UP

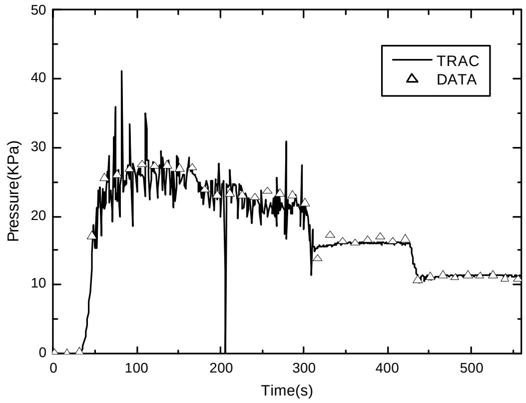

Figure 4 Differential Pressure between UP and LP

Water Level

Figure 5 show a comparison of water level at core and downcomer between the experiment data and the calculated one by TRAC code. In the experiment DC level increase due to steam generator simulator steam injection. The level difference between DC and core was about 3m. As the injected steam mass flow decreased, this water level gap was decreased to 1 m. TRAC predicted this water level of DC and core very well as shown at Figure 5. However, the calculated water level higher than that of experimental data after 290 sec. The core simulator water injection started to inject saturated water into the core. Level difference in DC and core was result from the mistake that core simulator volume (45.5m^3) was not considered in vessel volume. If this volume has been encountered in the calculation, then the calculated water level at final stage would be decreased to the experimental data level. Calculated water level in figure 5 was the collapsed water level based on the cell void fraction and fluid density etc. And the water level of experimental data was based on the pressure difference within two points.

Figure 6 shows the water level in DC for four azimuthal points was compared with experimental data and the predicted level by TRAC code. Experimental data showed smoothed water level transient and the water level at the measure point between cold leg 1 and 2 was higher than other points about 0.5 m. However, TRAC over predicted the water level difference within azimuthal DC regions about 1 m. From detailed study, it was found that this discrepancy was caused by water level measurement difference between TRAC calculation and the experimental methods. Water level calculation in TRAC code module used the collapsed water level within two axial cells. So, the TRAC code could over predict the water level involving the fluid flowing above the actual water level. If water level calculation were based on the pressure difference, TRAC water level calculation would be more close to the test. As mentioned above, after 290 sec, the calculated water level has an error due to miscounting of vessel volume in TRAC input.

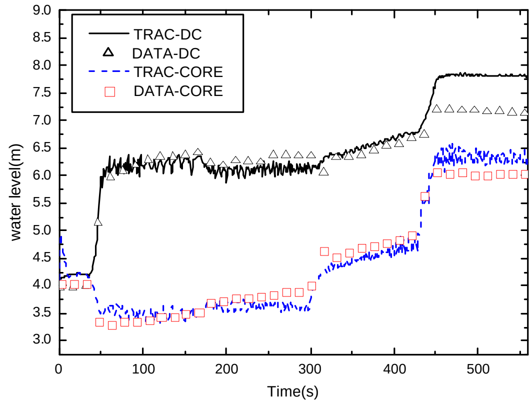

Figure 5 Core and DC Water Level

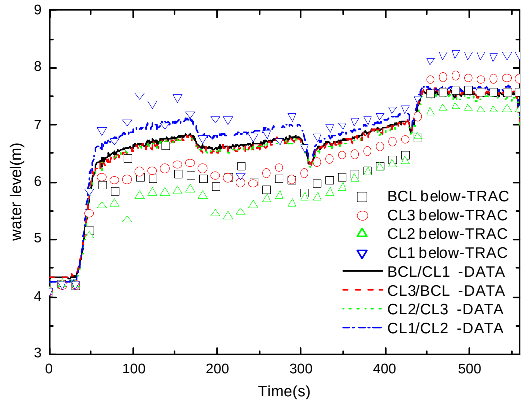

Figure 6 DC Azimuthal Water level

5. Sensitivity Study and Discussion

TRAC calculation discussed above section 4 made good agreement with the experimental result. There are so many variable options used in above base case. Two cases have been selected for sensitivity study. For Case 1, additional interfacial drag correlation option, blasius option was used. And for Case 2, DVI injection location cell in DC have been shifted near cell based on the Case 1. These cases have been used as sensitivity study in UPTF 21A for refill phase and found that most sensitive parameters for the study of downcomer phenomena.

Figure 7 shows the downcomer pressure response for the base case, case 1, case 2 and experimental data. When the blasius option for the interfacial drag option (case 1) was used, pressure in DC was slightly over predicted and water level was also. In the case of ECC injection location has been changed on the basis of case 1, DC pressure was under predicted and the water level was predicted nearly well.

Calculated steam mass flow rate at intact cold legs and broken cold leg has been compared with the related experimental data. At all cases used as sensitivity study, steam mass flow rate at intact cold leg was over predicted and under predicted at broken cold leg. Even though more steam injected into the downcomer in calculation, the code under predicted the break steam mass flow and over predicted break water mass flow. In other words, it is believed that TRAC code over predicted the bypass or entrainment and condensation phenomena.

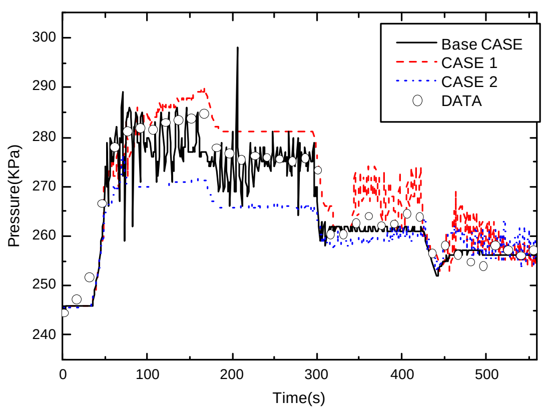

Figure 7 DC Pressure for Sensitivity Study

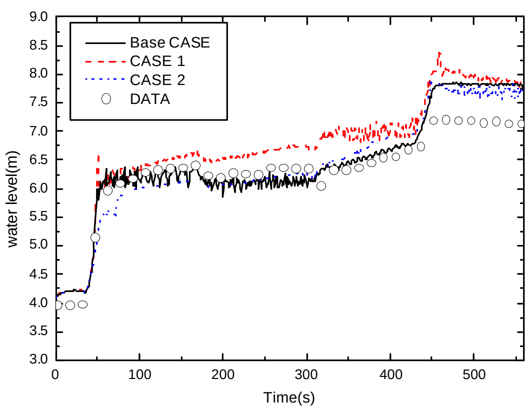

Figure 8 DC Water Level for Sensitivity Study

6. Findings and Remarks

In the present study, the capability of TRAC-M/F77 code in predicting the downcomer water level and entrainment under downcomer injection condition during reflood phase was evaluated using the experiment data of the UPTF Test 21A. The facility was modeled in detail, and the test condition was simulated for both code calculations. From the analysis on the predicted behavior and the comparison with the test result, the obtained findings are as follows:

The TRAC-M/F77 code can reasonably predict the global parameter behavior including system pressure, water level during the reflood phase under downcomer injection condition and have good predictability in vessel and loop pressure response and relevant water level. For more precise calculation in LBLOCA reflood phase using the TRAC code, particular attention should be paid in geometry nodding related to fluid flow and used model selection.

References

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