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International Agreement Report

Semiscale S-NC-02 and S-NC-03 Natural Circulation Tests Performed by RELAP5/MOD3.3 Patch05

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ABSTRACT

Experimental tests S-NC-2 and S-NC-3 were used to assess the RELAP5/MOD3.3 Patch05 computer code. The code developers concluded that it appears the interphase drag model allowed too much liquid to be entrained thus affecting the results of the calculation and that further investigation into the interphase drag model is warranted. The purpose of the present study was to investigate by sensitivity study the influence of interphase drag in the primary system.

The natural circulation experiments were performed in the Semiscale Mod-2A test facility, which is a small-scale model of the primary system of a four-loop Pressurized Water Reactor (PWR). The tests selected were Semiscale natural circulation tests S-NC-02 and S-NC-03. For sensitivity calculations, the latest RELAP5/MOD3.3 Patch05 computer code has been used. The ASCII input deck was obtained in the frame of RELAP5 code distribution for the auto validation purposes. The Symbolic Nuclear Analysis Package (SNAP) graphical user interface animation mask has been created to better understand the influence of varying interphase drag on natural calculated physical phenomena and processes. The results for S-NC-2 test showed that interphase drag coefficient has some influence on the mass flow during natural circulation, but smaller than suspected by code developers. For S-NC-3 test, it was confirmed that equating the height and distribution of the two-phase mixture in calculation within the U-tubes with the experimental condition is essential to predict correctly the degraded heat transfer phenomena.

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EXECUTIVE SUMMARY

In this study the integral effects problem used for development assessment of RELAP5/MOD3.3 Patch05 computer code has been selected. The problem selected is Semiscale natural circulations tests S-NC-2 and S-NC-3. The code developers reported that RELAP5/MOD3.3 Patch05 simulated the Semiscale natural circulation tests reasonably well for the higher primary coolant system mass inventories. Also, at the higher steam generator mass inventories, the code calculations are in good agreement with the measured data. It was concluded that it appears the interphase drag model allowed too much liquid to be entrained thus affecting the results of the calculation and that further investigation into the interphase drag model is warranted. The purpose of the present study was to investigate by sensitivity study the influence of interphase drag in the primary system.

The latest RELAP5/MOD3.3 Patch05 computer code has been selected for calculations and Symbolic Nuclear Analysis Package (SNAP) for animation purposes. The natural circulation experiments were performed in the Semiscale Mod-2A test facility, which is a small-scale model of the primary system of a four-loop Pressurized Water Reactor (PWR). The ASCII input deck for RELAP5/MOD3.2 was obtained in the frame of RELAP5 code distribution for the auto validation purposes. Manual corrections were needed to adapt the RELAP5 input model of Semiscale Mod-2A test facility to the latest RELAP5/MOD3.3 Patch05.

The selected S-NC-2 test examined single-phase, two-phase, and reflux steady state modes by varying the primary side system mass at core power 60 kW with a constant steam generator secondary side condition. In this study additional cases have been studied, varying interphase drag coefficient value.

The S-NC-3 test examined primary side two-phase natural circulation behavior under varying steam generator secondary side mass inventory at a core power of 62 kW. In this study besides varying interphase drag coefficient value, also calculations with slightly reduced primary coolant system inventory have been performed.

The Symbolic Nuclear Analysis Package (SNAP) animation mask has been created, which helps to better understand the influence of varying interphase drag on natural calculated physical phenomena and processes. The results for S-NC-2 test showed that interphase drag coefficient has some influence on the mass flow during natural circulation, but smaller than suspected by code developers. For S-NC-3 test, it was confirmed that equating the height and distribution of the two-phase mixture in calculation within the U-tubes with the experimental condition is essential to predict correctly the degraded heat transfer phenomena.

Finally, SNAP animation masks have contributed much to the physical understanding of the natural circulation phenomena, especially by showing the distribution of the two-phase mixture in the calculation.

ACKNOWLEDGMENTS

The author acknowledge the research core funding no. P2-0026 that was financially supported by the Slovenian Research Agency. The Krško nuclear power plant and Slovenian Nuclear Safety Administration (SNSA) supported this research through CAMP project no. POG-U3-KE-R4/104/12 (NEK no. 3180019).

ABBREVIATIONS AND ACRONYMS

CAMP	Code Applications and Maintenance Program
HT	heat transfer
FW	feedwater
PCS	Primary Coolant System
PWR	Pressurized Water Reactor
RELAP	Reactor Excursion and Leak Analysis Program
SG	steam generator
SNAP	Symbolic Nuclear Analysis Package
SNSA	Slovenian Nuclear Safety Administration
SPACE	Safety and Performance Analysis Code for Nuclear Power Plants

1 INTRODUCTION

The S-NC-2 and S-NC-3 tests performed in the Semiscale Mod-2A test facility were used to assess the RELAP5/MOD3.3 Patch05 computer code. The code developers reported [1] that RELAP5/MOD3.3 Patch05 simulated the Semiscale natural circulation tests reasonably well for the higher primary coolant system mass inventories. Also, at the higher steam generator mass inventories, the code calculations are in good agreement with the measured data. It was concluded that it appears the interphase drag model allowed too much liquid to be entrained thus affecting the results of the calculation and that further investigation into the interphase drag model is warranted. Therefore, the purpose of the present study was to perform sensitivity study for RELAP5/MOD3.3 Patch 05 best-estimate system thermal-hydraulic code by varying interphase drag in the hot leg and steam generator (SG) U-tubes.

2 METHODS USED

2.1 Semiscale Mod-2A Test Facility Description

The natural circulation experiments were performed in the Semiscale Mod-2A test facility, which is a small-scale model of the primary system of a four-loop pressurized water reactor (PWR). The facility incorporates the major components of a PWR including steam generators, vessel, downcomer, pumps, pressurizer, and loop piping.

The Mod-2A facility was the first Semiscale Mod designed specifically to run small break experiments. The inclusion of the Type II-full-length steam generator in the intact loop made possible almost complete 1:1 scaling of elevation that is critical for natural circulation type phenomena. For the first time, external band heaters were used on the loop piping to offset heat loss, which is critical in a small-scale high pressure facility such as Semiscale. The heat loss is on the order of the core decay heat for much of the transient, therefore external heating is needed to reduce heat loss. A bypass line between the vessel upper head and downcomer inlet annulus contained an adjustable valve to set the core bypass flow rate. In the Semiscale Mod-2A single loop configuration, the intact loop pump was replaced with a spool piece containing an orifice that simulated the hydraulic resistance of a locked pump rotor. In addition, the vessel was modified from the normal Mod-2A configuration for all the experiments by removing the vessel upper head to ensure a uniform heatup of the entire system and to avoid condensation in upper-head structures (i.e. the upper vessel was capped in the normal Mod-2A).

2.2 Description of S-NC-02 and S-NC-03 Natural Circulation Tests

The S-NC-02 tests simulated were performed at 60 kW (6% of full Semiscale core power). The objective of the steady state S-NC-02 natural circulation test was to study thermal hydraulic response during the three modes of natural circulation: single-phase, two-phase, and reflux. The secondary side conditions were constant, while on primary side the mass inventory was varied, influencing the natural circulation. At this power level, 16 different steady-state conditions were obtained.

The S-NC-3 tests were performed at a core power of 62 kW and a constant primary system mass inventory 91.8% varying steam generator secondary side mass inventory. By varying the steam generator secondary mass, the effective heat transfer area from primary to secondary was changed. The objective of the test was to study the effect of different steam generator secondary condition on two-phase natural circulation. There were a series of 10 steady state conditions obtained.

2.3 RELAP5 Input Model Description

Transient simulations were performed using an ASCII input deck prepared by the Idaho National Engineering Laboratory to analyze the S-NC-2 natural circulation experiments [1], which was imported into Symbolic Nuclear Analysis Package (SNAP) [2]. Manual corrections were needed to adapt the RELAP5 input model of Semiscale Mod-2A test facility to the latest RELAP5/MOD3.3 Patch05. The nodalization scheme of the MOD-2A Semiscale facility consisted of 62 Hydraulic Components and 9 Heat Structures as shown in Figure 1.

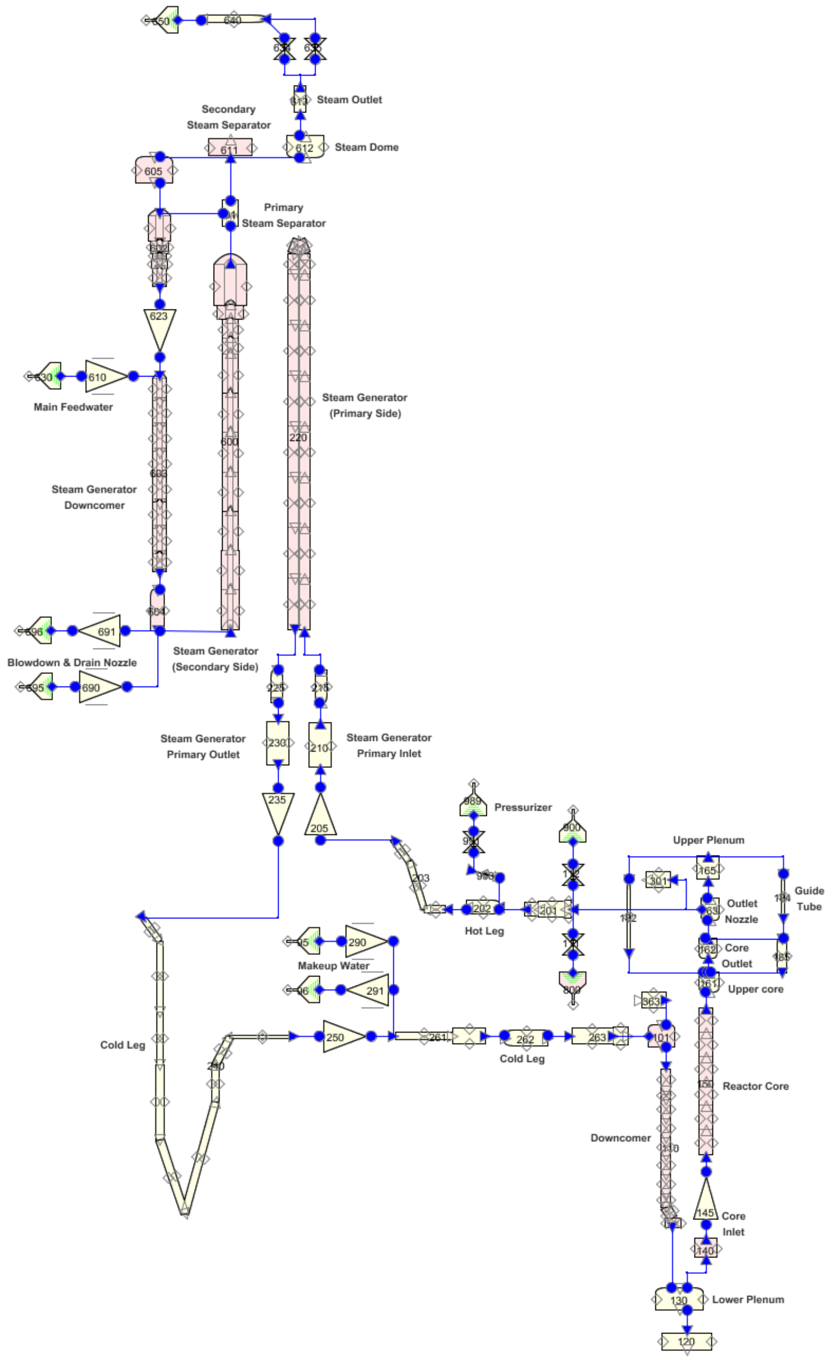

Figure 1 RELAP5 Input Model of Semiscale Mod-2A Single Loop Represented by SNAP

The reactor vessel is modelled with external downcomer, lower plenum, lower head, active core, upper plenum, upper head bypass line, simulated guide tubes and support column. The intact loop was modelled with a hot leg, an intermediate leg, a pump spool piece, and a cold leg. This intact loop hot leg is connected to the reactor vessel upper plenum volume and cold leg is connected to the volume at a reactor downcomer. The pressuriser surge line is connected to hot leg. The secondary side was modelled with feedwater, downcomer, boiling space, a separator, steam dome, a normal steam discharge and an auxiliary feedwater source.

2.4 Selected Scenarios

The 16 cases were selected to be analyzed in the frame of the S-NC-02 test, with reducing the primary coolant system (PCS) inventory from 100% to 61.2% as shown in Table **1**, where CXX_P-NN.N% means: Case no. XX with PCS inventory (P) at NN.N percentage. The time dependent junction and volume were connected to the cold leg. The primary fluid was drained out of the system through this junction (start time at 600 s), with the controllers allowing outflow until the desired primary side mass inventory was achieved and then stopping the further flow.

Table 1 Cases Simulated in the Frame of S-NC-02 Test

Case Number	PCS inventory (%)	Calculation label
C1	100.0	C1_P-100.0%
C2	97.6	C2_P-97.6%
C3	96.3	C3_P-96.3%
C4	95.2	C4_P-95.2%
C5	94.2	C5_P-94.2%
C6	93.1	C6_P-93.1%
C7	90.9	C7_P-90.9%
C8	87.8	C8_P-87.8%
C9	84.8	C9_P-84.8%
C10	83.6	C10_P-83.6%
C11	80.6	C11_P-80.6%
C12	77.6	C12_P-77.6%
C13	74.4	C13_P-74.4%
C14	71.4	C14_P-71.4%
C15	66.3	C15_P-66.3%
C16	61.2	C16_P-61.2%

For S-NC-3 the specific value of 91.8% of PCS inventory was chosen from the result of test S-NC-02 which is corresponding to the primary side inventory value at which the mass flow rate in the primary side was at its peak. After the system reached equilibrium, the mass inventory in the steam generator secondary side was reduced step-by-step. In the process of the reduction of mass inventory in the steam generator secondary side, the primary side natural circulation was allowed to stabilize. The major parameters examined were natural circulation flow rate and system temperature distribution. Ten cases with different heat transfer area in the steam generator secondary side were used in this study. The value of 100% secondary mass means the normal narrow range level in the steam generator. The S-NC-03 test cases simulated are shown in Table 2, where CXX_S-NN.N% means: Case no. XX with secondary side mass inventory (S) at NN.N percentage.

Table 2 Cases Simulated in the Frame of S-NC-03 Test

Case Number	SG Secondary Side Heat Transfer Area (%)		Calculation label
C10	100.0		C10_S-100.0%
C11	99.1		C11_S99.1%
C12	86.9		C12_S-86.9%
C13	75.5		C13_S-75.5%
C14	67.4		C14_S-67.4%
C15	55.5		C15_S-55.5%
C16	43.6		C16_S-43.6%
C17	33.2		C17_S-33.2%
C18	22.7		C18_S-22.7%
C19	15.2		C19_S-15.2%

For both tests in the frame of sensitivity study the interphase drag coefficient was varied for two cases: ‘R5(drag=0.8)’ in which the drag coefficient was multiplied by 0.8 and ‘R5(drag=1.2)’ in which the multiplication factor 1.2 was used, using RELAP5 values for uncertainty analysis. Calculations using default interphase coefficient were labelled ‘R5(base)’.

3 RESULTS

3.1 Results S-NC-2 Test

The results for S-NC-2 test are shown in Figures 2 through 27. The sensitivity of results on drag coefficient value variation in range 0.8 to 1.2 for S-NC-2 test are shown in Figure 2. The calculated results are compared to experimental data for mass flow rate, hot leg fluid temperature, primary side steam generator (SG) outlet fluid temperature, and primary system pressure. The difference of density is the only driving force for natural circulation. The fluid density differences occur as a result of fluid heating in the core region (causing the liquid to become less dense) and cooling fluid in the steam generators (causing the fluid to become denser). Natural circulation will occur in a PWR primary loop (in the absence of pumped flow) whenever buoyant forces caused by differences in loop fluid densities are sufficient to overcome the flow resistance of loop components (steam generators, primary coolant pumps, etc.). Progression from the single-phase mode through the two phase and reflux condensation modes occurs as primary system liquid mass inventory decreases.

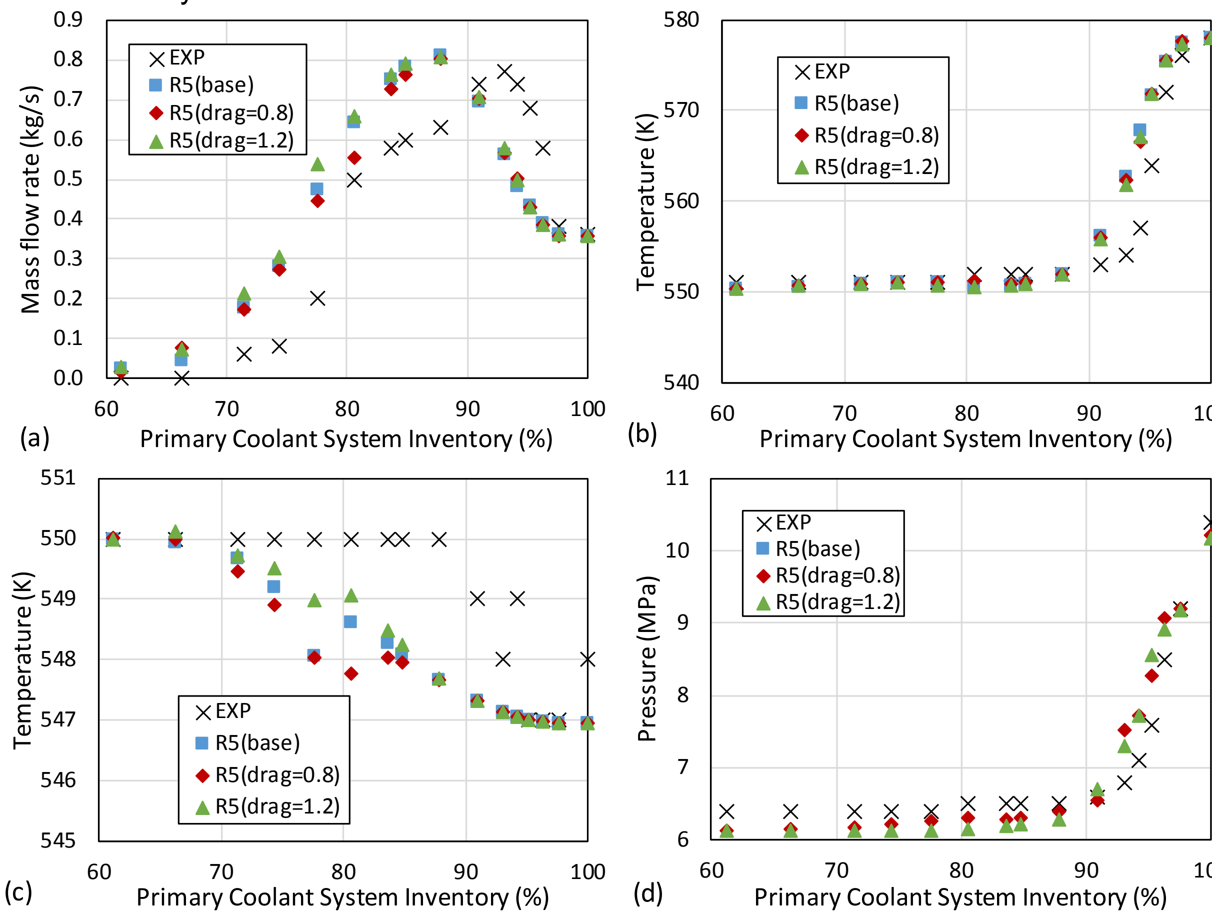

Figure 2 Comparison between RELAP5 Sensitivity Calculations Varying Drag Coefficient (0.8 to 1.2) and Experiment for S-NC-2 Test as a Function of Primary Coolant System Inventory: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

The calculations have been performed for 1500 s. After initial 600 s of steady state calculation, the controllers start to drain primary system to the desired PCS inventory and 900 were used in calculation to stabilize the conditions. The calculated results agree well with the experiment in the 97% to 100% PCS inventory range. Between 70% and 94% of PCS inventory, there is a two-phase region, while reflux mode is between 60% and 70% of the PCS inventory. For a slower increase of mass flow when inventory is decreasing from 97% to about 88% the code documentation report [1] states that it is suspected that the interphase drag allowed more liquid to be carried up in the hot leg, thus affecting the density head difference and resulting in a slower mass flow rate. The slower mass flow rate (see Figure 2(a)) in turn affected the fluid temperature and pressure response as shown in Figures 2(b), 2(c) and 2(d). However, the impact of drag variation coefficient value is rather small in the 88% to 97% mass inventory range. It may be seen that impact of drag variation is larger in the 70% to 82% mass inventory range. In the reflux mode the mass flow was oscillatory (see e.g., Figure 16(left)), therefore mean value of oscillation is shown in Figure 2(a). The calculated and measured data agree well during reflux mode (60% to 70% mass inventory range).

The sensitivity of mass flow on drag coefficient value variation is further shown in Figures 3 through 18, showing mass flow on the left and void fraction condition during the test on the right. From void fraction condition, one may indicate the single (Figures 3 through 9) and two phase flow (Figures 10 through 16), while for reflux condensation the indication is large oscillations in flow with approximately zero average flow (Figures 17 through 18). Smaller drag coefficient value of 0.8 (case 'R5(drag=0.8)') has some influence on the mass flow, the largest in the two-phase region (see Figure 13, Case C11_P-80.6% with primary coolant system inventory 80.6%).

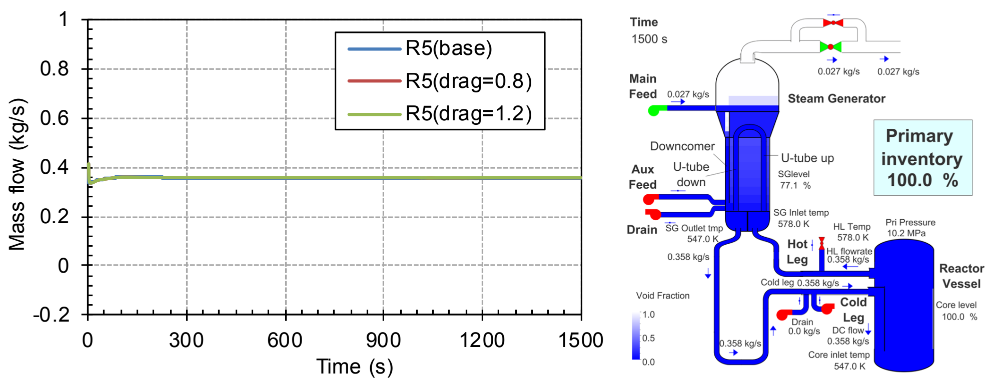

Figure 3 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C1_P-100.0% (left) and Liquid Distribution at 1500 s for Base Case (right)

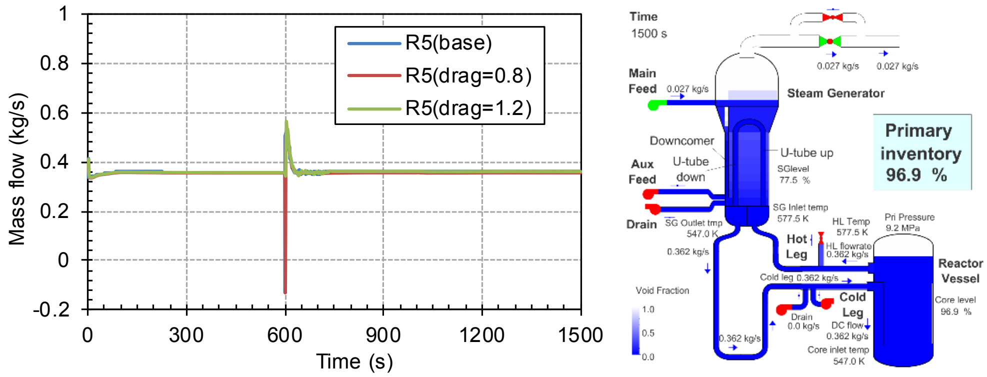

Figure 4 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C2_P-97.6% (left) and Liquid Distribution at 1500 s for Base Case (right)

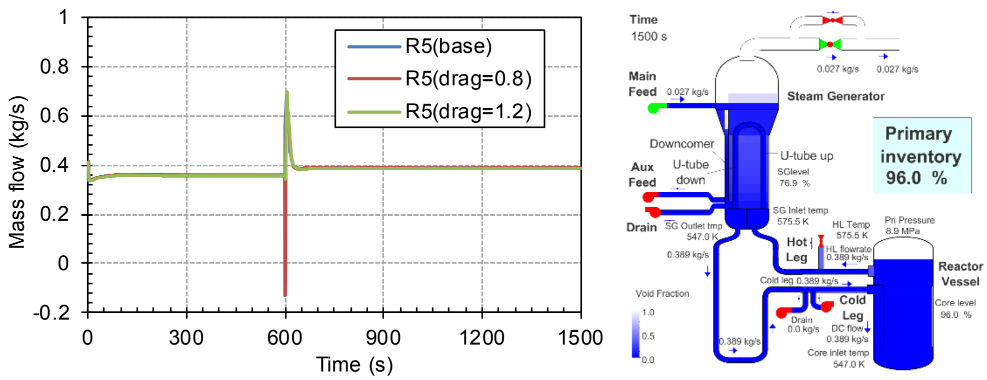

Figure 5 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C3_P-96.3% (left) and Liquid Distribution at 1500 S for Base Case (right)

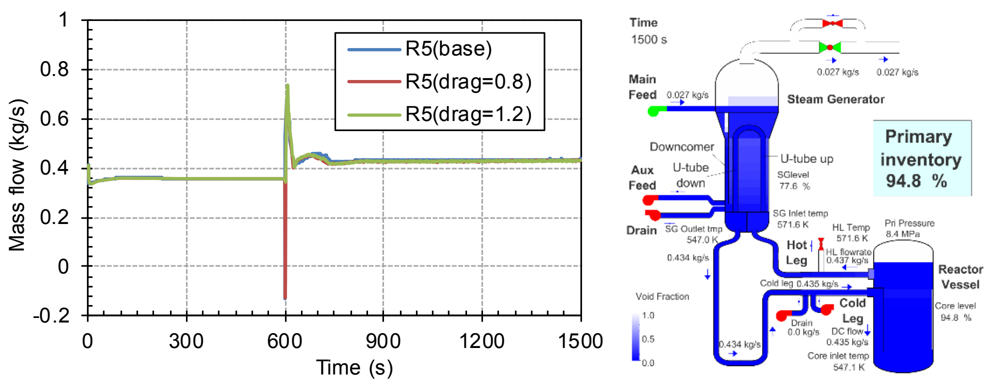

Figure 6 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C4_P-95.2% (left) and Liquid Distribution at 1500 S for Base Case (right)

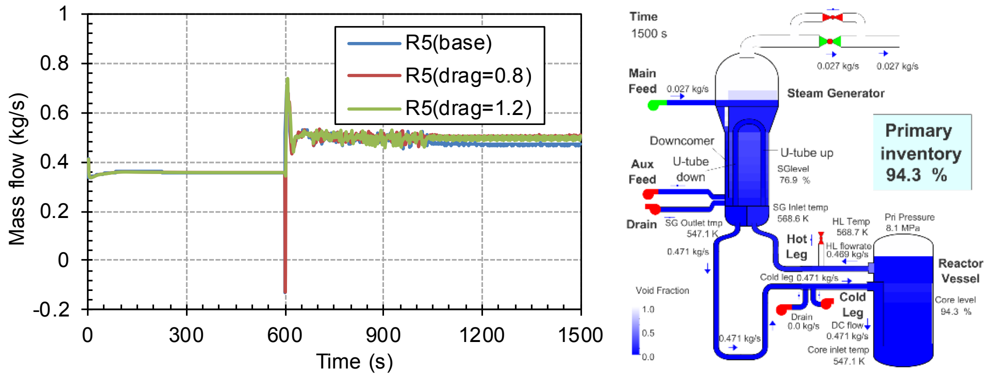

Figure 7 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C5_P-94.2% (left) and Liquid Distribution at 1500 S for Base Case (right)

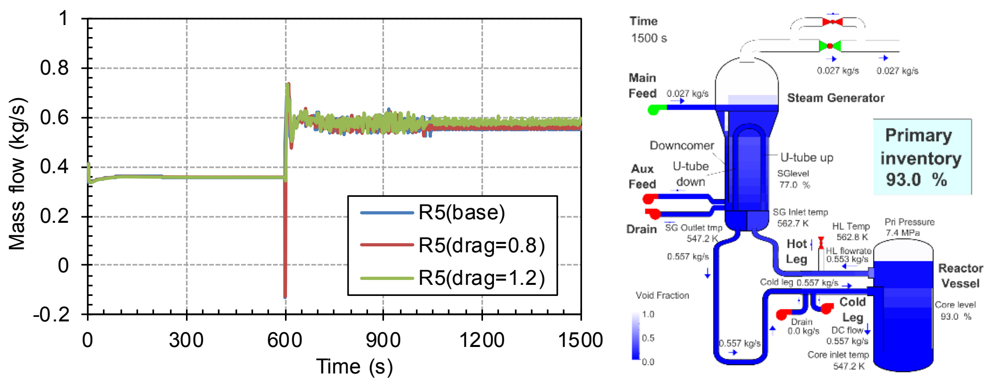

Figure 8 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C6_P-93.1% (left) and Liquid Distribution at 1500 S for Base Case (right)

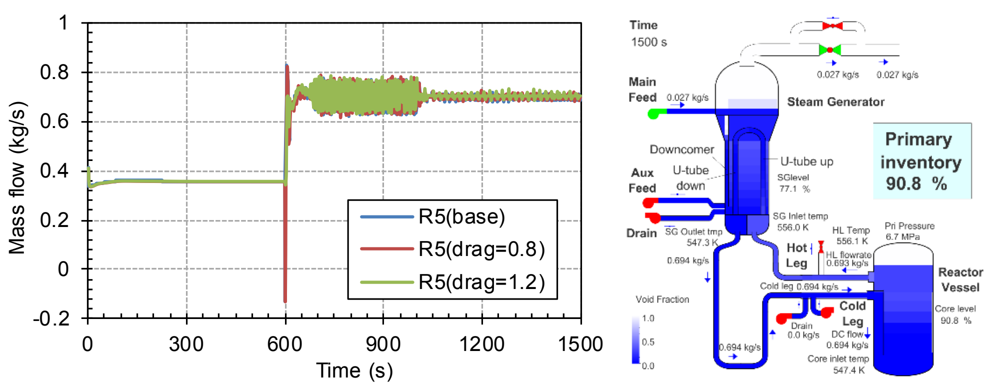

Figure 9 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C7_P-90.9% (left) and Liquid Distribution at 1500 S for Base Case (right)

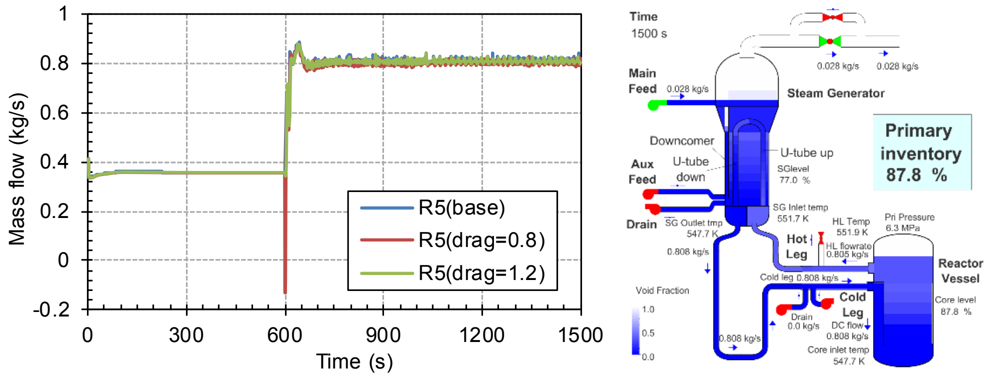

Figure 10 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C8_P-87.8% (left) and Liquid Distribution at 1500 S for Base Case (right)

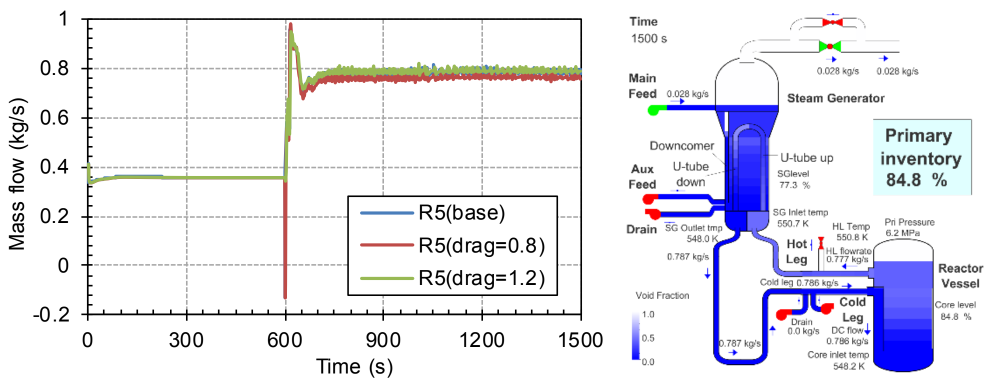

Figure 11 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C9_P-84.8% (left) and Liquid Distribution at 1500 S for Base Case (right)

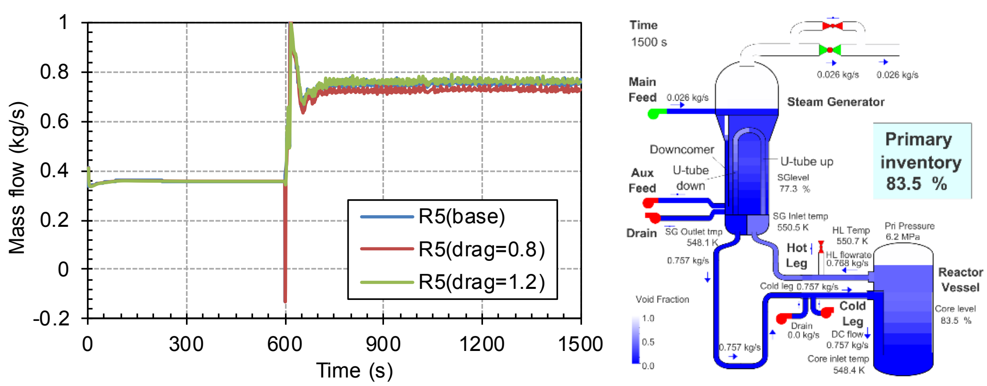

Figure 12 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C10_P-83.6% (left) and Liquid Distribution at 1500 S for Base Case (right)

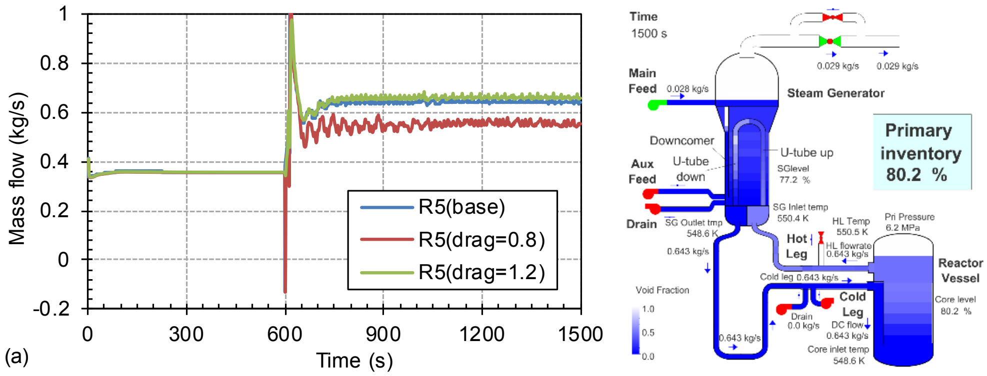

Figure 13 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C11_P-80.6% (left) and Liquid Distribution at 1500 S for Base Case (right)

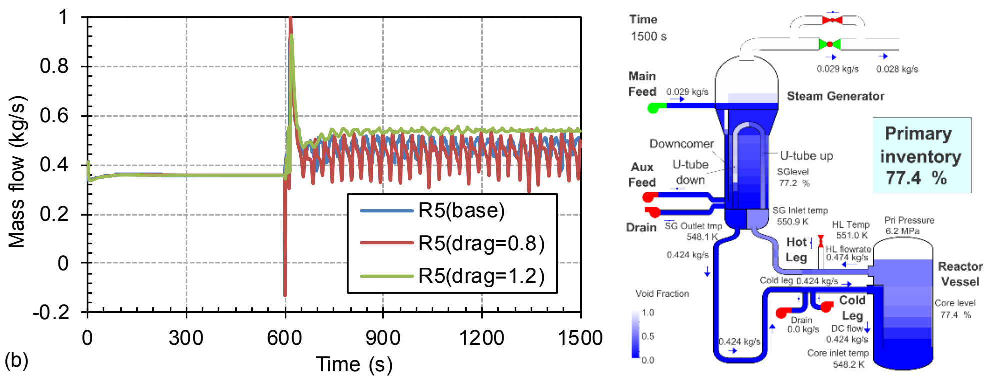

Figure 14 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C12_P-77.6% (left) and Liquid Distribution at 1500 S for Base Case (right)

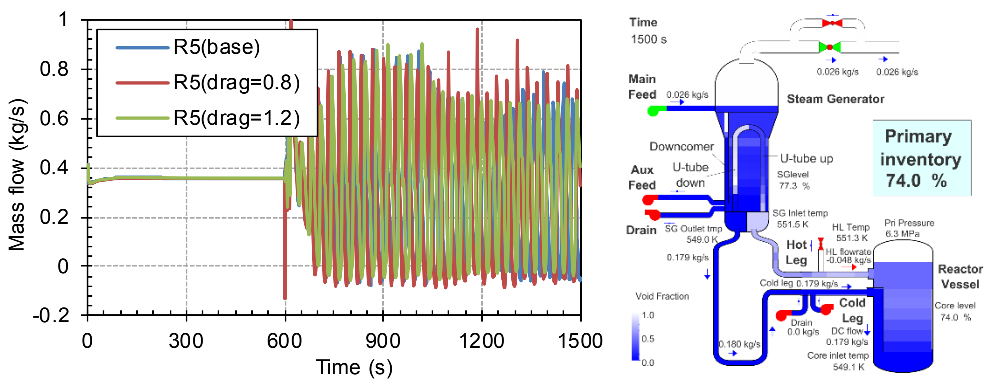

Figure 15 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C13_P-74.4% (left) and Liquid Distribution at 1500 S for Base Case (right)

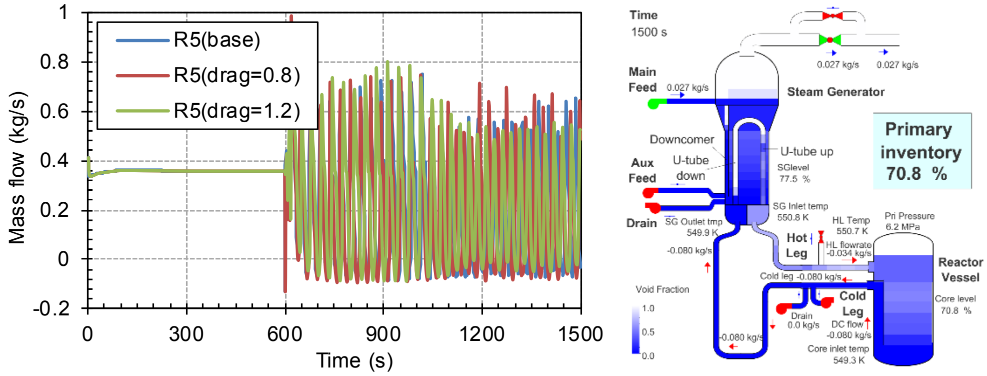

Figure 16 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C14_P-71.4% (left) and Liquid Distribution at 1500 S for Base Case (right)

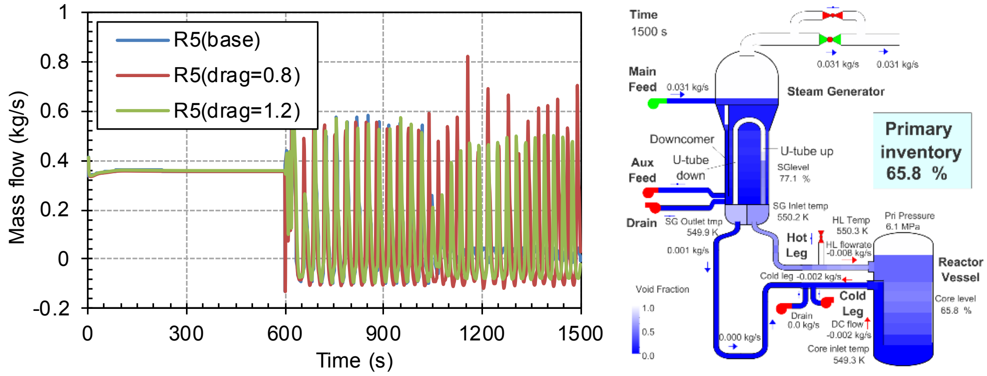

Figure 17 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C15_P-66.3% (left) and Liquid Distribution at 1500 S for Base Case (right)

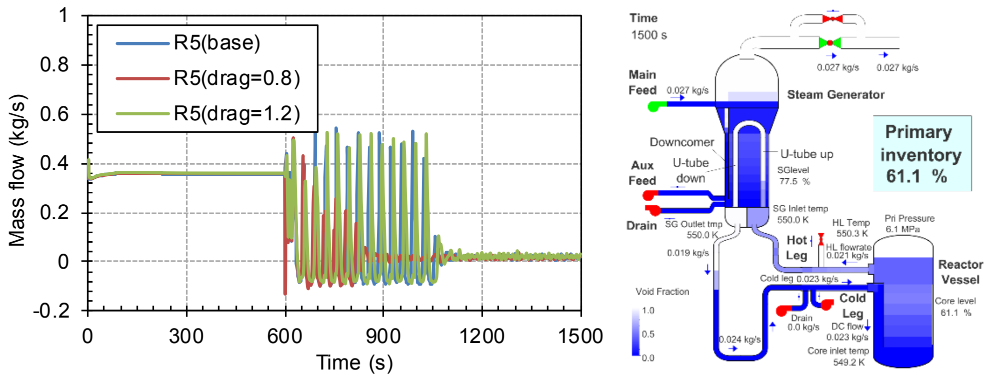

Figure 18 Mass Flowrate Dependence on 20% Drag Coefficient Variation for S-NC-2 Test Case C16_P-61.2% (left) and Liquid Distribution at 1500 S for Base Case (right)

The sensitivity of results on very large (dial) drag coefficient value variation in range 0.1 to 10 for S-NC-2 test are shown in Figure 19. From Figure 19(a) it can be seen when drag coefficient is reduced 10 times and one the primary coolant inventory is below 90%, in the two-phase and reflux mode, the mass flowrate is close to the experimental values. When the primary coolant inventory is above 90%, the influence of interfacial drag coefficient is small. Increase of drag coefficient value for 10 times increases the discrepancy between the calculated values and measured data, when the primary coolant mass is reduced below 90%. By increasing the drag coefficient the mass flowrate is increased, because more liquid water in entrained in the two-phase flow. The influence of drag coefficient on hot leg temperature shown in Figure 19(b) and pressure shown in Figure 19(d) is small. However, at the exit of steam generator the temperature has the largest discrepancy in calculation with decreased drag coefficient, when the primary coolant mass is reduced below 90%. This temperature is influenced also by conditions on the secondary side.

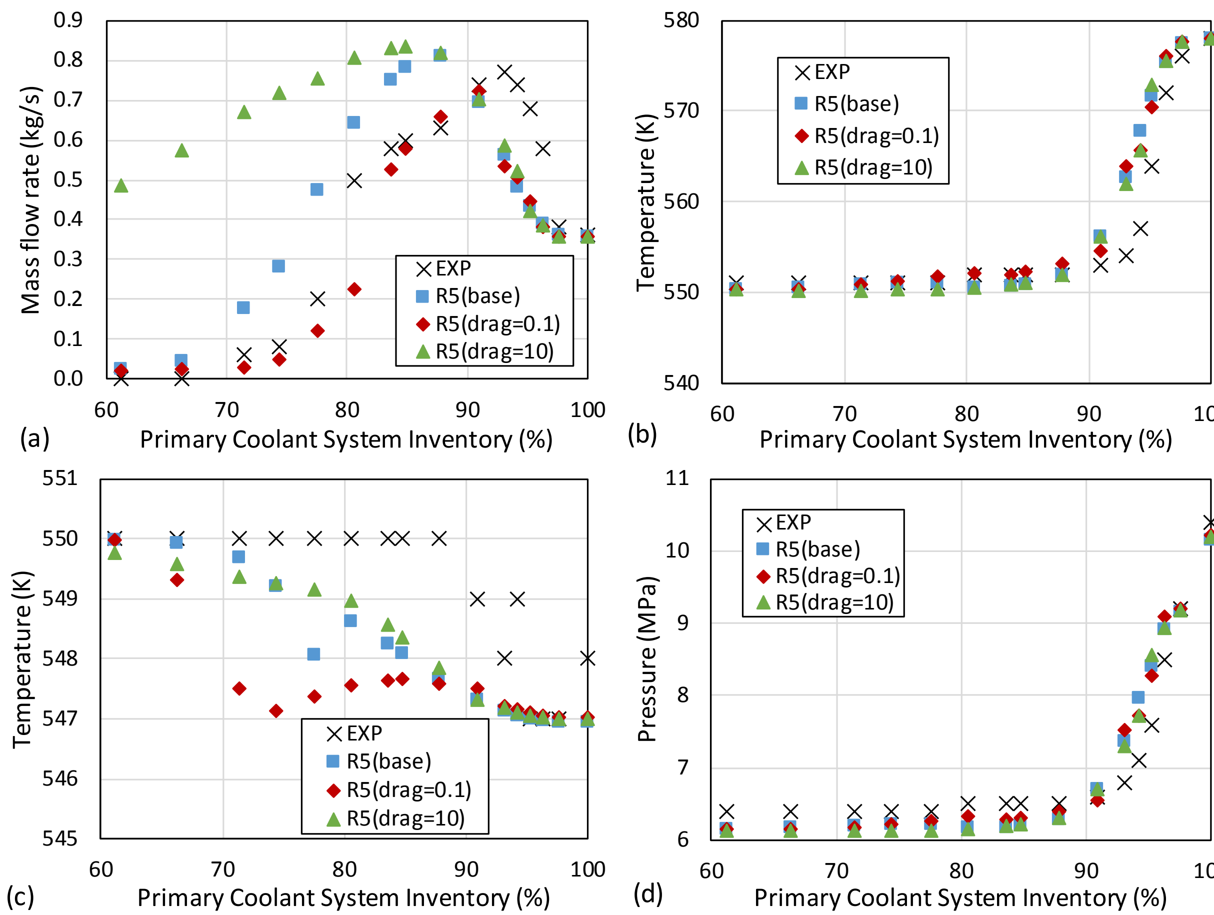

Figure 19 Comparison Between Relap5 Sensitivity Calculations Varying Drag Coefficient (0.1 to 10) and Experiment for S-NC-2 Test as a Function of Primary Coolant System Inventory: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

Finally, the influence of dial drag coefficient variations on mass flow for all cases is shown in Figures 20 through 27. The influence on flow is more significant in the two phase flow and reflux mode. The smaller is the drag coefficient value, the smaller is the mass flow. In Figure 20 there is no spike 600 s, as primary coolant system mass was not decreased (i.e. remains 100% through all the calculation). In cases with drag coefficient is reduced to 10% of nominal value and primary coolant mass is below 90%, the calculated mass flows are lower than in base case.

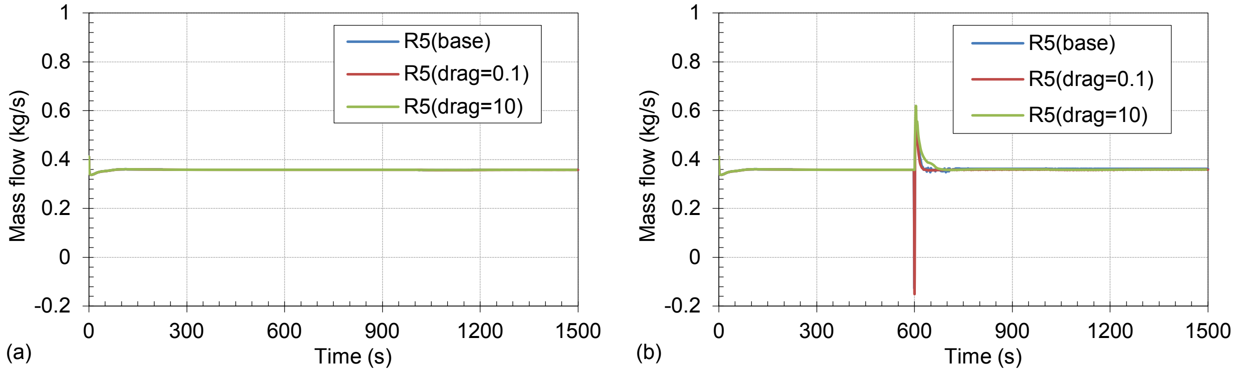

Figure 20 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C1_P-100.0% and (b) C2_P-97.6%

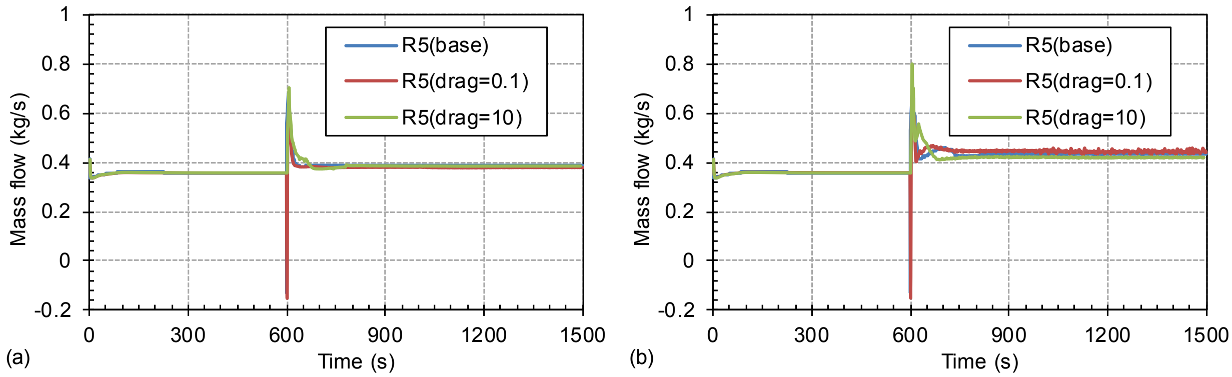

Figure 21 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C3_P-96.3% and (b) C4_P-95.2%

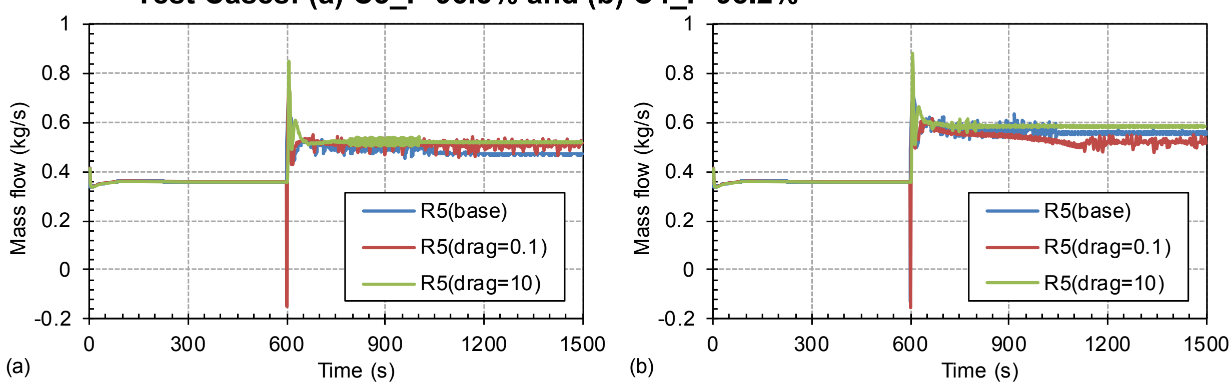

Figure 22 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C5_P-94.2% and (b) C6_P-93.1%

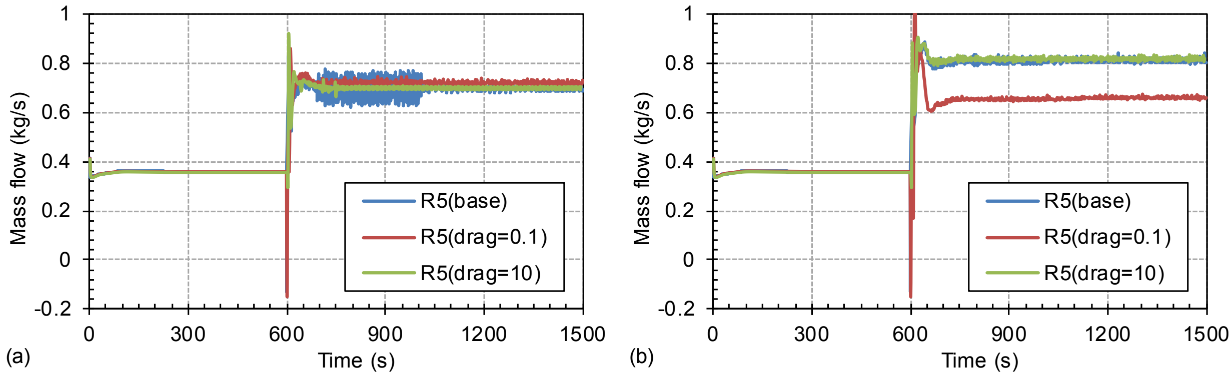

Figure 23 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C7_P-90.9% and (b) C8_P-87.8%

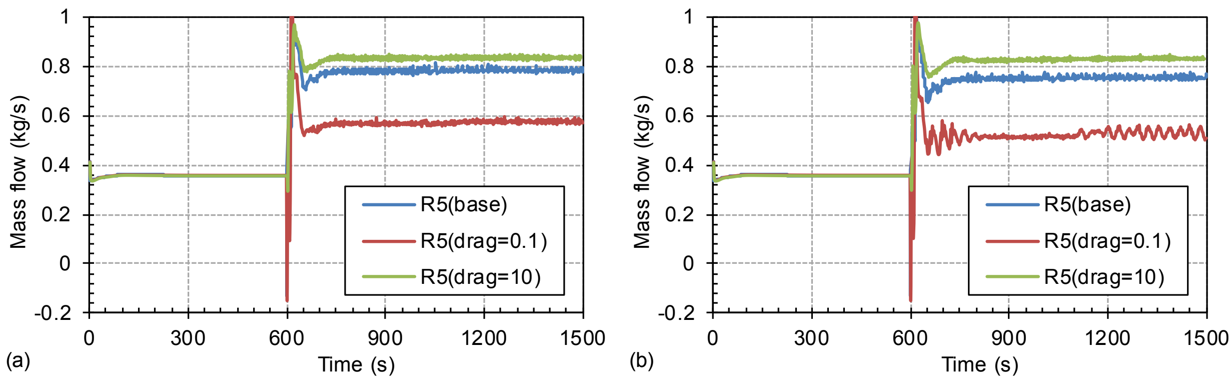

Figure 24 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C9_P-84.8% and (b) C10_P-83.6%

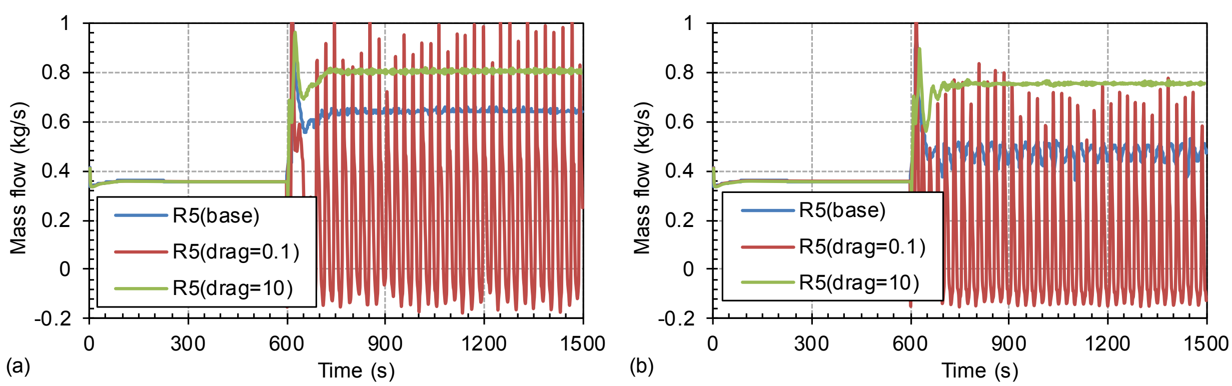

Figure 25 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C11_P-80.6% and (b) C12_P-77.6%

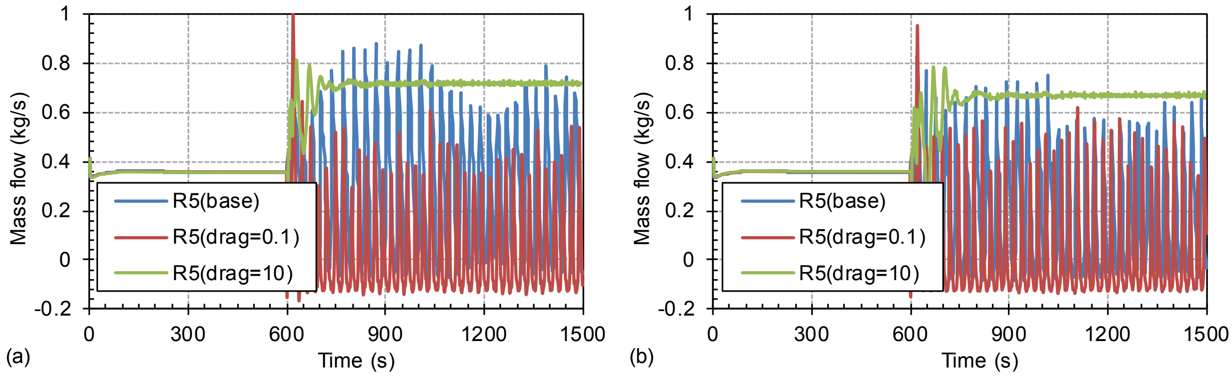

Figure 26 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C13_P-74.4% and (b) C14_P-71.4%

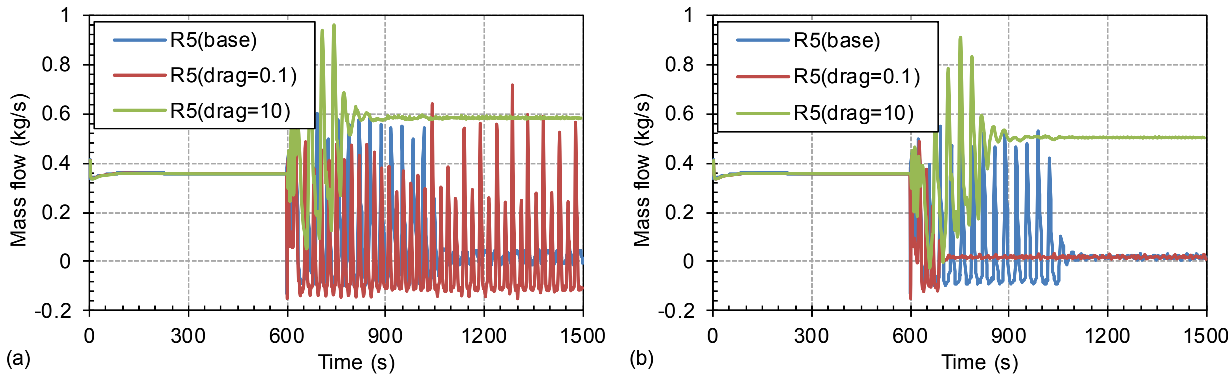

Figure 27 Mass Flowrate Dependence on Dial Value Drag Coefficient Variation for S-NC-2 Test Cases: (a) C15_P-66.3% and (b) C16_P-61.2%

3.2 Results S-NC-3 Test

Figures 28 through 31 show the sensitivity calculations in which drag coefficient is varied for S-NC-3 test cases C10_S-100.0%, C13_S-75.5%, C16_S-43.6% and C19_S-15.2%, respectively. The parameters shown are mass flow rate, hot leg fluid temperature, primary side steam generator outlet fluid temperature, and primary system pressure. In all four cases the drag coefficient value variation has some influence on the parameters. When interphase drag coefficient is decreased (case labelled 'R5(drag_0.8)'), comparison with the base case (case labeled 'R5(base)') showed that the hot leg temperature and primary pressure steady state values achieved after 600 s increased slightly, the primary system mass flow decreased slightly, while steam generator outlet temperature is practically unchanged (exception is C16_S-43.6%). The opposite is true, when interphase drag coefficient is increased (case labelled 'R5(drag_1.2)'). The calculated results are less sensitive to drag coefficient value variation than in the S-NC-2 test. This means that vapor-liquid interphase drag looks not a major reason to explain the discrepancy in the natural circulation mass flow rate. This is also in agreement with the recent findings obtained with Korean SPACE computer code [3].

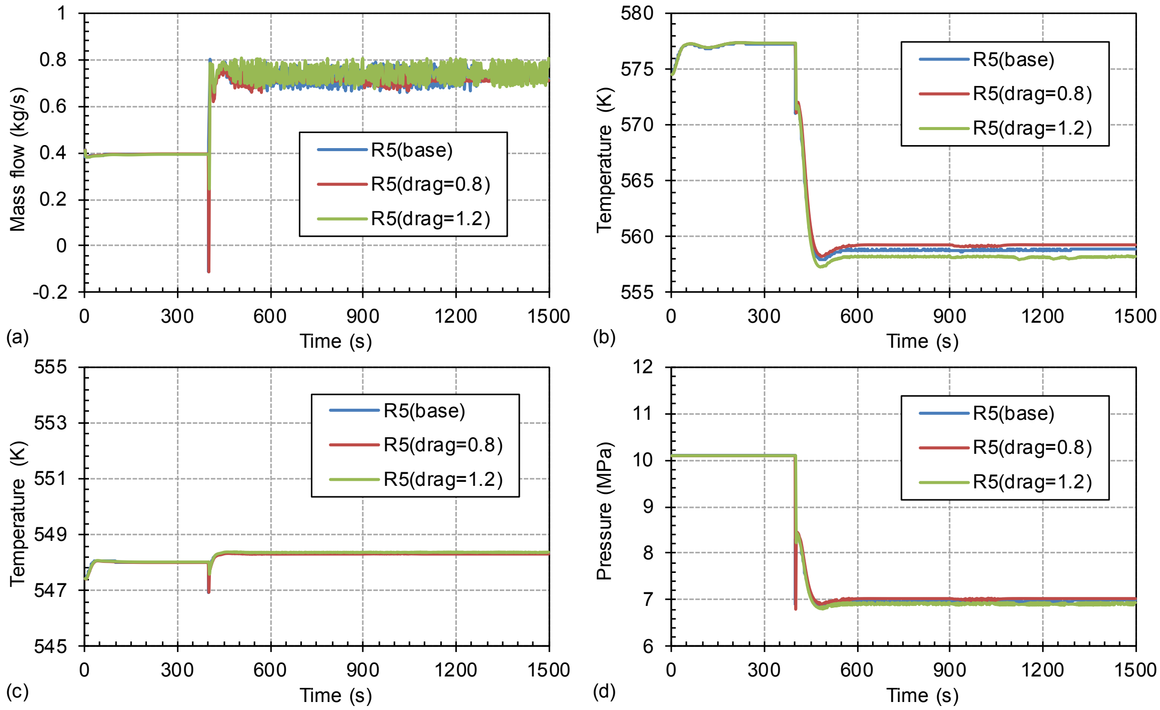

Figure 28 Sensitivity Calculations Varying Drag Coefficient for S-NC-3 Test Case C10_S-100.0%: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

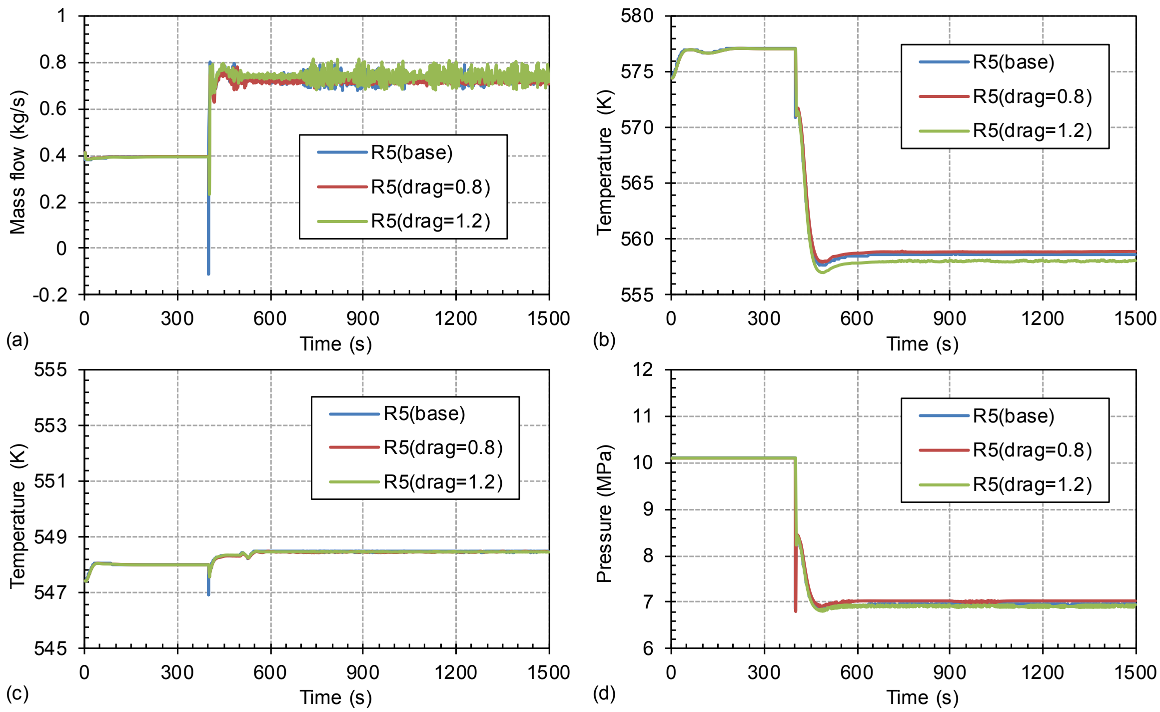

Figure 29 Sensitivity Calculations Varying Drag Coefficient for S-NC-3 Test Case C13_S-75.5%: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

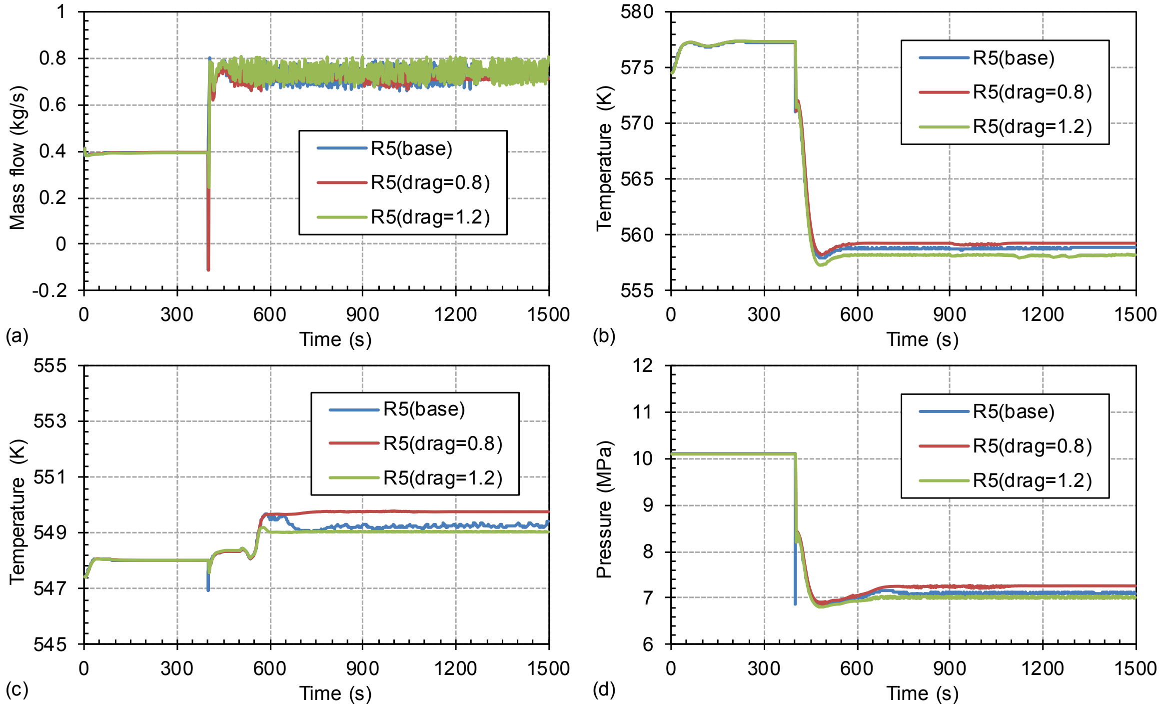

Figure 30 Sensitivity Calculations Varying Drag Coefficient for S-NC-3 Test Case C16_S-43.6%: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

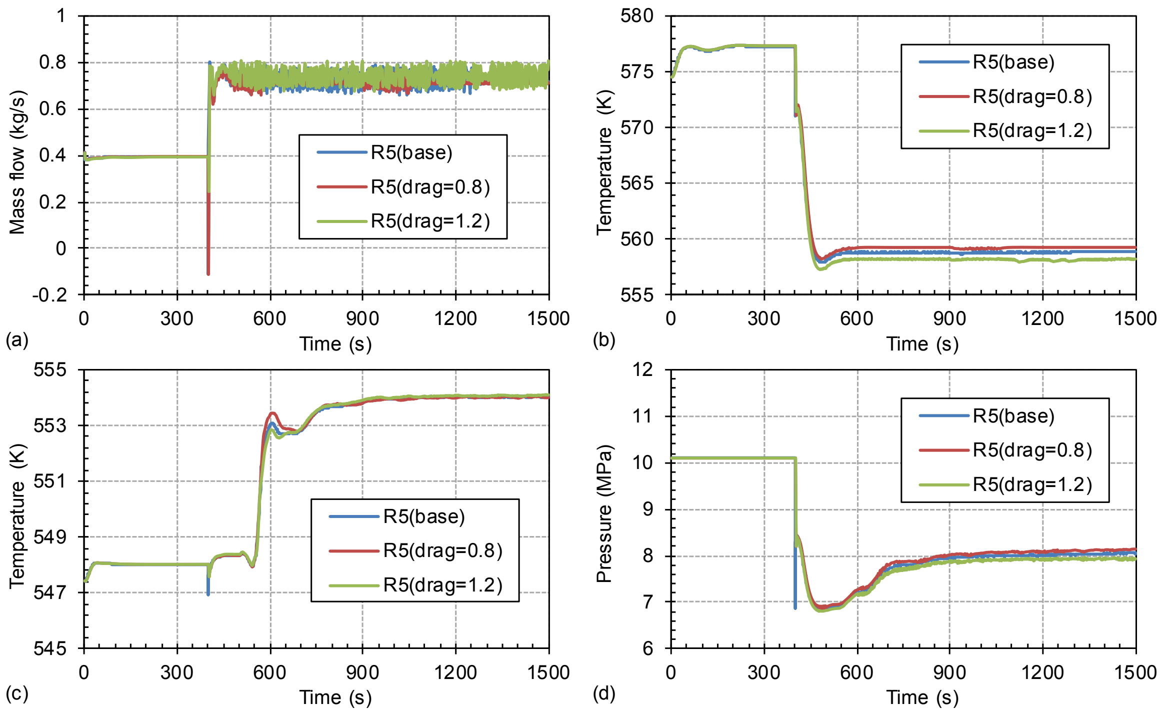

Figure 31 Sensitivity Calculations Varying Drag Coefficient for S-NC-3 Test Case C19_S-15.2%: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

The sensitivity of average steady state results on drag coefficient value variation in range 0.8 to 1.2 for S-NC-3 test are shown in Figure 32. The calculated results are compared to experimental data for mass flow rate, hot leg fluid temperature, primary side steam generator outlet fluid temperature, and primary system pressure. Above 55% steam generator heat transfer area the agreement in mass flow rate is good and subsequently also hot leg fluid temperature, primary side steam generator outlet fluid temperature, and primary system pressure are in good agreement. Below 55% steam generator heat transfer area the mass flow rate is overpredicted and subsequently hot leg fluid temperature, primary side steam generator outlet fluid temperature, and primary system pressure are underpredicted.

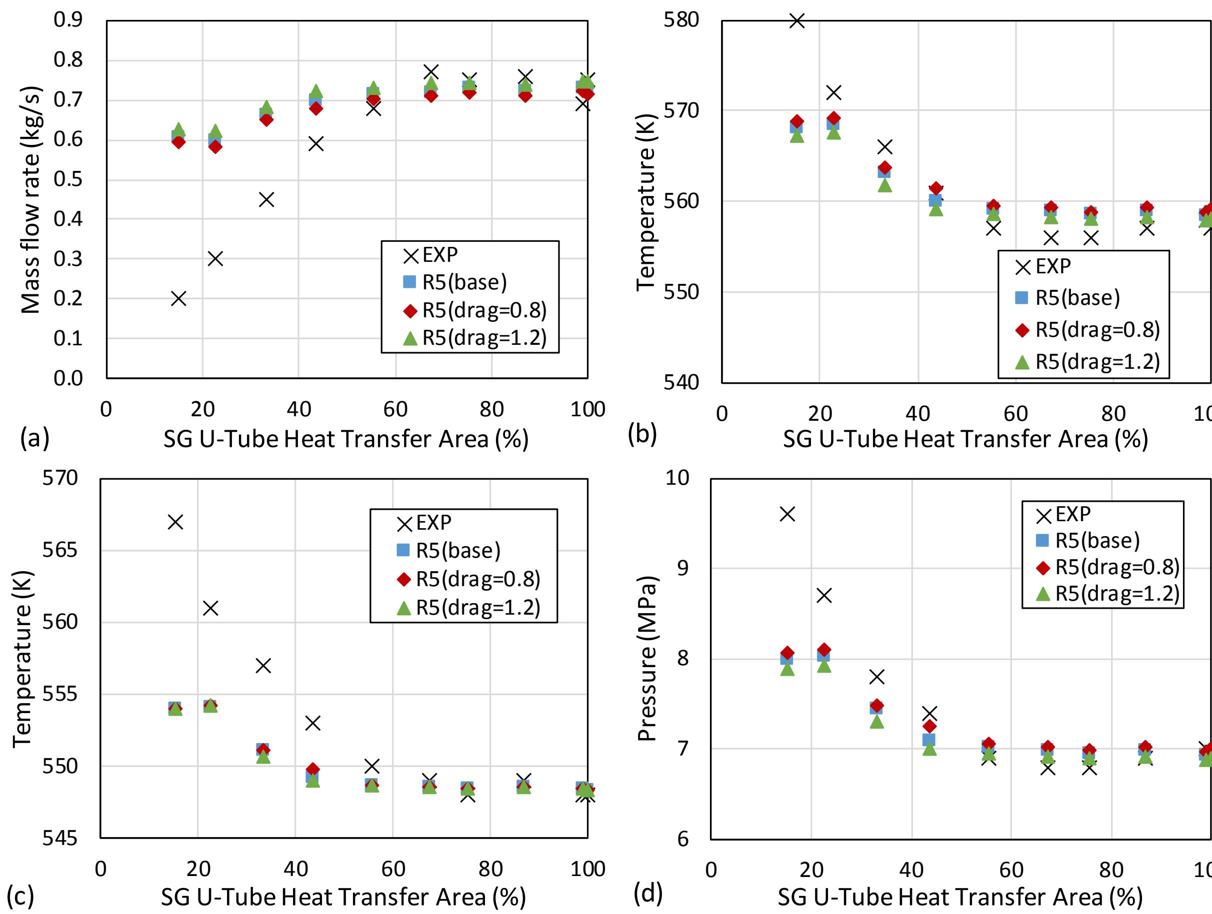

Figure 32 Comparison Between RELAP5 Sensitivity Calculations Varying Drag Coefficient and Experiment for S-NC-3 Test as a Function of SG U-Tube Heat Transfer Area: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

The study [4] states that in the S-NC-3 calculations with primary inventory set at 92% full, the cited experimental value, which corresponds to the inventory where the peak two-phase natural circulation flow was measured in S-NC-2. Further, it is stated that the occurrence of this peak two-phase flow implies that bubbles are just reaching the top of the U-tubes and being pulled over into the downside. At the same inventory, their S-NC-2 calculation shows all the bubbles condensing out lower in the upside of the U-tubes. They found that the primary inventory must be dropped to 85% before the predicted primary inventory distribution has bubbles at the U-tube bend and the calculated two-phase natural circulation flow peaks. To their opinion, matching the height and distribution of the two- phase mixture within the U-tubes relative to the height and distribution of secondary side liquid should be very important in correctly calculating the degraded heat transfer behavior seen in S-NC-3.

This was followed also in the study [3] for SPACE computer code. The quantitative agreement between calculated and measured primary flow rate has improved when the primary mass inventory used in the calculations was set to 87% rather than 92%. Therefore, in our calculations the cases with mass inventory reduced to 87.7%, 84.8% and 83.6% were studied. In all three cases the mass flow increases compared to base case with 91.8% primary coolant system inventory as shown in Figures 33 through 37.

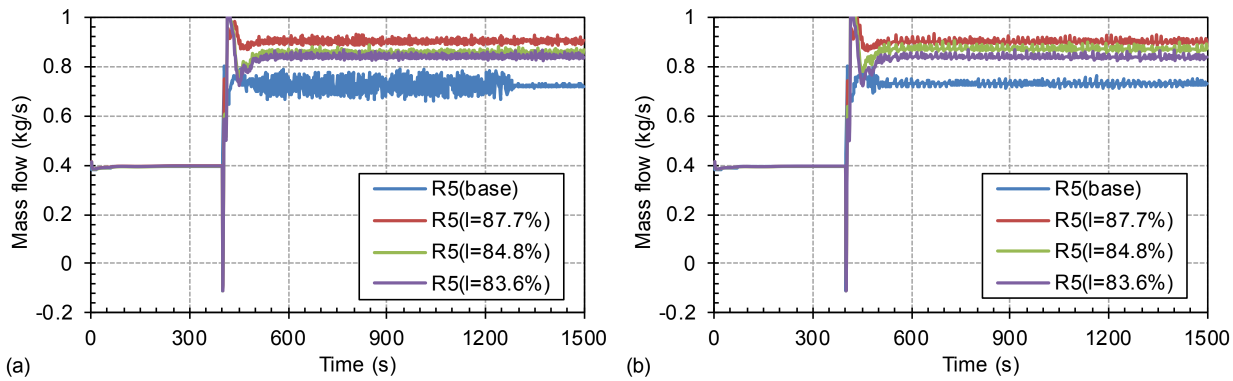

Figure 33 Mass Flowrate Dependence on Initial Primary Coolant System Inventory for S-NC-3 Test Cases: (a) C10_S-100.0% and (b) C11_S99.1%

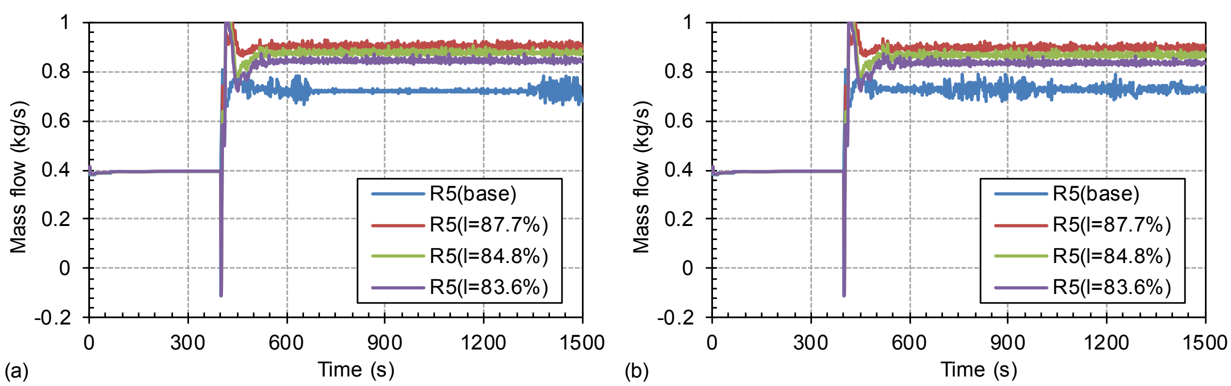

Figure 34 Mass Flowrate Dependence on Initial Primary Coolant System Inventory for S-NC-3 Test Cases: (a) Cases C12_S-86.9% and (b) C13_S-75.5%

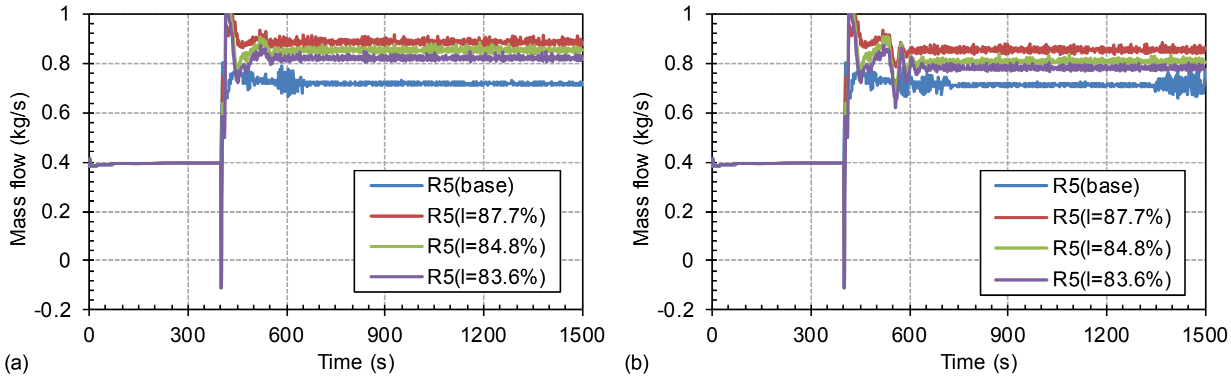

Figure 35 Mass Flowrate Dependence on Initial Primary Coolant System Inventory for S-NC-3 Test Cases: (a) C14_S-67.4% and (b) C15_S-55.5%

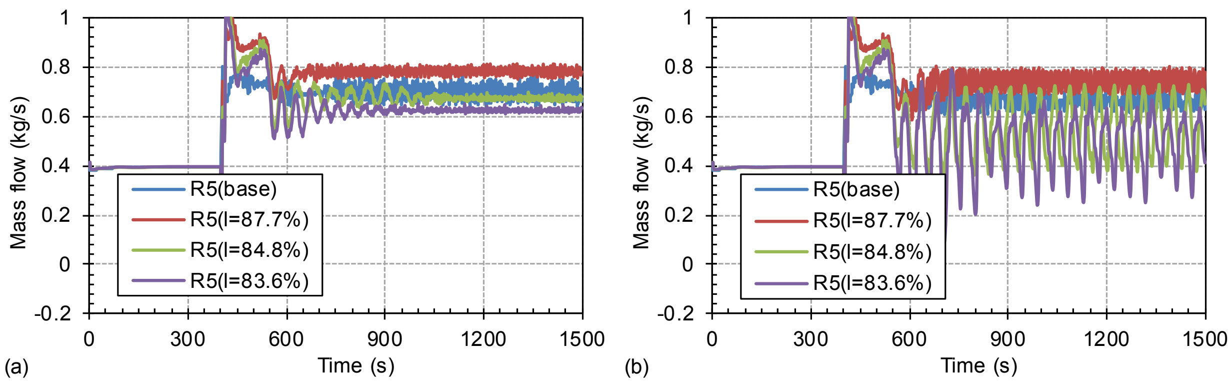

Figure 36 Mass Flowrate Dependence on Initial Primary Coolant System Inventory for S-NC-3 Test Cases: (a) C16_S-43.6% and (b) C17_S-33.2%

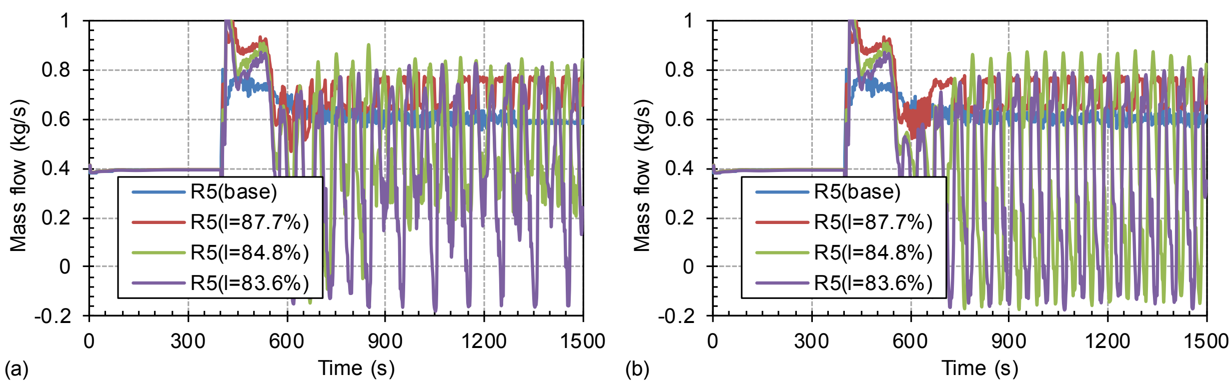

Figure 37 Mass Flowrate Dependence on Initial Primary Coolant System Inventory for S-NC-3 Test Cases: (a) C18_S-22.7% and (b) C19_S-15.2%

As shown in Figure 38(a) the higher mass flow rate resulted in lower calculated fluid temperatures and a lower primary system pressure as can be seen from Figures 38(b), 38(c) and 38(d). Reduction of primary system coolant inventory causes better agreement of mass flow rate with experimental data, while hot leg fluid temperature and primary pressure are in larger disagreement.

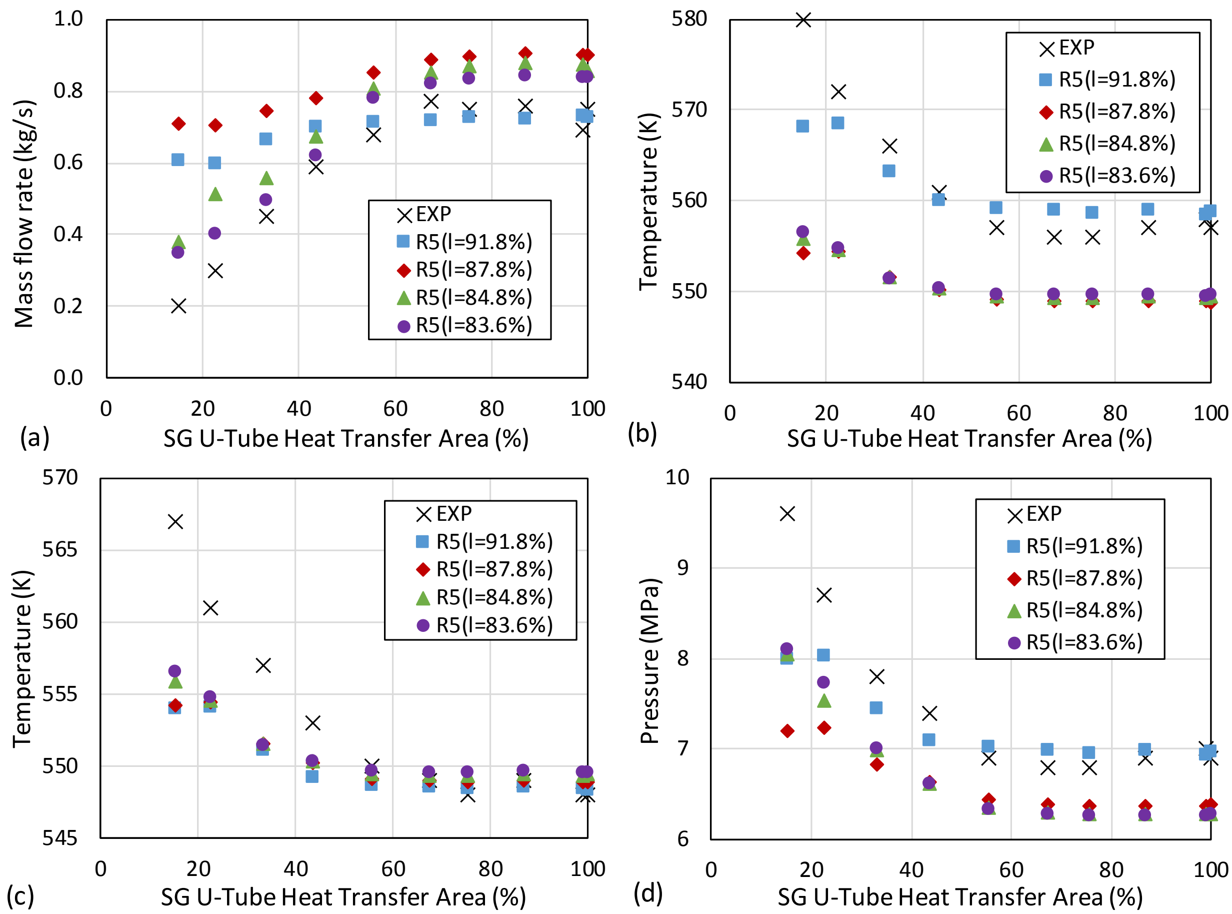

Figure 38 Comparison Between RELAP5 Sensitivity Calculations Varying Primary Coolant System Inventory and Experiment for S-NC-3 Test as a Function of SG U-Tube Heat Transfer Area: (a) Primary System Mass Flowrate, (b) Hot Leg Fluid Temperature, (c) SG Outlet Temperature, (d) Primary Pressure

Finally, Figures 39 through 42 show liquid distribution on the primary and secondary side for the C19_S-15.2%, in which primary system coolant reduction was set to 83.6%. The 10 s time increments have been selected, as the oscillation period is approximately 60 s. The oscillation period is demonstrated by comparing Figures 39 and 42, which are approximately the same.

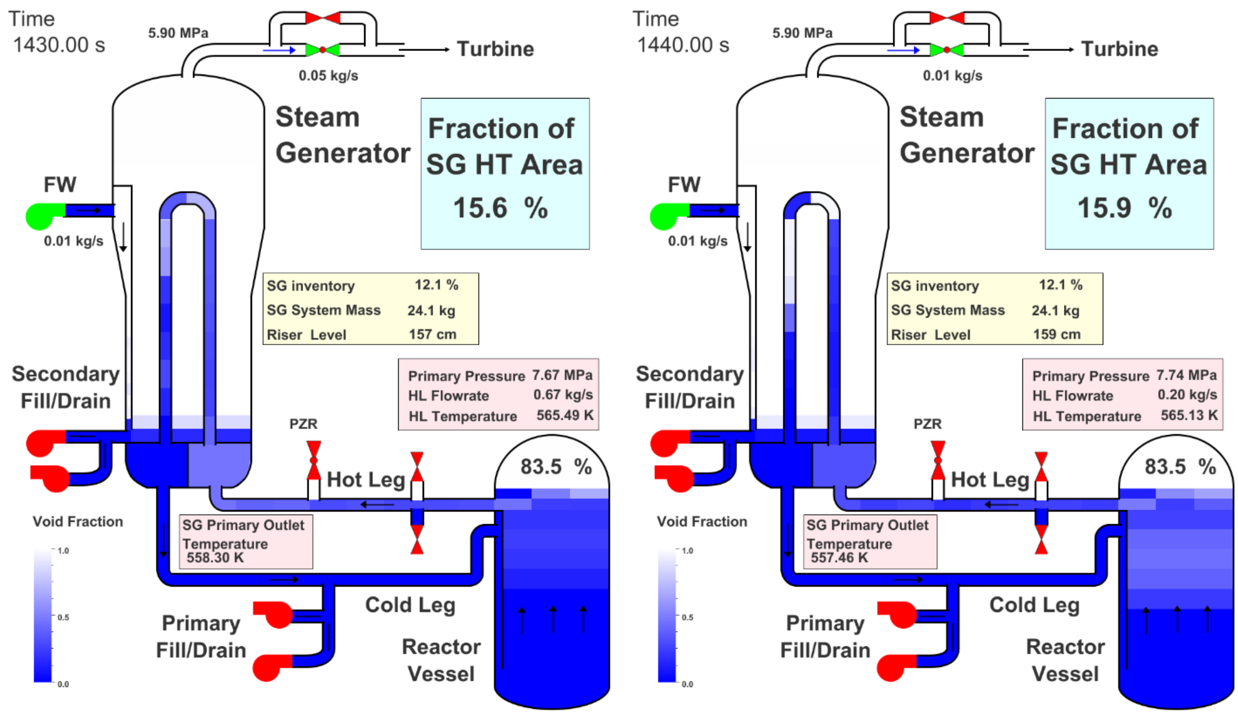

Figure 39 Animation Mask for S-NC-03 Calculated Case C19_S-15.2% with Primary Side Filled as in S-NC-02_P-83.6% at 1430 s (left) and 1440 s

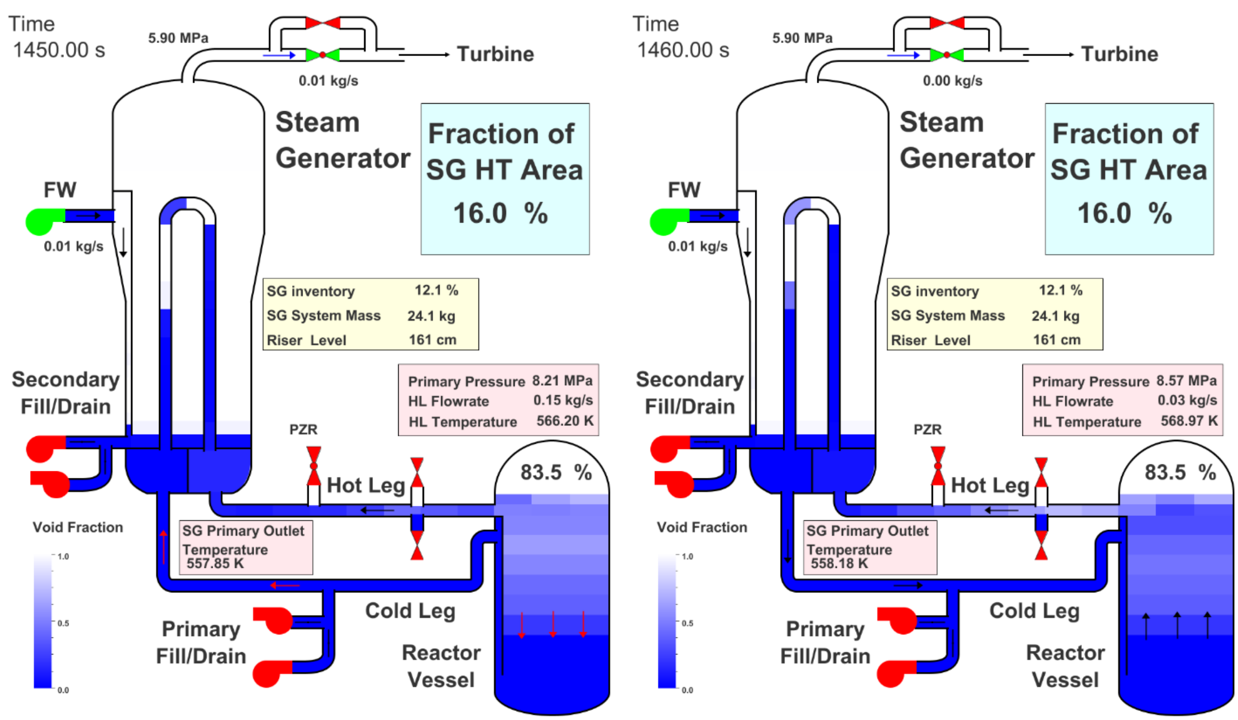

Figure 40 Animation Mask for S-NC-03 Calculated Case C19_S-15.2% with Primary Side Filled as in S-NC-02_P-83.6% at 1450 s (left) and 1460 s

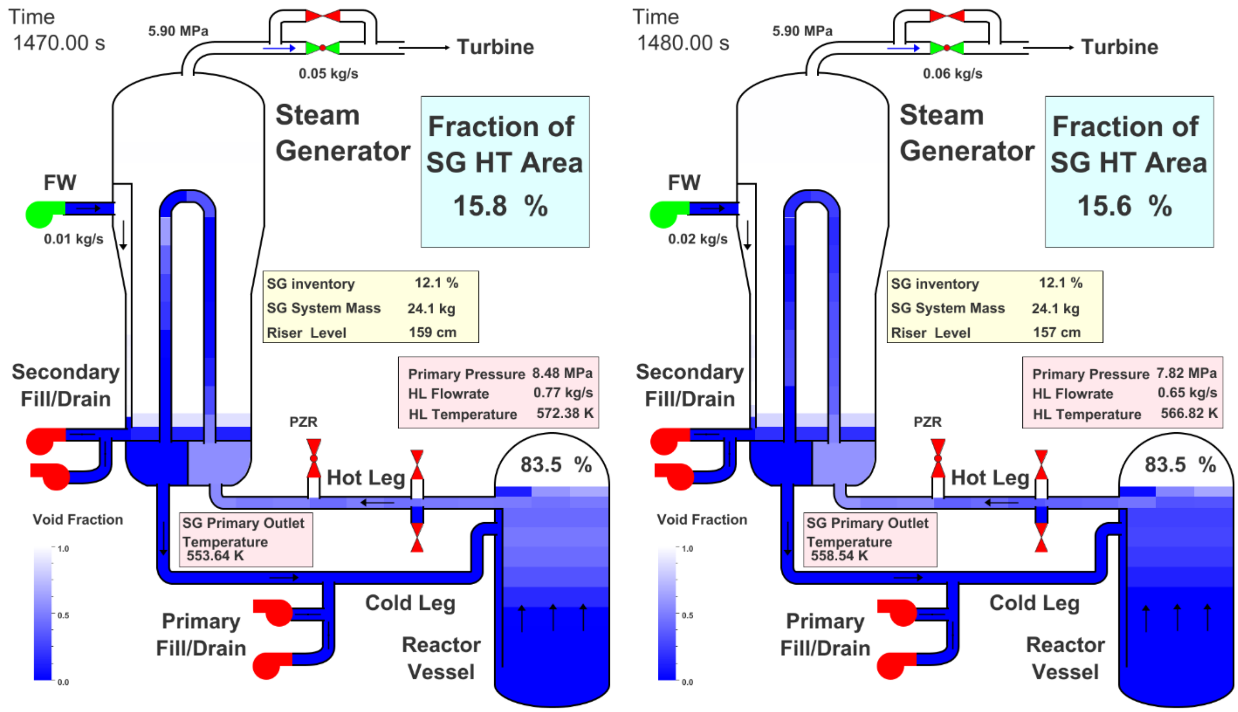

Figure 41 Animation Mask for S-NC-03 Calculated Case C19_S-15.2% with Primary Side Filled as in S-NC-02_P-83.6% at 1470 s (left) and 1480 s

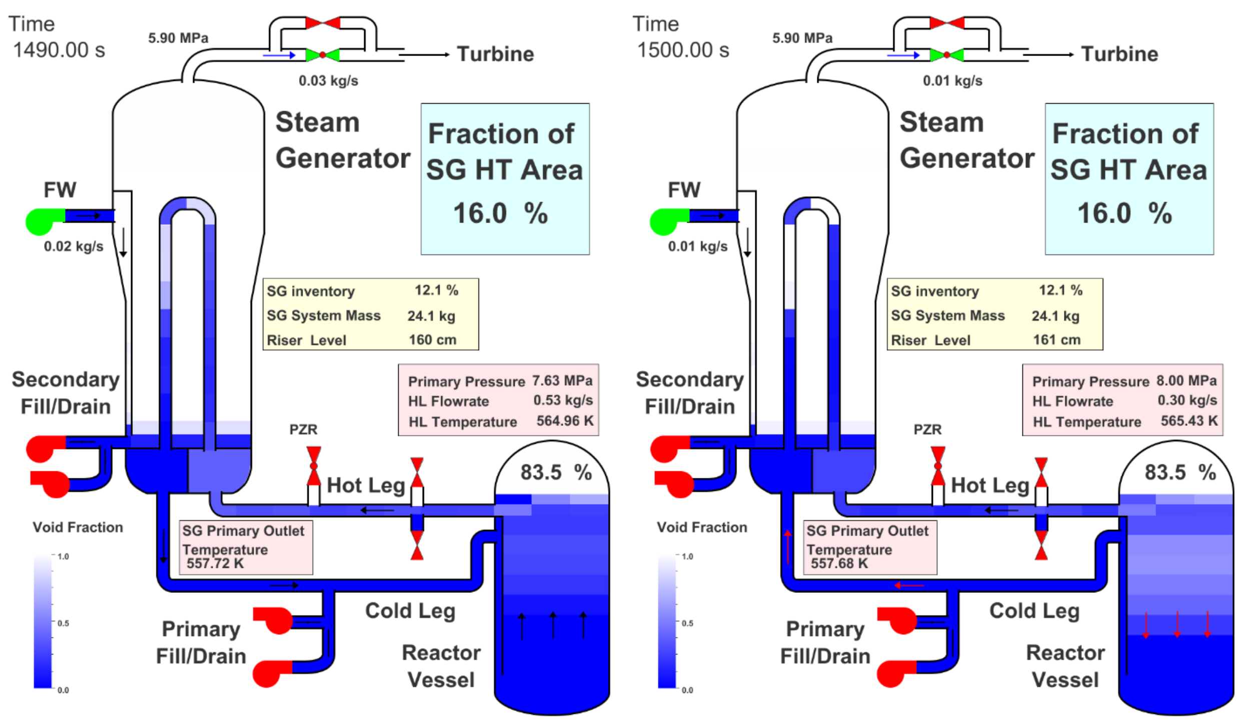

Figure 42 Animation Mask for S-NC-03 Calculated Case C19_S-15.2% with Primary Side Filled as in S-NC-02_P-83.6% at 1490 s (left) and 1500 s (right)

4 CONCLUSIONS

The RELAP5/MOD3.3 Patch05 computer code calculations of Semiscale S-NC-2 at a different primary side mass inventory test and S-NC-3 in the degraded heat transfer condition test have been performed and compared to the experimental data. The sensitivity study was performed for interphase drag coefficient. The results for S-NC-2 test showed that interphase drag coefficient has some influence on the mass flow during natural circulation, but smaller than suspected by code developers. For S-NC-3 test it was confirmed that equating the height and distribution of the two-phase mixture in calculation within the U-tubes with the experimental condition is essential to predict correctly the degraded heat transfer phenomena. Finally, Symbolic Nuclear Analysis Package (SNAP) animation masks have contributed much to the physical understanding of the natural circulation phenomena, especially by showing the distribution of the two-phase mixture in the calculation.

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[2] APT, Symbolic Nuclear Analysis Package (SNAP), User's Manual, Applied Programming Technology (APT), Inc., Version 2.2.1 - October 25 2012.

[3] S. Kim, M. Kim, Sensitivity Studies on Semiscale Natural Circulation Phenomena in Degraded Steam Generator Heat Transfer Area with SPACE Code, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 27-28, 2016.

[4] Chung-Nin Channy Wong, Lubomyra N. Kmetyk, RELAP5 Assessment: Semiscale Natural Circulation Tests S-NC-3, S-NC-4 and S-NC-8, NUREG/CR-3690, My 1984.

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10. SUPPLEMENTARY NOTES

K. Tien, NRC Project Manager

11. ABSTRACT (200 words or less)

Experimental tests S-NC-2 and S-NC-3 were used to assess the RELAP5/MOD3.3 Patch05 computer code. The code developers concluded that it appears the interphase drag model allowed too much liquid to be entrained thus affecting the results of the calculation and that further investigation into the interphase drag model is warranted. The purpose of the present study was to investigate by sensitivity study the influence of interphase drag in the primary system.
The natural circulation experiments were performed in the Semiscale Mod-2A test facility, which is a small-scale model of the primary system of a four-loop Pressurized Water Reactor (PWR). The tests selected were Semiscale natural circulation tests S-NC-02 and S-NC-03. For sensitivity calculations, the latest RELAP5/MOD3.3 Patch05 computer code has been used. The ASCII input deck was obtained in the frame of RELAP5 code distribution for the auto validation purposes. The Symbolic Nuclear Analysis Package (SNAP) graphical user interface animation mask has been created to better understand the influence of varying interphase drag on natural calculated physical phenomena and processes. The results for S-NC-2 test showed that interphase drag coefficient has some influence on the mass flow during natural circulation, but smaller than suspected by code developers. For S-NC-3 test, it was confirmed that equating the height and distribution of the two-phase mixture in calculation within the U-tubes with the experimental condition is essential to predict correctly the degraded heat transfer phenomena.

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