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RELAP5 and TRACE Calculations of LOCA in PWR

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ABSTRACT

The accident at the Fukushima Dai-ichi nuclear power plant in 2011 demonstrated that external events could cause loss of all safety systems. In the Europe stress tests were performed and the need was identified to further improve the safety of the existing operating reactors. Therefore the safety upgrade programs were started. The objective of this study was to demonstrate that developed input model of two-loop pressurized water reactor (PWR) for TRACE thermal-hydraulic systems code can be used for independent calculations to be compared with RELAP5 computer code calculations. For demonstration the response of PWR to loss-of-coolant accident (LOCA) break spectrum from 10.16 cm (4 inch) to 30.48 cm (12 inch) was simulated. Only passive accumulators were assumed available. For calculations the latest TRACE Version 5.0 Patch 4 and RELAP5/MOD3.3 Patch 4 using both break flow models were used. The results showed that RELAP5 calculations using different break flow models are rather similar, therefore also other parameters are similar. The accumulators discharge was faster in TRACE calculation than in RELAP5 calculations. It can be concluded that different accumulator discharge influencing the break flow seems to be the largest contributor to the differences in the results between RELAP5 and TRACE.

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EXECUTIVE SUMMARY

The accident at the Fukushima Dai-ichi nuclear power plant in 2011 demonstrated that external events could cause loss of all safety systems. In the Europe stress tests were performed and the need was identified to further improve the safety of the existing operating reactors. Therefore the safety upgrade programs were started. The objective of this study was to demonstrate that developed input model of two-loop pressurized water reactor (PWR) for TRACE thermal-hydraulic systems code has the capability for independent assessment of RELAP5 computer code calculations. Namely, in the frame of the safety upgrade program the RELAP5 analyses have been performed by the plant to determine pressure and flow requirements for alternative safety injection pump for design extension conditions A (DEC-A) loss of coolant accidents (LOCA). For demonstration the response of PWR to loss-of-coolant accident (LOCA) was simulated. The break spectrum consists of 30.48 cm (12 inch), 20.32 cm (8 inch), 15.24 cm (6 inch), 12.7 cm (5 inch) and 10.16 cm (4 inch) equivalent diameter cold leg breaks. The initiating event was opening of the valve simulating the break. The reactor trip on (compensated) low pressurizer pressure (12.99 MPa) further caused the turbine trip. The safety injection (SI) signal was generated on the low-low pressurizer pressure signal at 12.27 MPa. On SI signal no active safety systems started (e.g. high pressure safety injection pumps and low pressure safety injection pumps and motor driven auxiliary feedwater pumps). Only passive components were assumed available, i.e. accumulators. All these LOCA scenarios with above assumptions lead to the core heatup. In this way the time available before significant core heatup could be obtained.

For calculations the latest TRACE Version 5.0 Patch 4 using extension of Ransom and Trapp critical flow model (default) and RELAP5/MOD3.3 Patch 4 using Henry-Fauske critical flow model (default) and Ransom-Trapp critical flow model (Option 50) were used.

The results showed that RELAP5 calculations using different break flow models are rather similar, therefore also other parameters are similar. When comparing TRACE results to RELAP5 results, the accumulators discharge was consistently faster in TRACE calculations than in RELAP5 calculations. Therefore the calculated TRACE break flow was also larger than RELAP5 calculated break flow during this period. This further leads to qualitative differences at the 30.48 cm break size scenario. It can be concluded that the different accumulator discharge influencing the break flow seems to be the largest contributor to the differences in the results between RELAP5 and TRACE.

ACKNOWLEDGMENTS

The authors acknowledge the financial support from Krško Nuclear Power Plant and Slovenian Nuclear Safety Administration within CAMP program (project no. POG-U3-KE-R4/104/12 – also NEK no.: 3120118) and from the state budget by the Slovenian Research Agency (program no. P2-0026).

ABBREVIATIONS

ACC	accumulator
AFW	auxiliary feedwater
ASCII	American Standard Code for Information Interchange
CVCS	chemical and volume control system
DEC-A	design extension conditions A
ECCS	emergency core cooling system
HPSI	high pressure safety injection
LOCA	loss-of-coolant accident
LPSI	low pressure safety injection
MFW	main feedwater
MSIV	main steam isolation valve
NPP	nuclear power plant
PORV	power operated relief valve
PRZ	pressurizer
PWR	Pressurized Water Reactor
RCP	reactor coolant pump
RCS	reactor coolant system
RELAP	Reactor Excursion and Leak Analysis Program
RPV	reactor pressure vessel
SG	steam generator
SI	safety injection
SL	surge line
SNAP	Symbolic Nuclear Analysis Package
WR	wide range

1. INTRODUCTION

Slovenian Krško nuclear power plant is a one unit plant with pressurized water reactor (PWR), a two-loop Westinghouse design with thermal power 1994 MW. In the frame of Krško Safety Upgrade Program the RELAP5 calculations have been also used to define requirements for alternative safety injection pump. To support independent assessment of Krško Safety Upgrade Program there was a need to make code comparison, therefore TRACE code has been proposed for comparison calculations.

To define requirements for safety injection pump, loss of coolant accidents (LOCA) were simulated in a two-loop PWR by Krško nuclear power plant (NPP). Therefore in this study independent analyses of loss-of-coolant accident (LOCA) break spectrum by RELAP5 and TRACE computer codes have been performed for comparison purposes. In Section 2 first the LOCA scenarios are described. Then the RELAP5 and TRACE thermal-hydraulic system computer codes are briefly described, followed by input model description for both computer codes. Then the initial and boundary conditions, resulting from steady state calculations are presented. Five break sizes ranging from 10.16 cm to 30.48 cm equivalent diameter break size in cold leg were simulated and for each break size three calculations were performed, one with TRACE using default option for critical flow model and two with RELAP5 using Henry-Fauske and Ransom-Trapp critical flow models. Then, results of the LOCA calculations are presented in Section 3, including discussion of the result. Finally, main conclusions are drawn.

2. METHODS USED

2.1 LOCA Scenario Description

In the LOCAs simulated at the beginning of transient only passive components were assumed available: two accumulators, pressurizer safety valves (not needed during LOCAs), and steam generator safety valves (not needed during LOCAs). All the LOCA scenarios simulated with above assumptions lead to the core heatup.

The initiating event is opening of the valve simulating the break in the cold leg with reactor operating at 100% power. The reactor trip on (compensated) low pressurizer pressure (12.99 MPa) further causes the turbine trip. The safety injection (SI) signal is generated on the low-low pressurizer pressure signal at 12.27 MPa. On SI signal no active safety systems start (e.g. high pressure safety injection (HPSI) pumps and low pressure safety injection (LPSI) pumps and motor driven (MD) AFW pumps). When pressure drops below 49.55 bars, both accumulators start to inject. Larger is the break size, faster is the accumulator discharge. When both accumulators are emptied, the reactor coolant system (RCS) mass inventory is again decreasing, resulting in core uncovering. The core starts to heat up and the calculations are terminated at 2100 K, if calculation is not aborted earlier.

2.2 Computer Codes Used

At the time of calculations the latest RELAP5 and TRACE thermal hydraulic system codes were used: U.S. NRC RELAP5/MOD3.3 Patch 4 (Ref. 1) and TRACE Version 5.0 Patch 4 (Ref. 2), respectively. In June 2016 new RELAP5/MOD3.3 Patch 5 (Ref. 3) was released as a result of maintenance of the code, without any new critical flow models. The RELAP5/MOD3.3 Patch 4 has built in two models for critical flow: Henry-Fauske critical flow model which is default and Ransom-Trapp critical flow model (Option 50 need to be used). The TRACE has built in as default the critical flow model which is extension of Ransom and Trapp critical flow model.

2.3 RELAP5 Input Model

To perform the analyses, the base RELAP5 input model of Krško NPP has been used. Krško NPP is a two loop PWR, Westinghouse type, with reactor power uprated to 1994 MW. The input model has been validated by plant transients (e.g. Ref. 4). It has been used for several safety analyses including reference calculations for Krško full scope simulator verification (Refs. 5 and 6). The base model consists of 469 control volumes, 497 junctions and 378 heat structures with 2107 radial mesh points. When imported ASCI file into SNAP, the hydraulic components view has been generated semi automatically (hydraulic components with connections generated automatically, annotations and layout manually). In terms of SNAP this gives 304 hydraulic components and 108 heat structures. Hydraulic components in SNAP consist of both volumes and junctions, where pipe with more volumes is counted as one component. Each heat structure in SNAP connected to pipe is counted as one component in SNAP and not as many heat structures as pipe volumes like counted in RELAP5 output file. This explains the difference in numbers of heat structures in Figure 1 and that reported in RELAP5 output file.

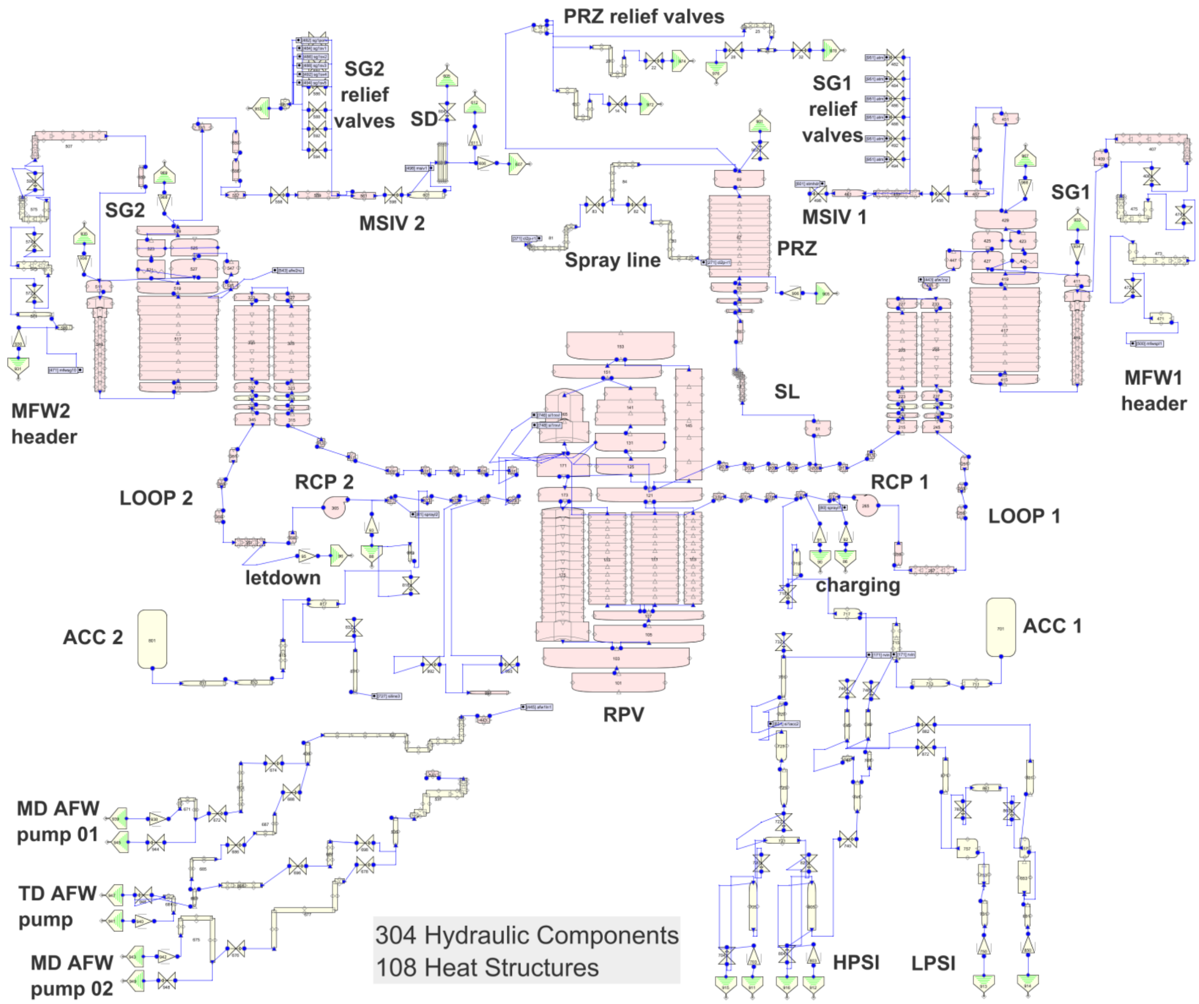

Figure 1 RELAP5 Krško NPP Hydraulic Components View

Modeling of the primary side includes the reactor pressure vessel (RPV), both loops (LOOP 1 and 2), the pressurizer (PRZ) vessel, pressurizer surge line (SL), pressurizer spray lines and valves, two pressurizer power operated relief valves (PORVs) and two pressurizer safety valves, chemical and volume control system (CVCS) charging and letdown flow, and reactor coolant pump (RCP) seal flow. Emergency core cooling system (ECCS) piping includes high pressure safety injection (HPSI) pumps, accumulators (ACCs), and low pressure safety injection (LPSI) pumps. The secondary side consists of the SG secondary side, main steam line, main steam isolation valves (MSIVs), SG relief and safety valves, and main feedwater (MFW) piping. The turbine valve is modeled by the corresponding logic. The turbine is represented by time dependent volume. The MFW and AFW (auxiliary feedwater) pumps are modeled as time dependent junctions.

2.4 TRACE Input Model

The one-dimensional TRACE plant input model was obtained from an existing RELAP5/MOD3.3 plant input deck (Ref. 9). The conversion of the RELAP5 input model to TRACE input model was performed using SNAP (Ref. 8) and following the JSI RELAP5 to TRACE conversion method. A detailed description regarding the conversion procedure can be found in Ref. 7. Several modifications were manually brought to the TRACE input model during the conversion process, mostly related to Heat Structures boundary conditions, Accumulator model option and Hydraulic connections of Pipe components that originated from RELAP5 Branch components. Several Control Block Data have been modified too. For more details refer to Ref. 10. TRACE input model is shown in Figure 2. The number of SNAP hydraulic components is 473 and the number of heat structures is 108.

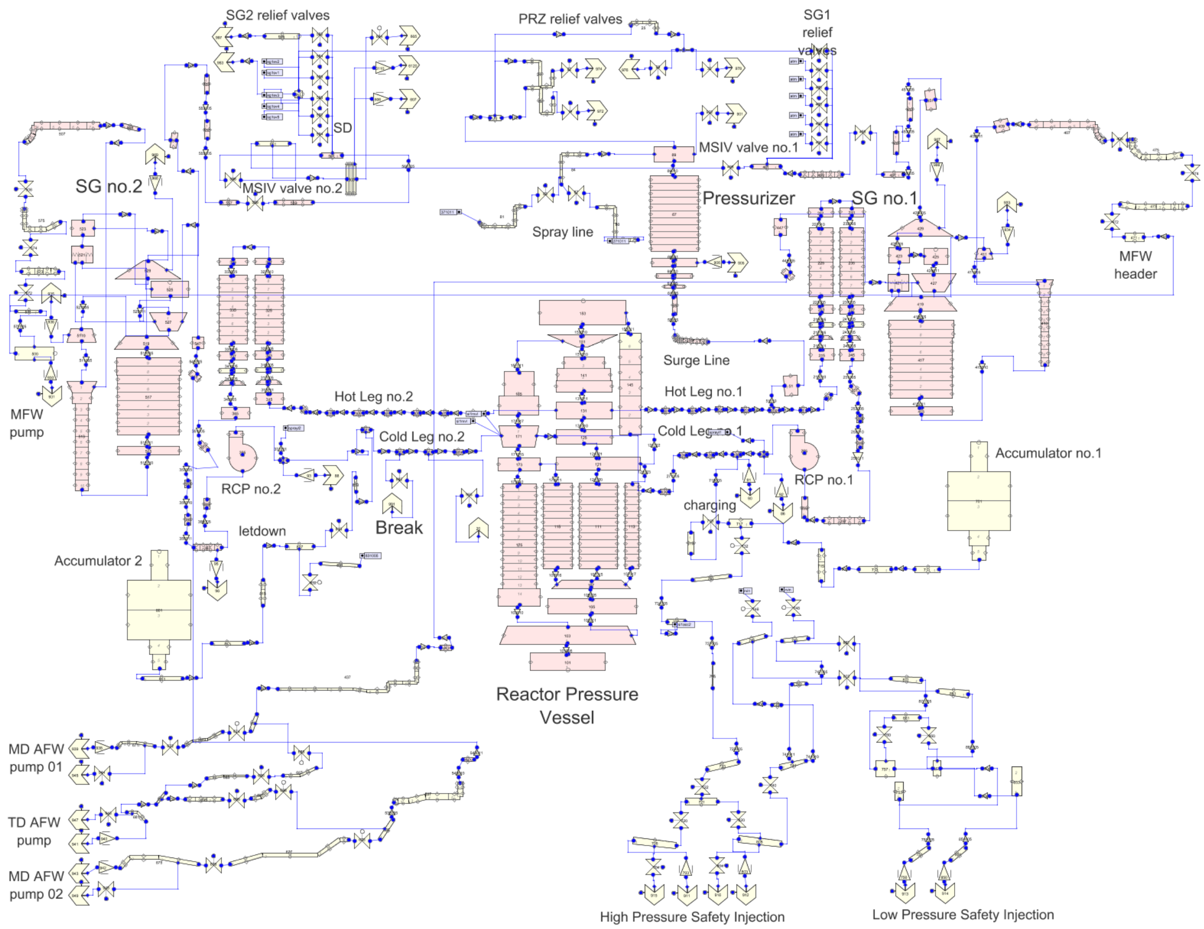

Figure 2 TRACE Krško NPP Hydraulic Components View

2.5 Initial and Boundary Conditions

Table 1 shows initial and boundary conditions at the beginning of simulation. Initial values and boundary conditions are given for both loops (where applicable). It can be seen that RELAP5 initial and boundary conditions are a bit closer to reference PWR values than TRACE initial and boundary conditions. When looking TRACE values there is significant deviation in steam generator levels only due to separator model problems.

Table 1 Initial and Boundary Conditions

Parameter (unit)	Reference PWR	RELAP5/MOD3.3	TRACE
	Value		
Core power (MW)	1994	1994	1994
Pressurizer pressure (MPa)	15.513	15.513	15.512
Pressurizer level (%)	55.7	55.8	55.24
Average RCS temperature no. 1 (K)	578.15	578.15	579.26
Average RCS temperature no. 2 (K)	578.15	578.06	579.33
Cold leg temperature no. 1 (K)	558.75	559.51	561.34
Cold leg temperature no. 2 (K)	558.75	559.32	561.48
Hot leg temperature no. 1 (K)	597.55	596.79	597.22
Hot leg temperature no. 2 (K)	597.55	596.79	597.22
Cold leg flow no. 1 (kg/s)	4694.7	4721.2	4888.9
Cold leg flow no. 2 (kg/s)	4694.7	4719.6	4886.5
Steam generator pressure no. 1 (MPa)	6.281	6.438	6.619
Steam generator pressure no. 2 (MPa)	6.281	6.415	6.635
Steam generator NR level no. 1 (%)	69.3	69.3	6.2
Steam generator NR level no. 2 (%)	69.3	69.3	6.5
Steam flow no. 1 (kg/s)	544.5	541.3	539.9
Steam flow no. 2 (kg/s)	544.5	544.5	532.3
Main feedwater temperature (K)	492.6	492.8	493.7

Namely, besides expected steam flow there appears also liquid mass flow of 84.1 kg/s and 123.7 kg/s in steam line no. 1 and 2, respectively. The reason seems to be separator model in TRACE which needs improvement (bug report has been sent in December 2015). The plant TRACE input model of SG may also need some improvements. The problems of separator model to correctly separate steam and liquid at all possible boundary conditions caused that artificial steam generator level control during steady state calculation could not fill the steam generator levels to PWR reference values. As already mentioned, the liquid is flowing also to steam lines. Such separator model is serious limitation to perform calculation of any transient occurring on the secondary side. In LOCA calculations the influence of the secondary side is typically smaller than in the secondary side initiated transients because due to break the primary side empties and the natural circulation is terminated. Due to this fact and information that new version of TRACE will be released soon it was decided to perform comparison calculations with the current version, being aware of TRACE separator model limitation. It was judged that in spite of this deficiency LOCA calculations could be performed for larger breaks while at smaller break sizes the influence of secondary side on the primary side is expected to be larger and larger.

2.6 Simulated LOCA Break Cases

The breaks simulated were 10.16 cm (4 inch), 12.7 cm (5 inch), 15.24 cm (6 inch), 20.32 cm (8 inch) and 30.48 cm (12 inch) equivalent diameter cold leg breaks. For each break size three simulations were performed, two by RELAP5 and one by TRACE as can be seen from Table 2. In case of 30.48 cm break size additional TRACE calculation was performed, in which the TRACE accumulator discharge flow was tuned to RELAP5 accumulator discharge flow. In all simulations default values for break flows were used.

Table 2 LOCA Scenario Cases Simulated with RELAP5 and TRACE

Break size diameter	RELAP5/MOD3.3 using HF critical flow model	RELAP5/MOD3.3 using RT critical flow model	TRACE using extended RT critical flow model
10.16 cm (4 inch)	4_R5-HF	4_R5-RT	4_TRACE
12.7 cm (5 inch)	5_R5-HF	5_R5-RT	5_TRACE
15.24 cm (6 inch)	6_R5-HF	6_R5-RT	6_TRACE
20.32 cm (8 inch)	8_R5-HF	8_R5-RT	8_TRACE
30.48 cm (12 inch)	12_R5-HF	12_R5-RT	12_TRACE, 12_TRACE (ACC)*

* - TRACE accumulator discharge flow tuned to RELAP5 accumulator discharge flow

3. RESULTS

The results of LOCA break spectrum calculations are shown in Figures 3 through 62. For each break size the following parameters are shown: pressurizer pressure, cold leg no. 1 temperature, leg no. 1 temperature, break flow, core collapsed liquid level, core exit temperature, fuel cladding temperature, RCS mass, integrated break flow, mass injected by accumulators, accumulator no. 1 flow and accumulator no. 2 flow. Finally, in the discussion section additional Figures 63 and 63 are shown to explain the accumulator discharge flow.

3.1 LOCA with 10.16 cm Break Size

As has been indicated, at 10.16 cm break size (see Figures 3 through 14) there is some pressure plateau in primary pressure in RELAP5 calculations. It means that in this period secondary side is important. Due to explained limitations of TRACE separator model, the secondary side pressure drops and primary pressure follows it. Therefore the time sequence of further events in TRACE is faster. It should be noted that in the BETHSY LOCA calculations performed in the past (see Ref. 7), the mass discharged through accumulators was also much faster in TRACE simulation comparing to RELAP5. Both these facts resulted in earlier core heatup comparing to both RELAP5 calculations. Due to faster accumulator discharge the break flow significantly changes (increases) in the time period of accumulator discharging, influencing further the pressure, RCS mass, core collapsed liquid level, hot and cold leg temperatures, core exit temperature and fuel cladding temperature.

On the other hand, the influence of break flow model in case of RELAP5 calculations is more significant during initial blowdown. Therefore, slightly earlier heatup is predicted by Henry-Fauske (HF) critical flow model, which is higher in the initial period.

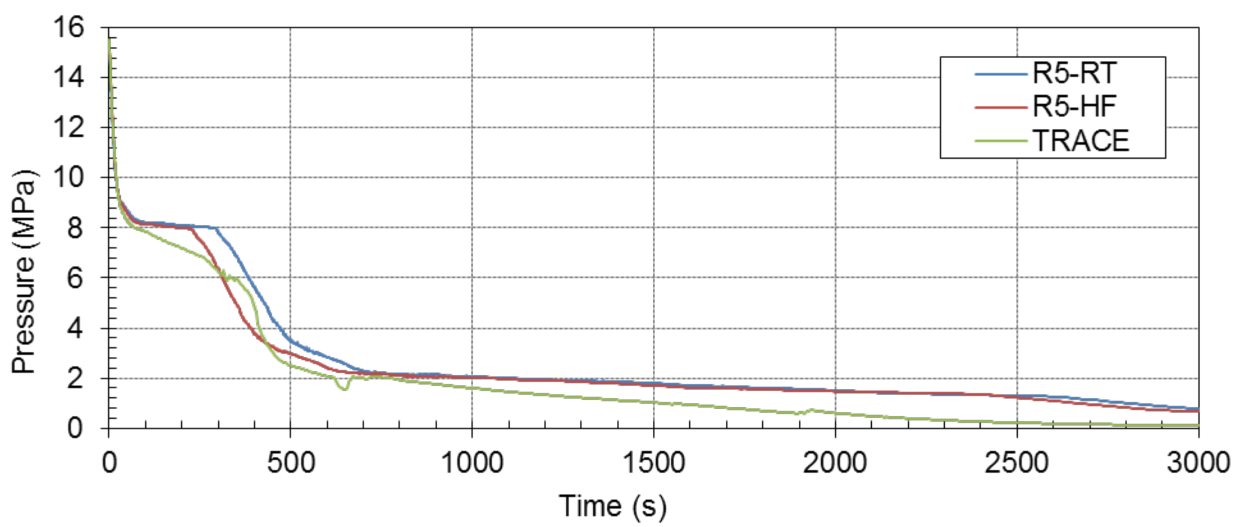

Figure 3 Pressurizer Pressure (10.16 cm)

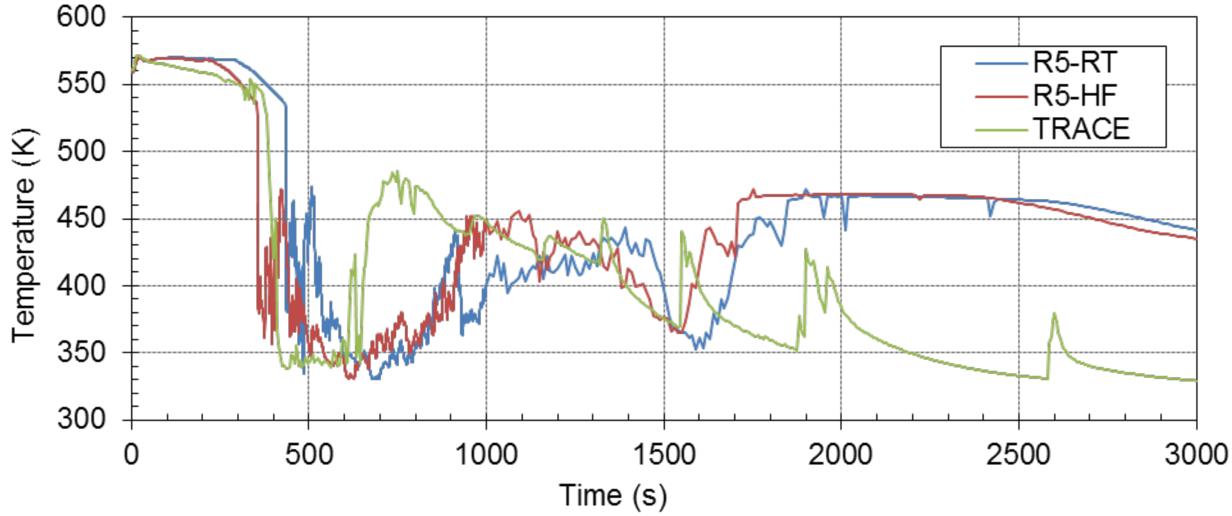

Figure 4 Cold Leg no. 1 Temperature (10.16 cm)

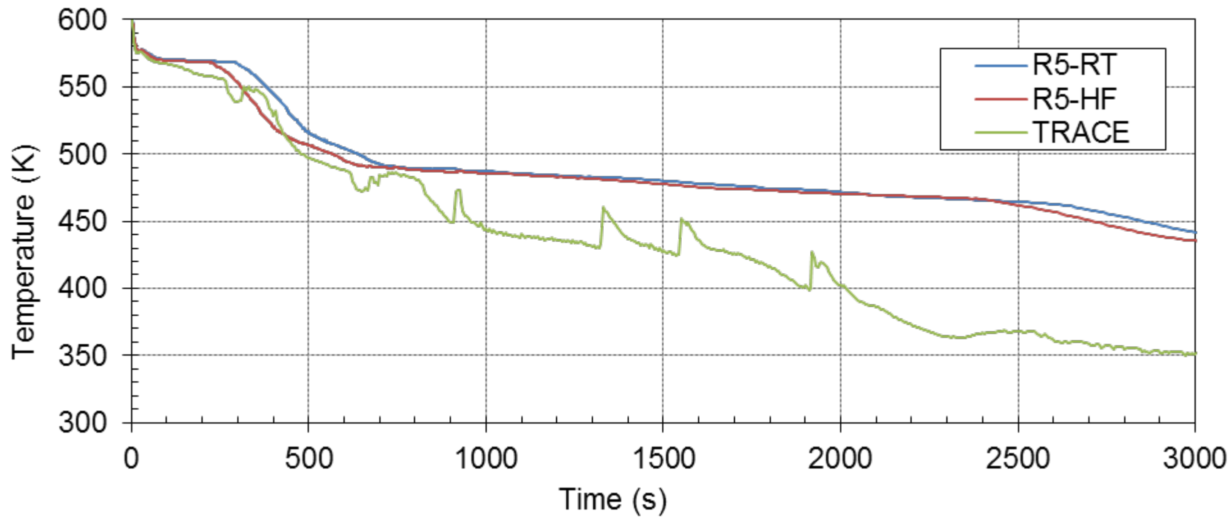

Figure 5 Hot Leg no. 1 Temperature (10.16 cm)

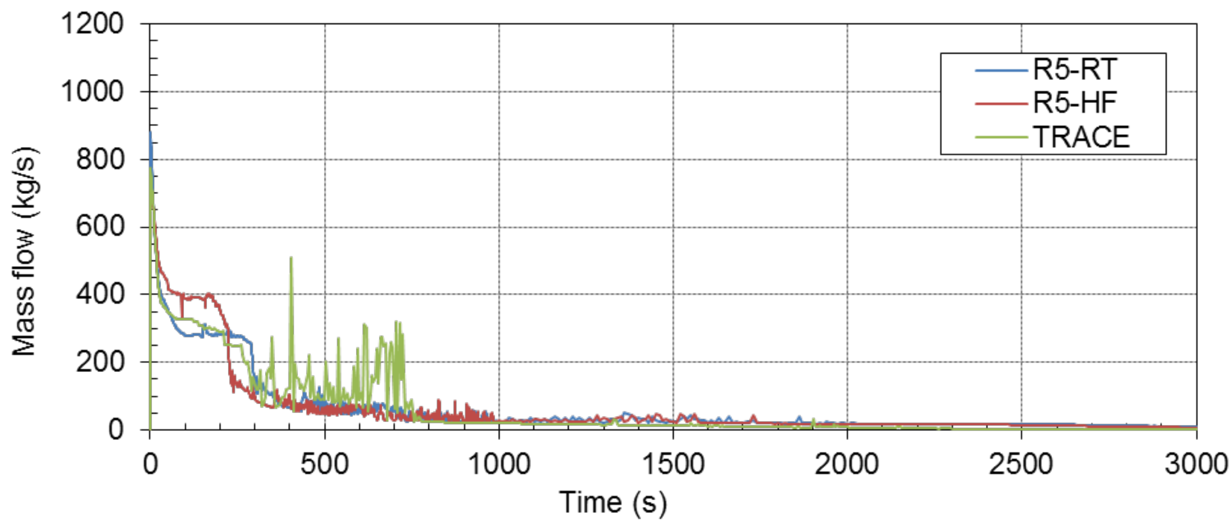

Figure 6 Break Flow (10.16 cm)

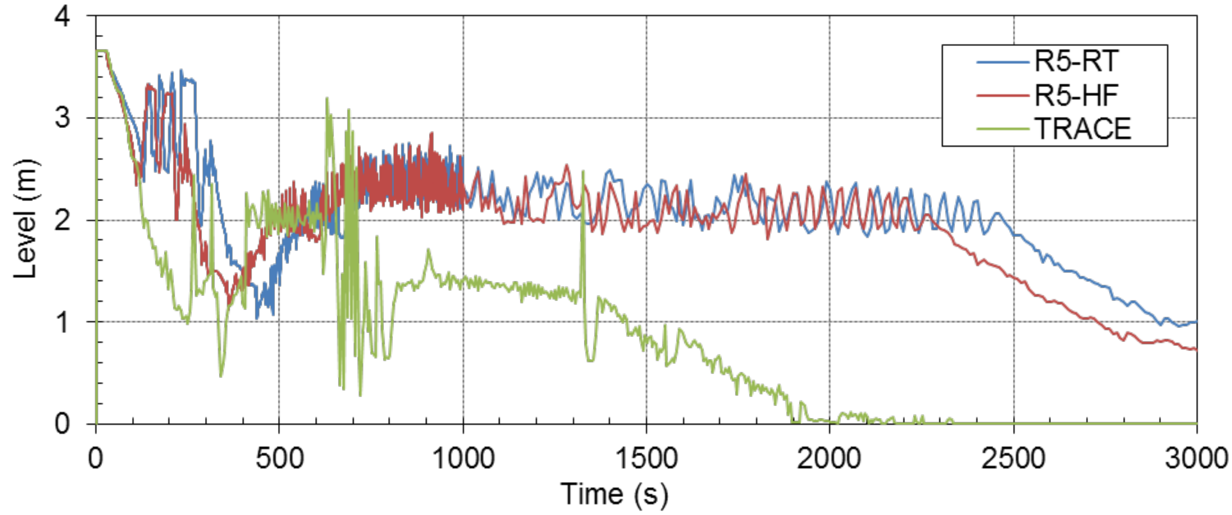

Figure 7 Core Collapsed Liquid Level (10.16 cm)

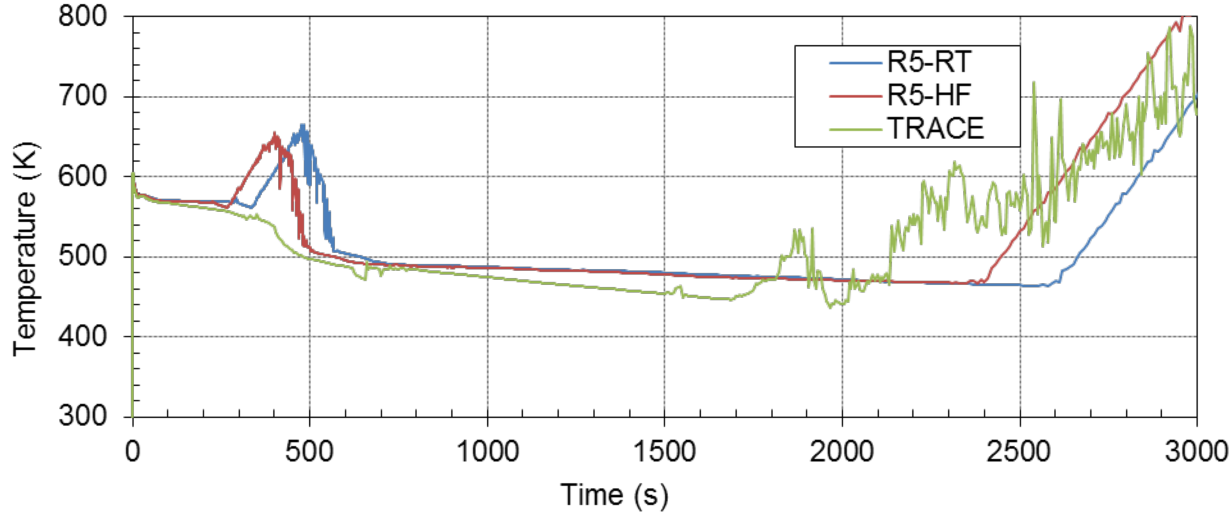

Figure 8 Core Exit Temperature (10.16 cm)

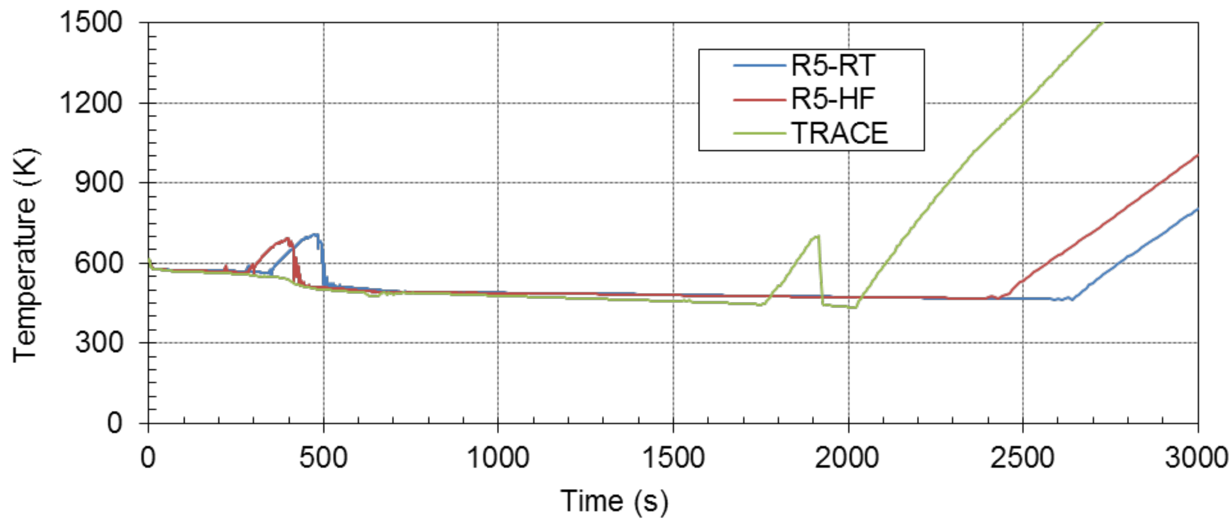

Figure 9 Fuel Cladding Temperature (10.16 cm)

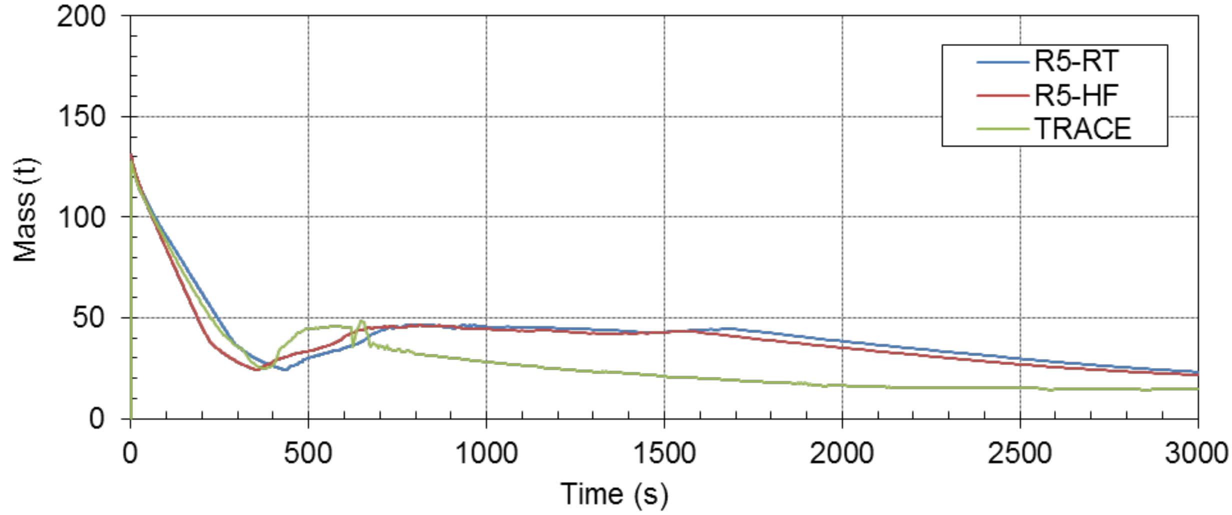

Figure 10 RCS Mass (10.16 cm)

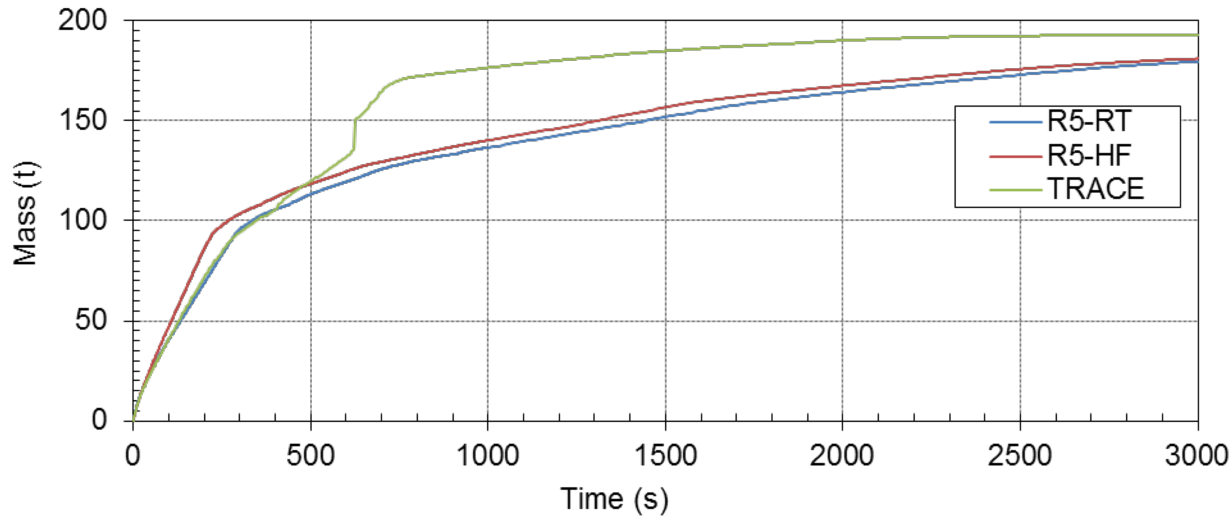

Figure 11 Integrated Break Flow (10.16 cm)

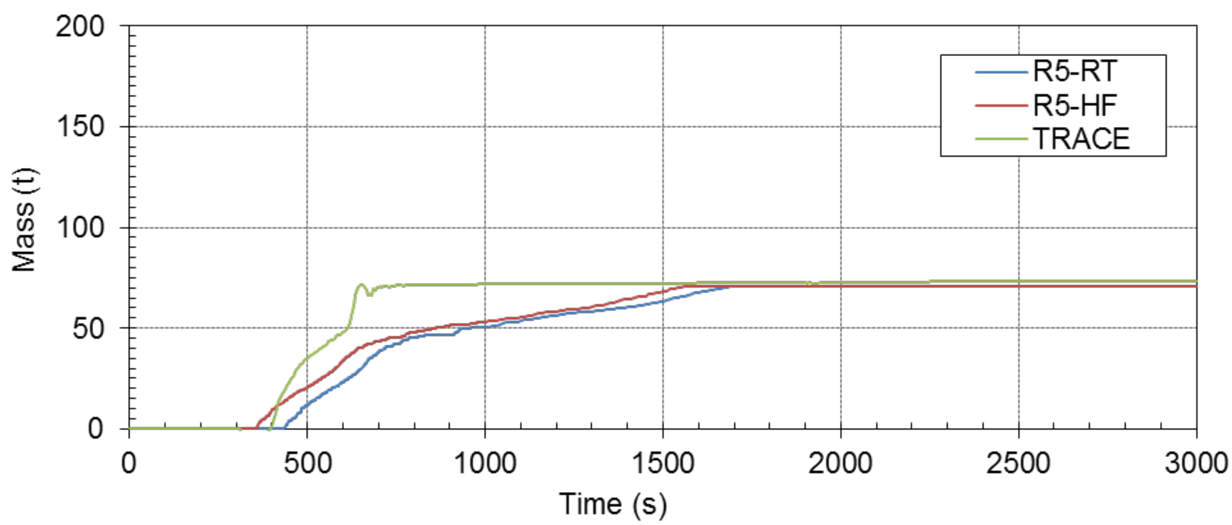

Figure 12 Mass Injected by Accumulators (10.16 cm)

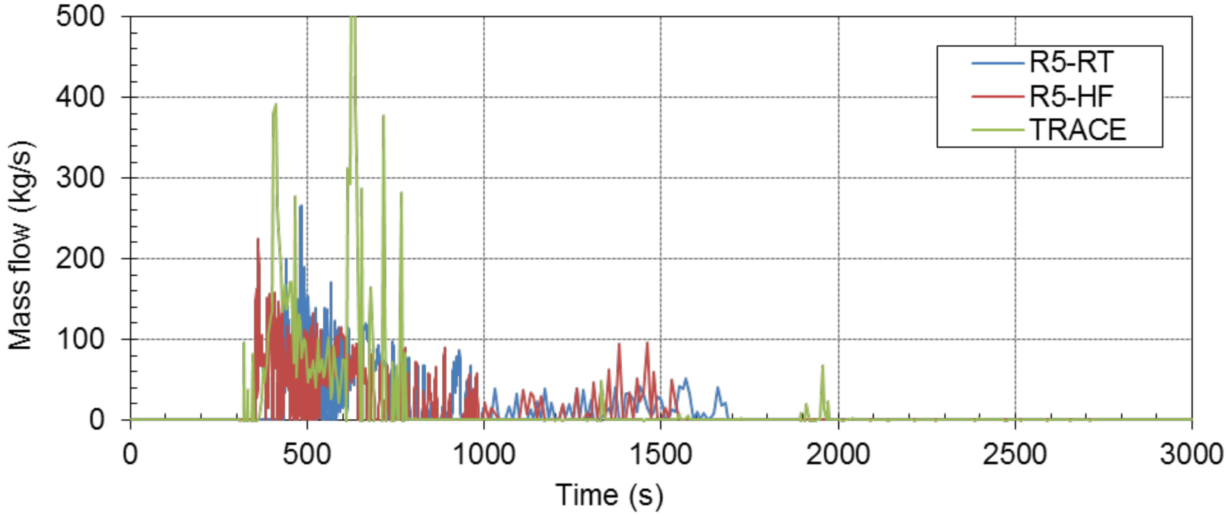

Figure 13 Accumulator no. 1 Flow (10.16 cm)

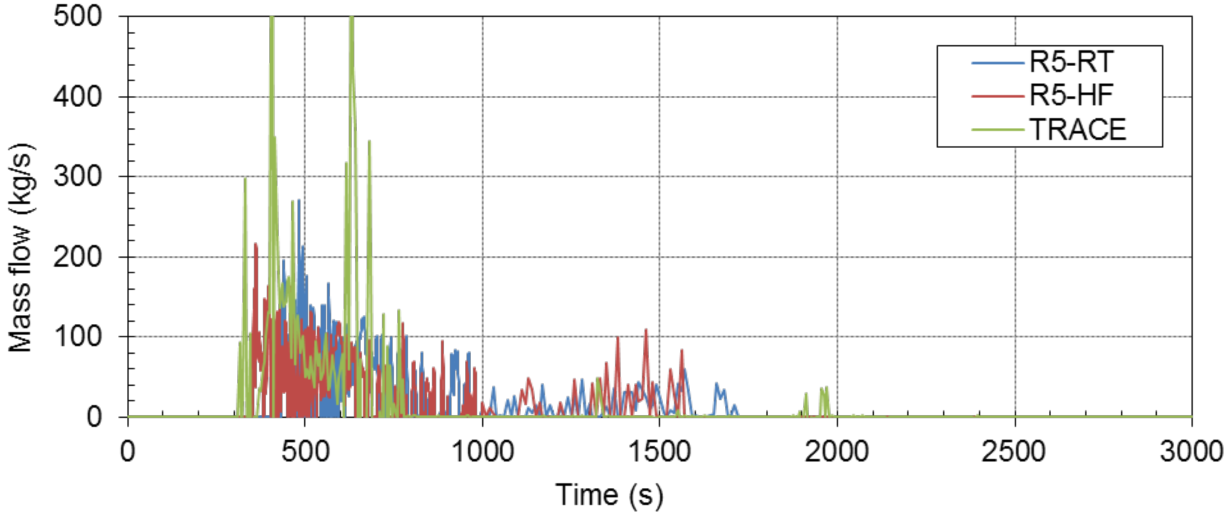

Figure 14 Accumulator no. 2 Flow (10.16 cm)

3.2 LOCA with 12.7 cm Break Size

In case of 12.7 cm break size (see Figures 15 through 26) the pressure plateau is shorter and also the accumulator influence on RCS mass is smaller, therefore also the difference between TRACE and RELAP5 simulations is smaller (see RCS mass, core collapsed liquid level, hot and cold leg temperatures, core exit temperature and fuel cladding temperature).

In all calculated case the core heatup started in about 30 minutes.

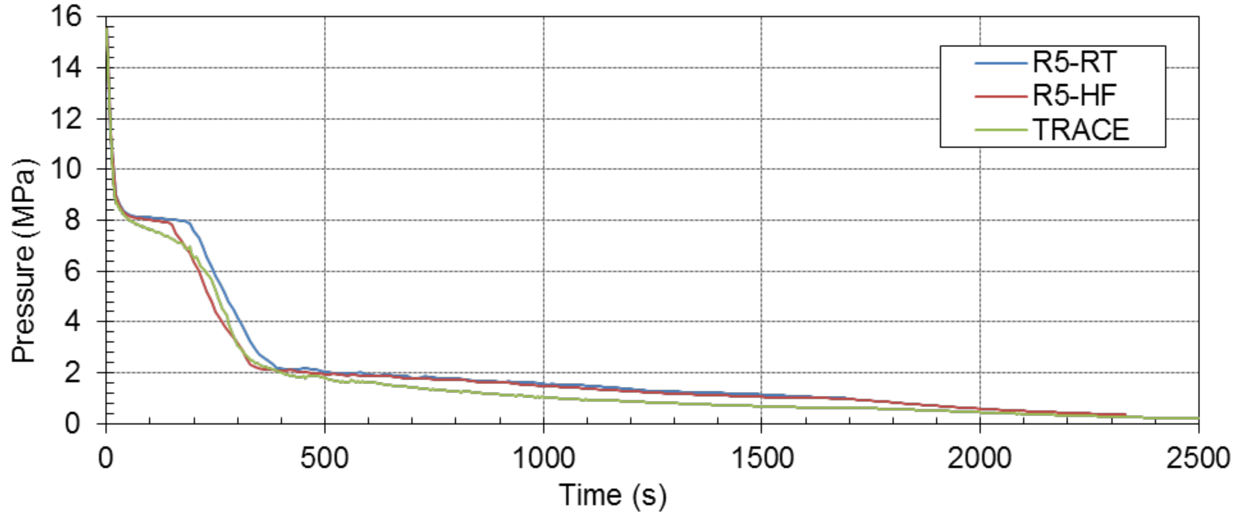

Figure 15 Pressurizer Pressure (12.7 cm)

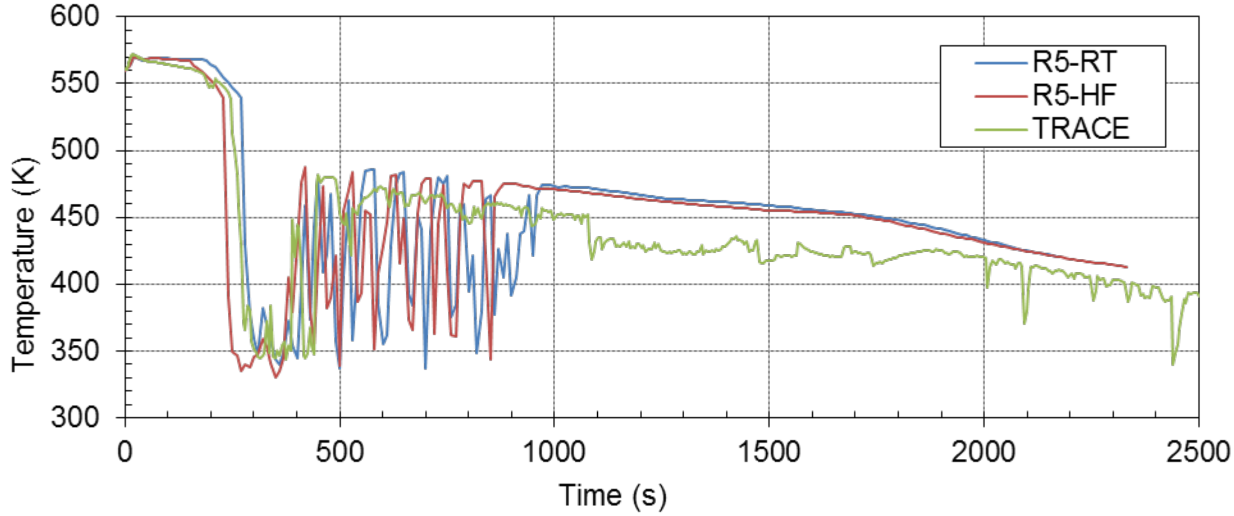

Figure 16 Cold Leg no. 1 Temperature (12.7 cm)

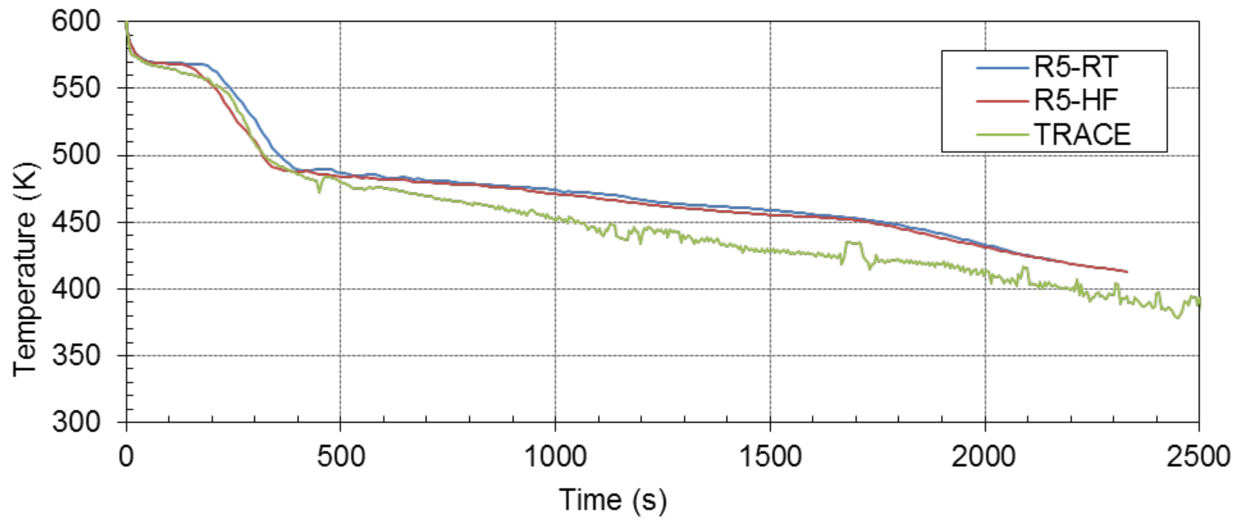

Figure 17 Hot Leg no. 1 Temperature (12.7 cm)

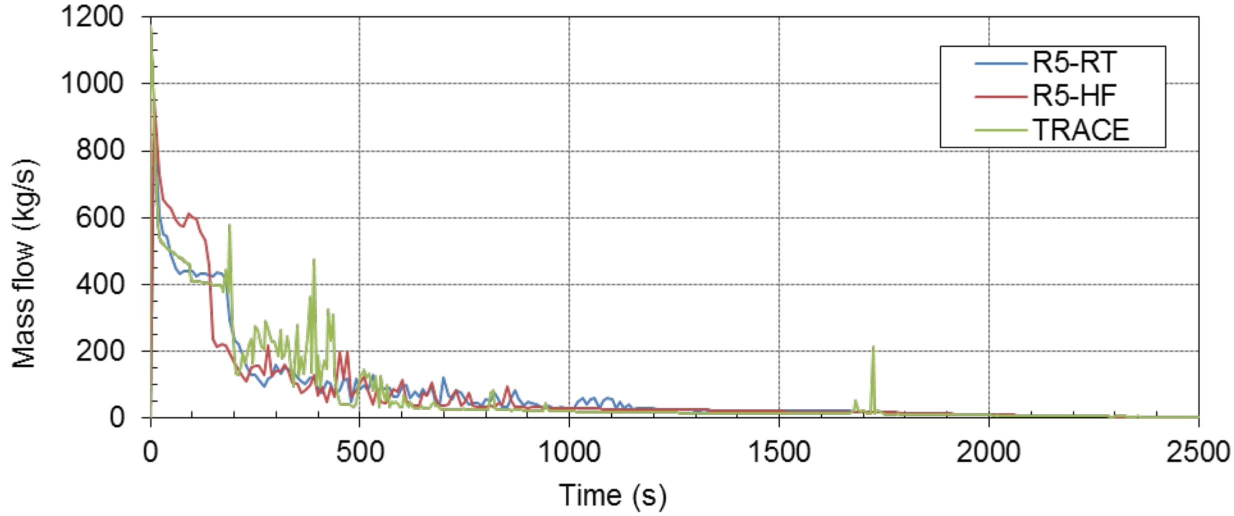

Figure 18 Break Flow (12.7 cm)

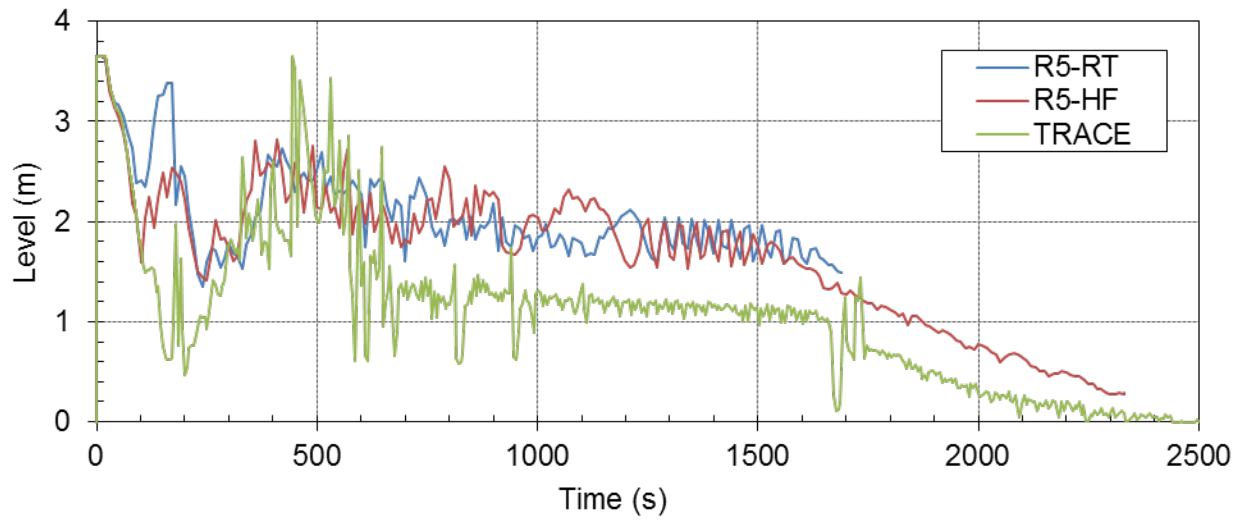

Figure 19 Core Collapsed Liquid Level (12.7 cm)

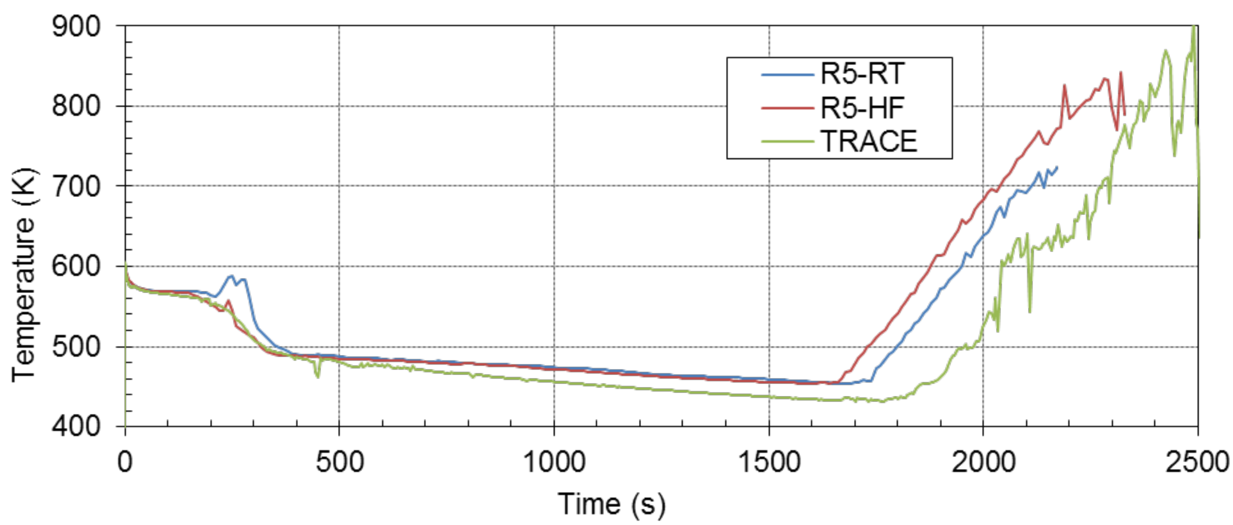

Figure 20 Core Exit Temperature (12.7 cm)

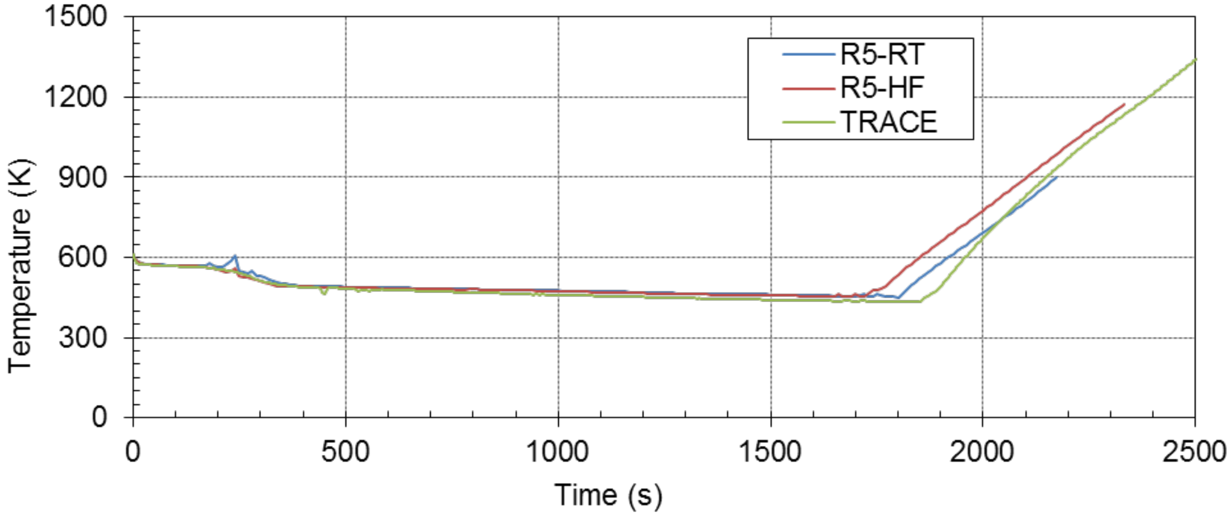

Figure 21 Fuel Cladding Temperature (12.7 cm)

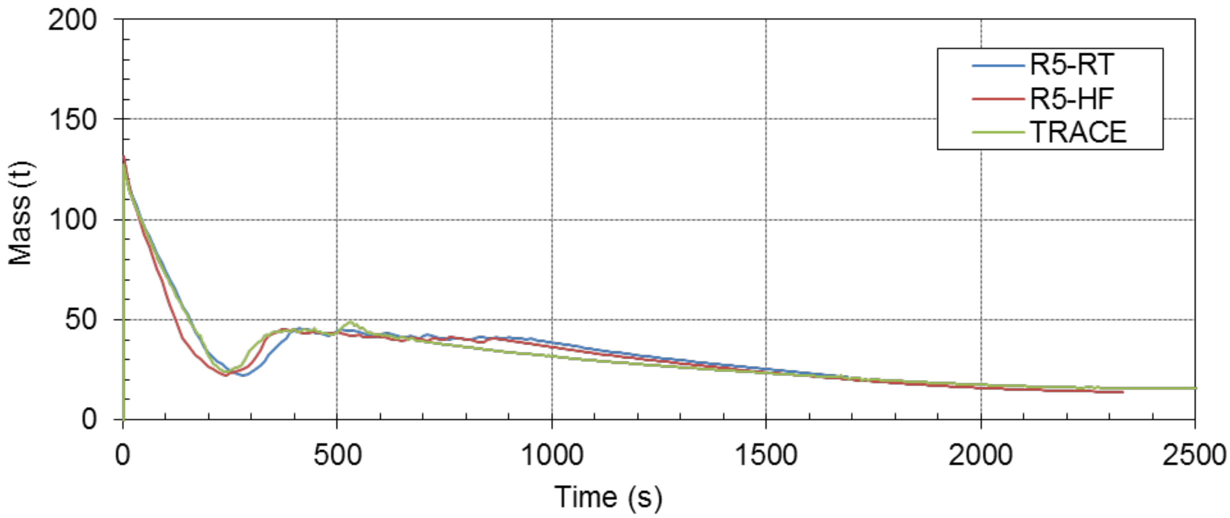

Figure 22 RCS Mass (12.7 cm)

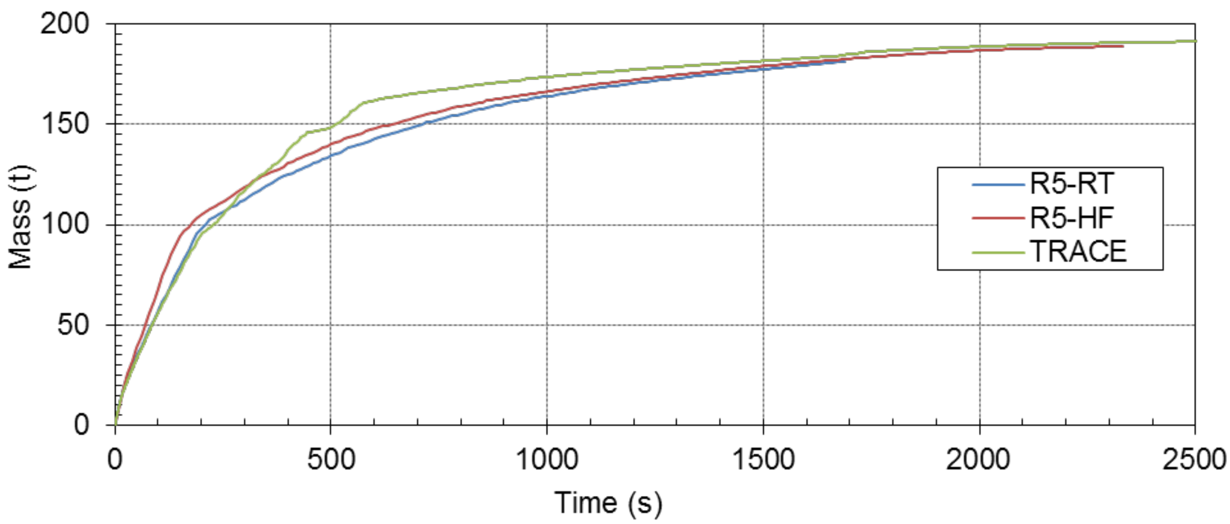

Figure 23 Integrated Break Flow (12.7 cm)

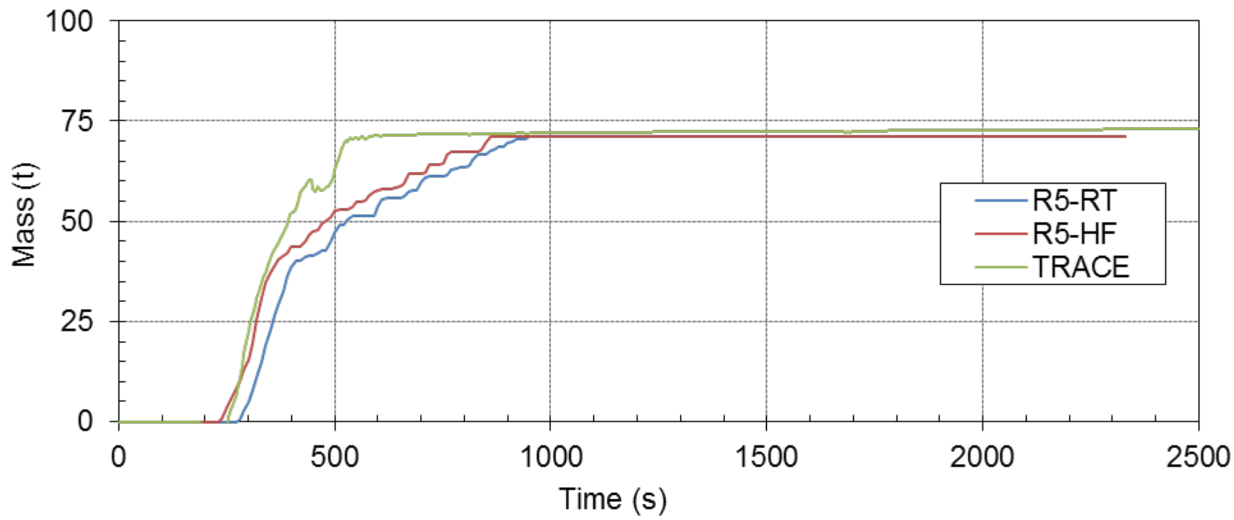

Figure 24 Mass Injected by Accumulators (12.7 cm)

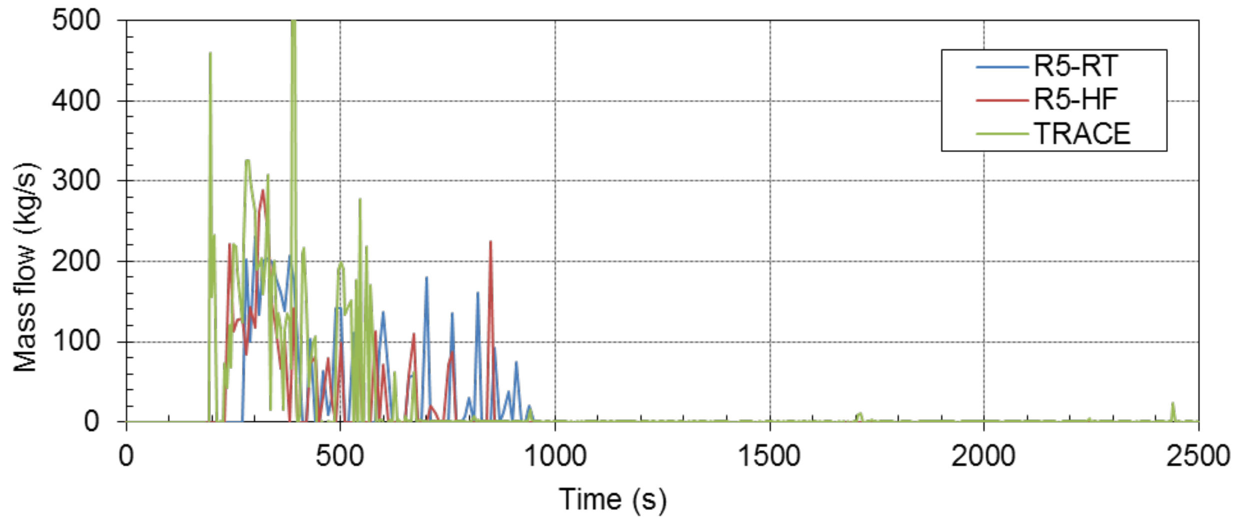

Figure 25 Accumulator no. 1 Flow (12.7 cm)

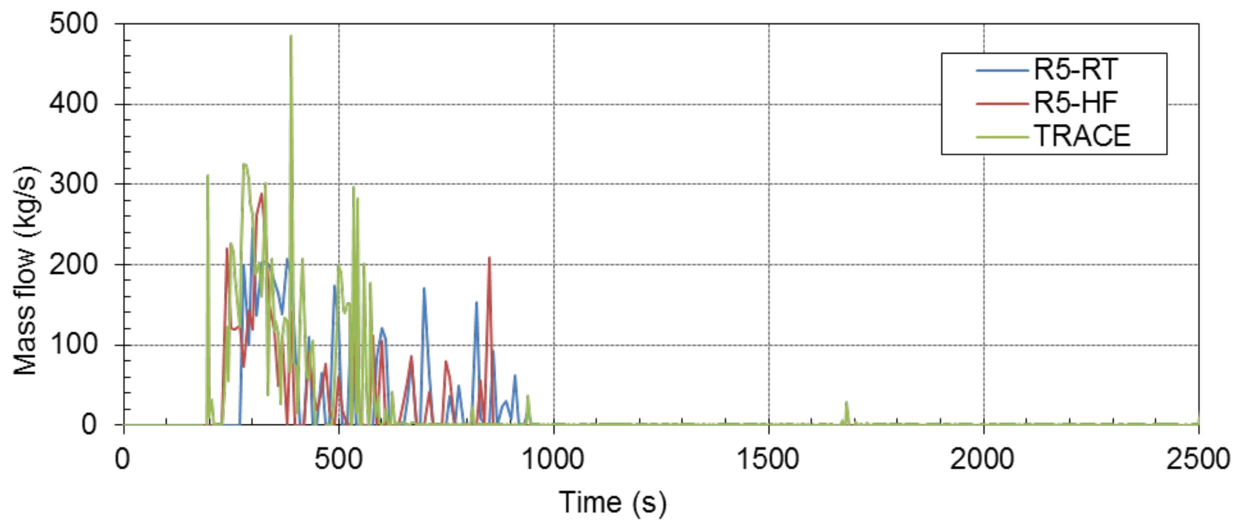

Figure 26 Accumulator no. 2 Flow (12.7 cm)

3.3 LOCA with 15.24 cm Break Size

In case of 15.24 cm break size (see Figures 27 through 38) the pressure plateau is even shorter and the difference between TRACE and RELAP5 simulations is smaller than in 12.7 cm break size case. The difference is now mainly due to faster accumulator emptying in case of TRACE calculation. This has further influence on pressurizer pressure, break flow, RCS mass, core collapsed liquid level, hot and cold leg temperatures, core exit temperature and fuel cladding temperature.

In all calculated case the core heatup started in about 20 minutes.

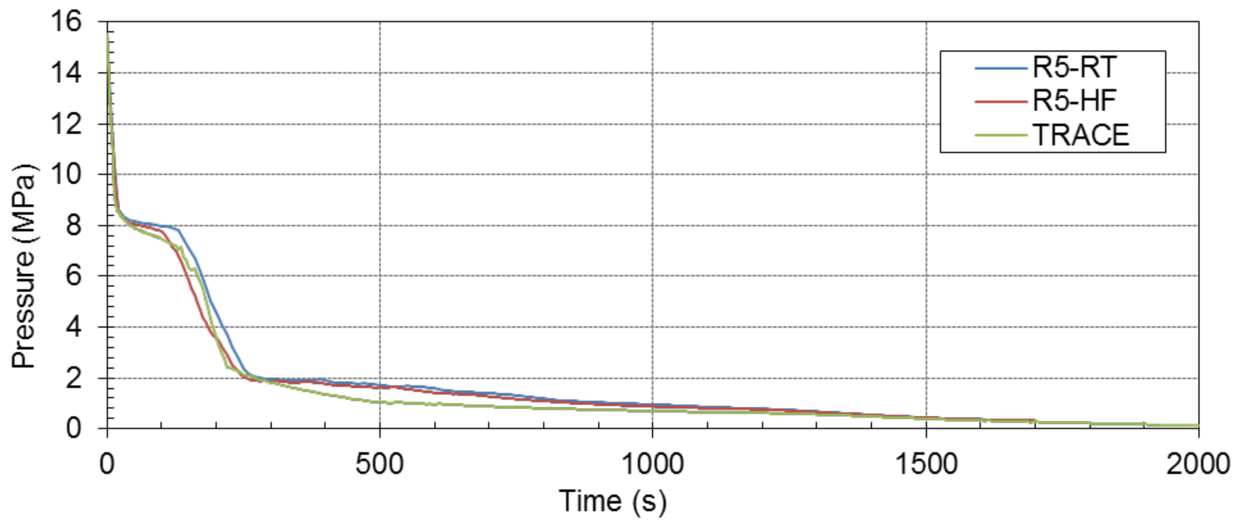

Figure 27 Pressurizer Pressure (15.24 cm)

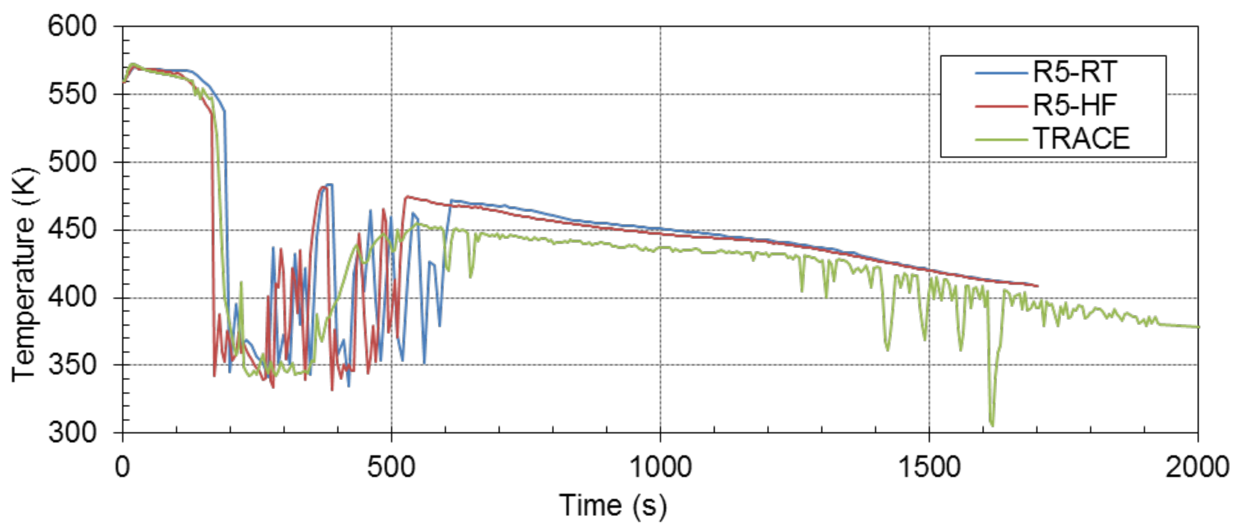

Figure 28 Cold Leg no. 1 Temperature (15.24 cm)

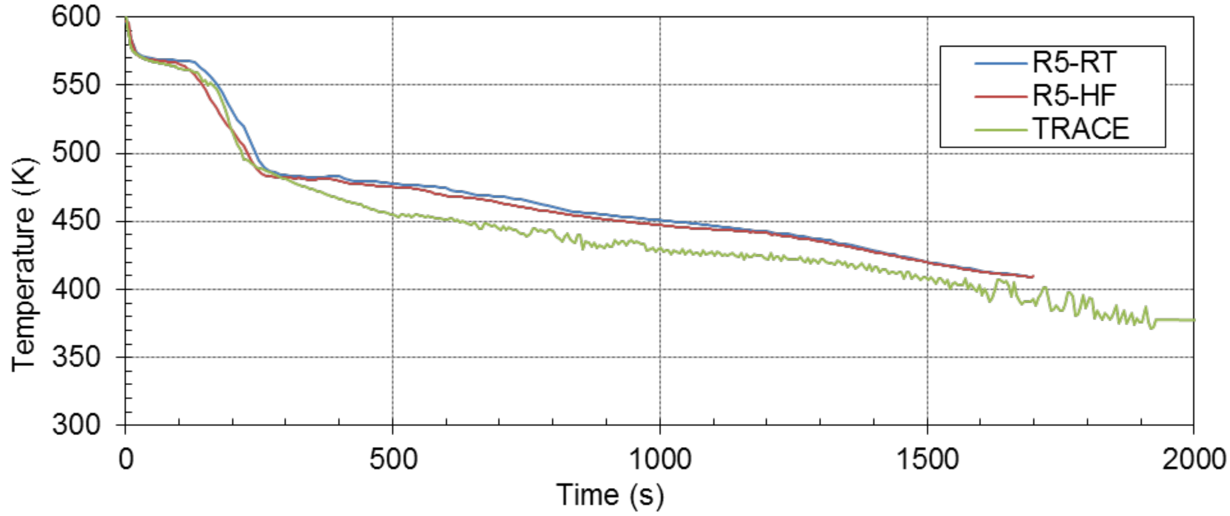

Figure 29 Hot Leg no. 1 Temperature (15.24 cm)

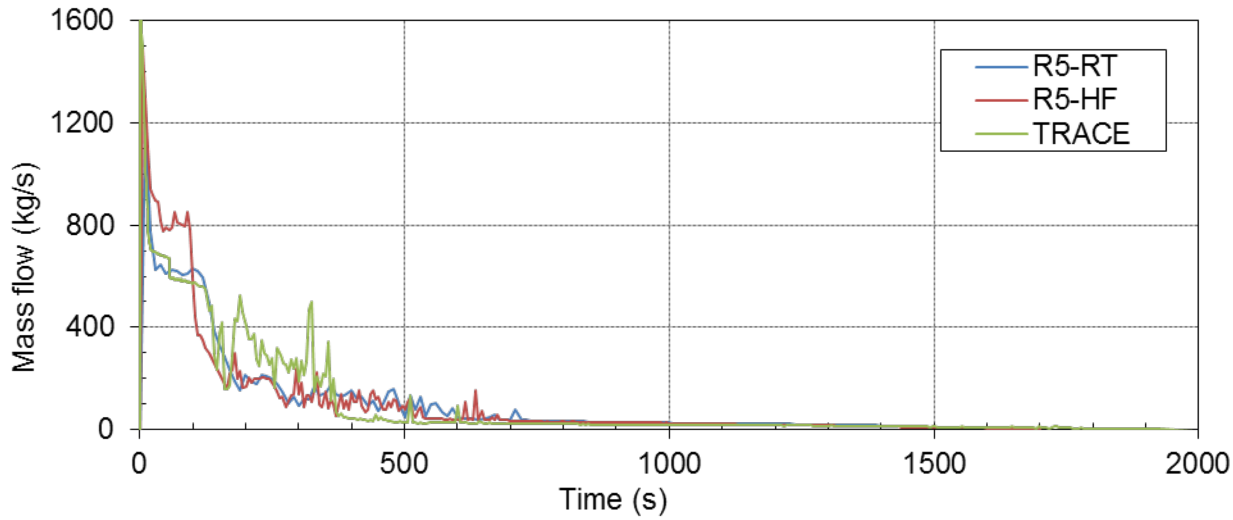

Figure 30 Break Flow (15.24 cm)

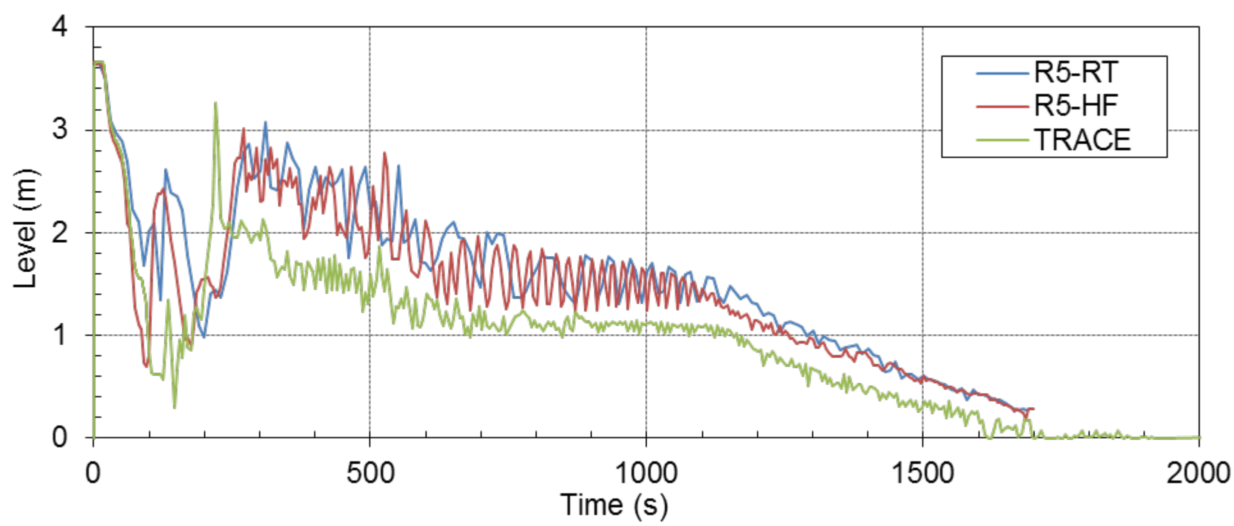

Figure 31 Core Collapsed Liquid Level (15.24 cm)

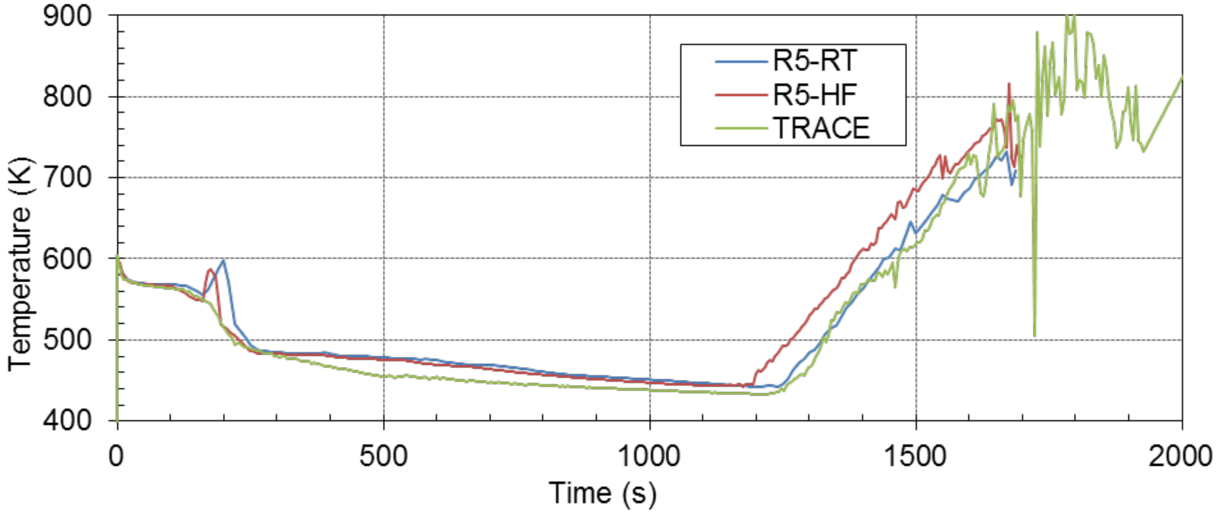

Figure 32 Core Exit Temperature (15.24 cm)

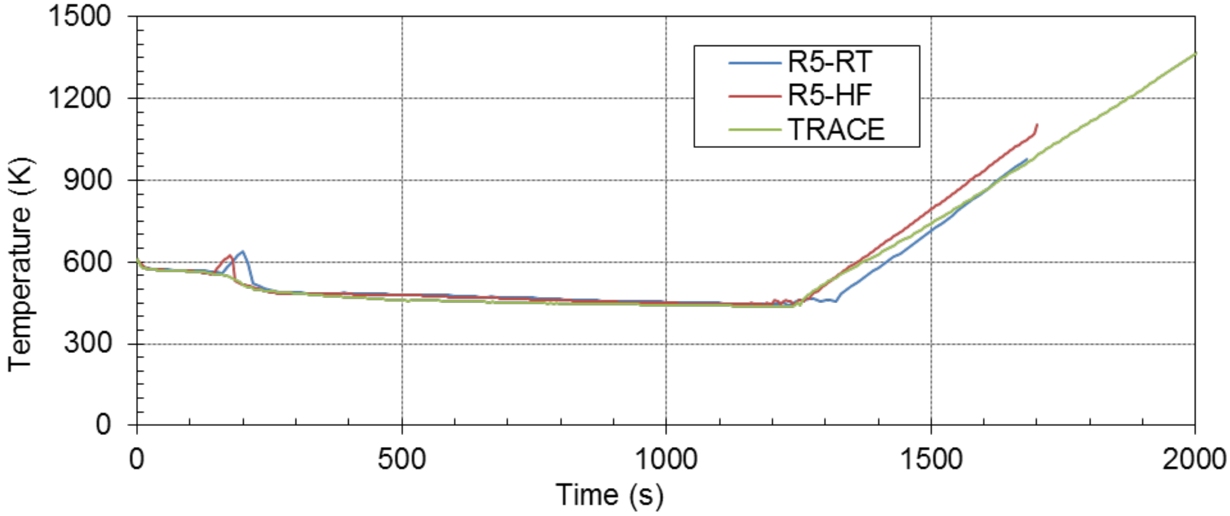

Figure 33 Fuel Cladding Temperature (15.24 cm)

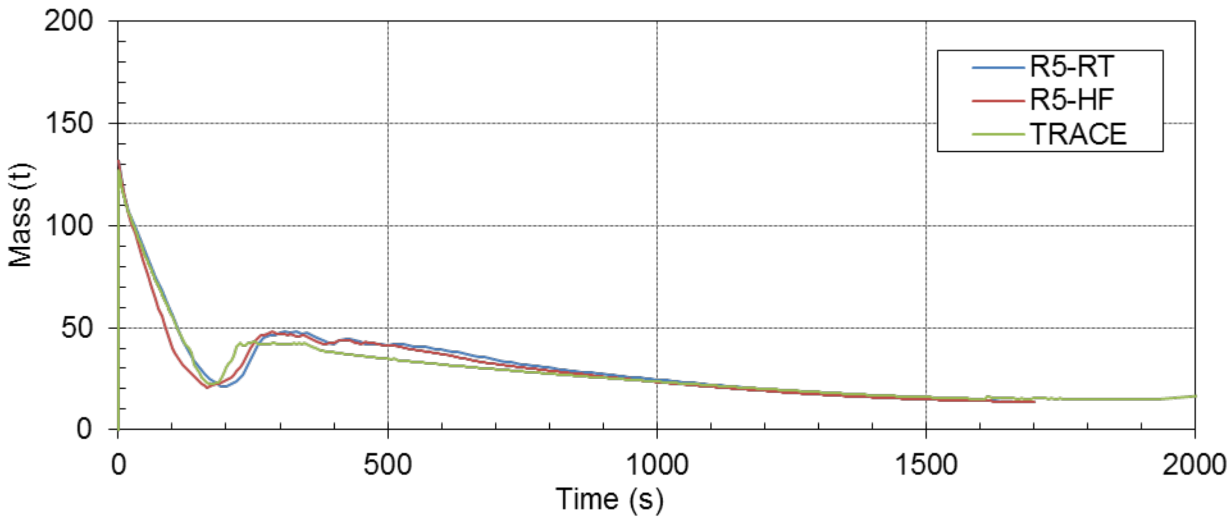

Figure 34 RCS Mass (15.24 cm)

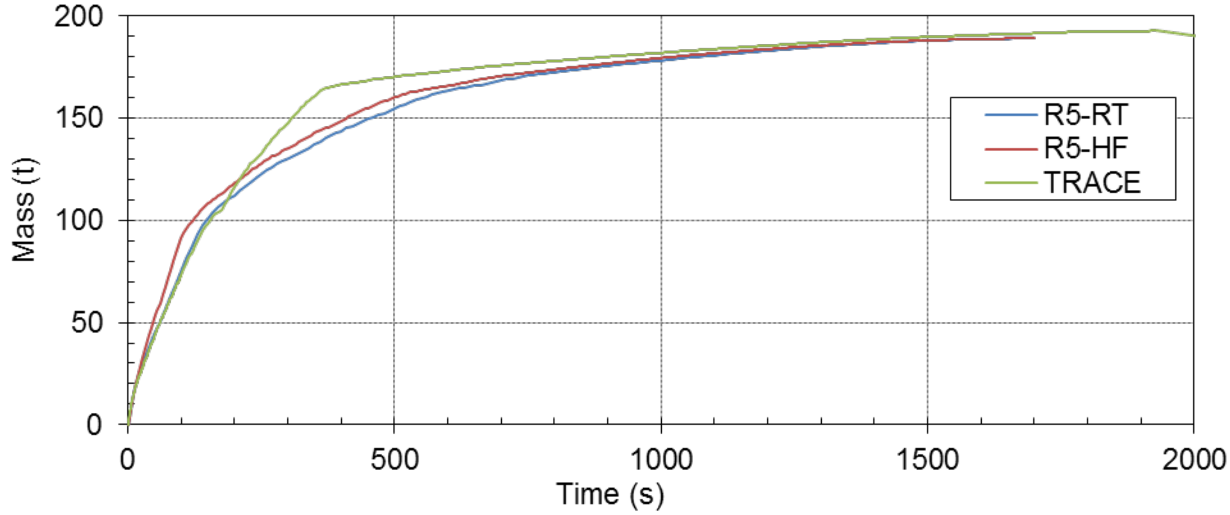

Figure 35 Integrated Break Flow (15.24 cm)

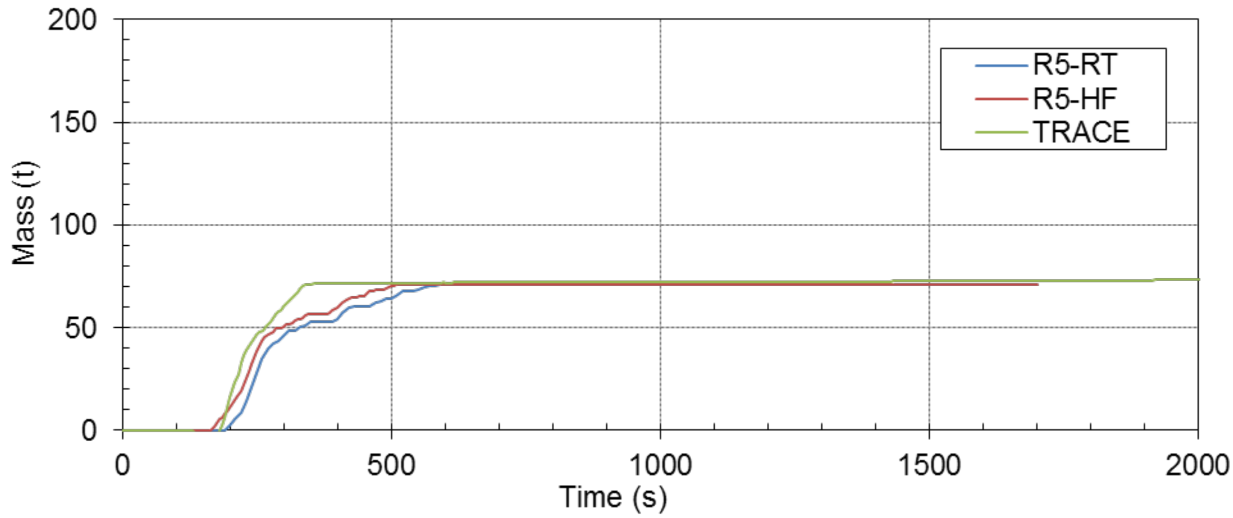

Figure 36 Mass Injected by Accumulators (15.24 cm)

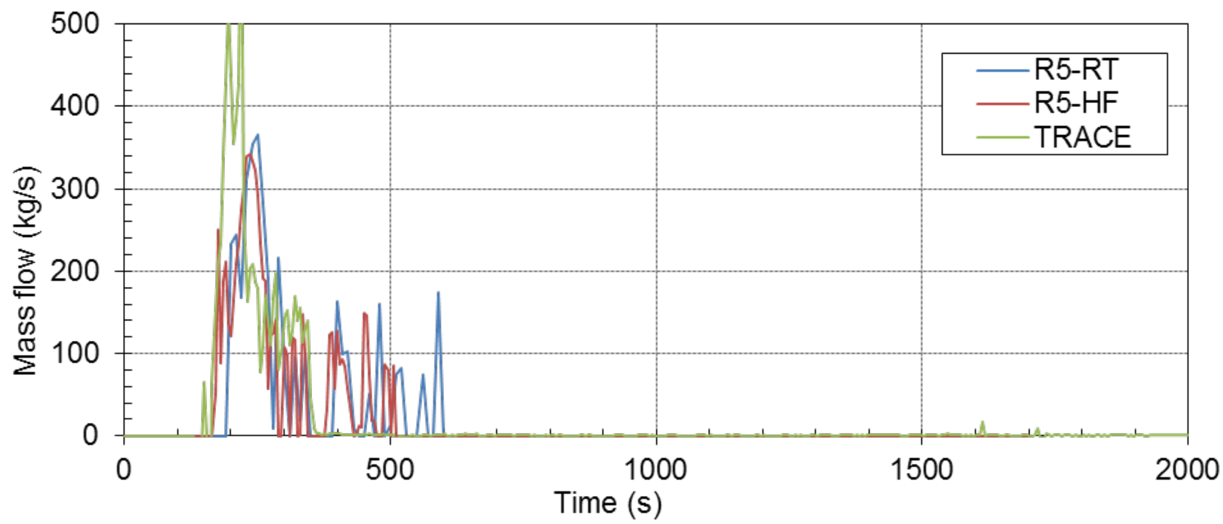

Figure 37 Accumulator no. 1 Flow (15.24 cm)

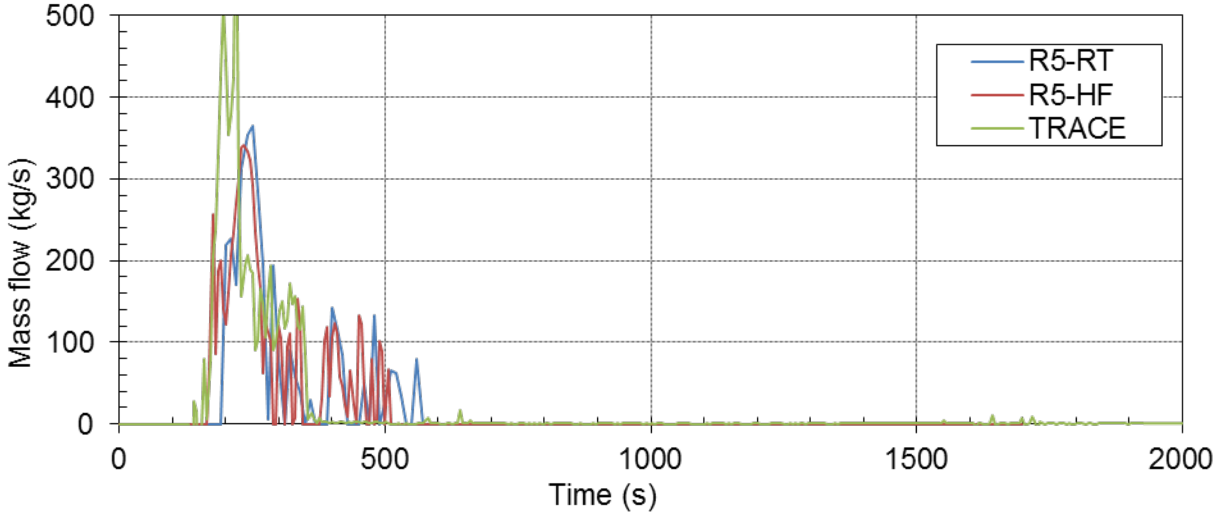

Figure 38 Accumulator no. 2 Flow (15.24 cm)

3.4 LOCA with 20.32 cm Break Size

In case of 20.32 cm break size (see Figures 39 through 50) the pressure plateau is negligible and the difference between TRACE and RELAP5 simulations is again very small. The differences started after accumulator injection. The period of accumulator emptying is short, but in the case of TRACE this period is significantly shorter comparing to RELAP5.

The faster accumulator discharge (higher injection flow) caused higher break flow (much of the injected water is thus lost through the break), the pressure drops faster and there is also less mass in the RCS in that period. However, later the break flow is smaller due to lower pressure and so the TRACE calculation after approximately 450 s agrees well with RELAP5 calculations.

In all calculated case the core heatup started in about 15 minutes.

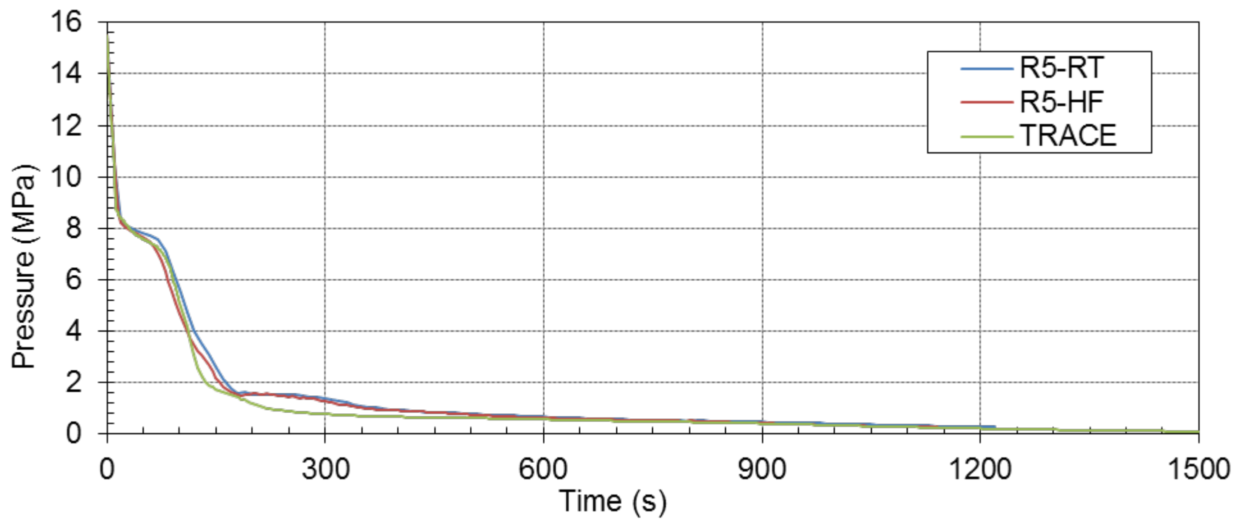

Figure 39 Pressurizer Pressure (20.32 cm)

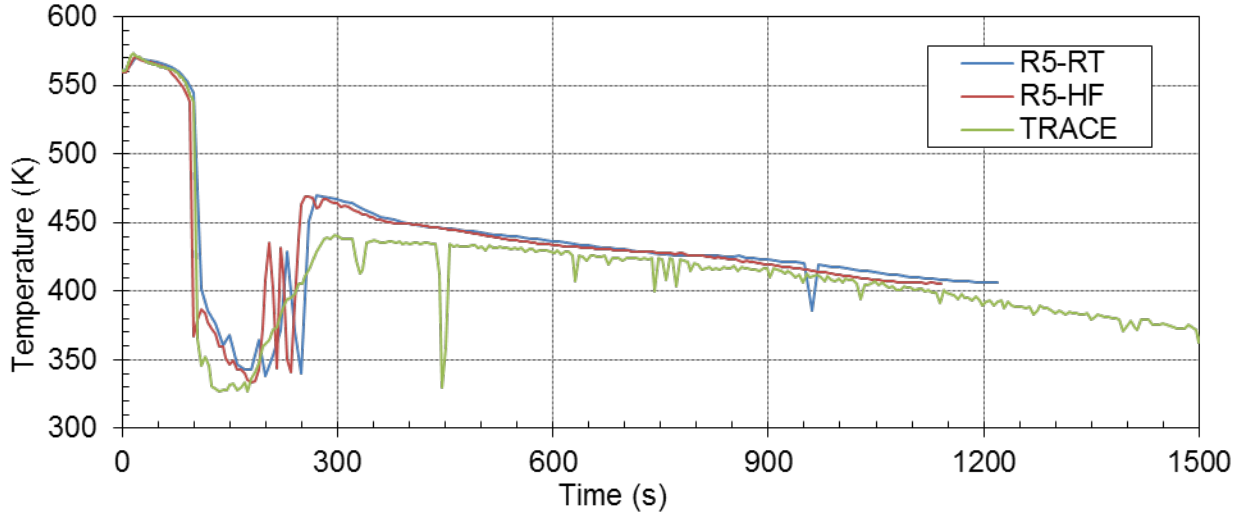

Figure 40 Cold Leg no. 1 Temperature (20.32 cm)

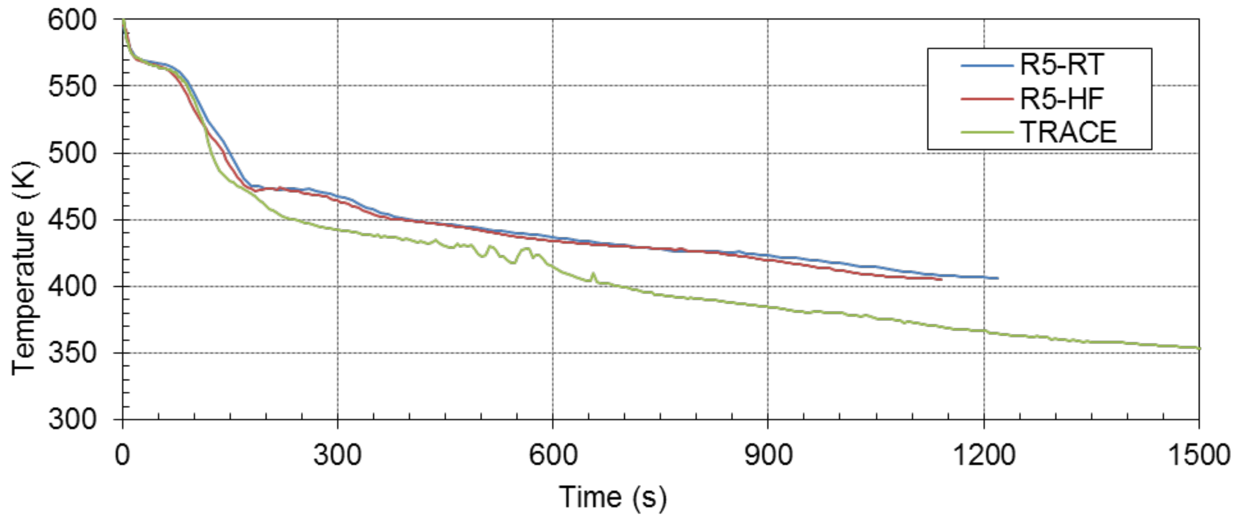

Figure 41 Hot Leg no. 1 Temperature (20.32 cm)

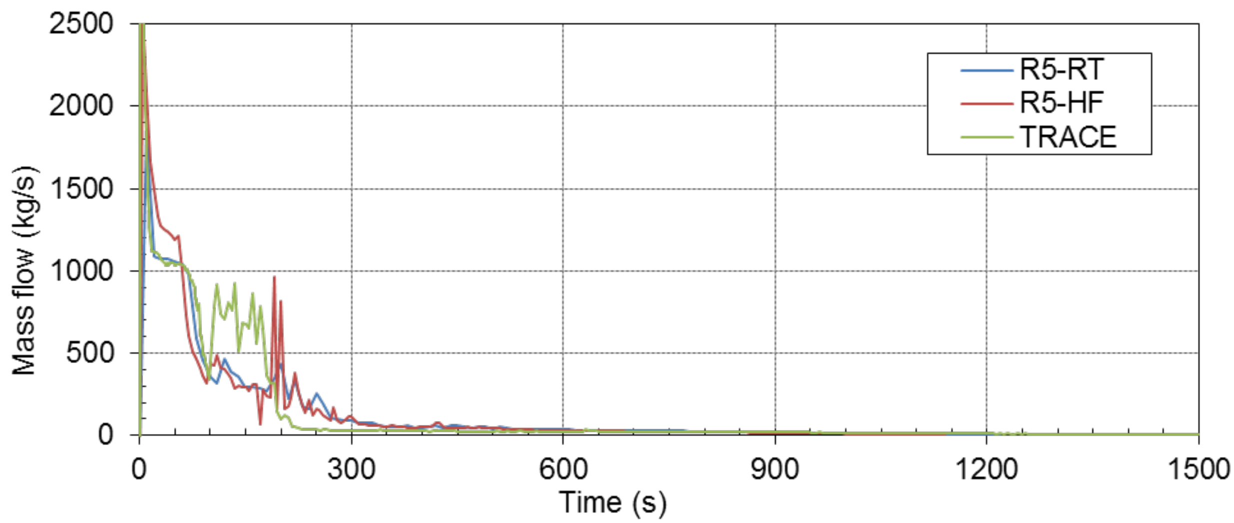

Figure 42 Break Flow (20.32 cm)

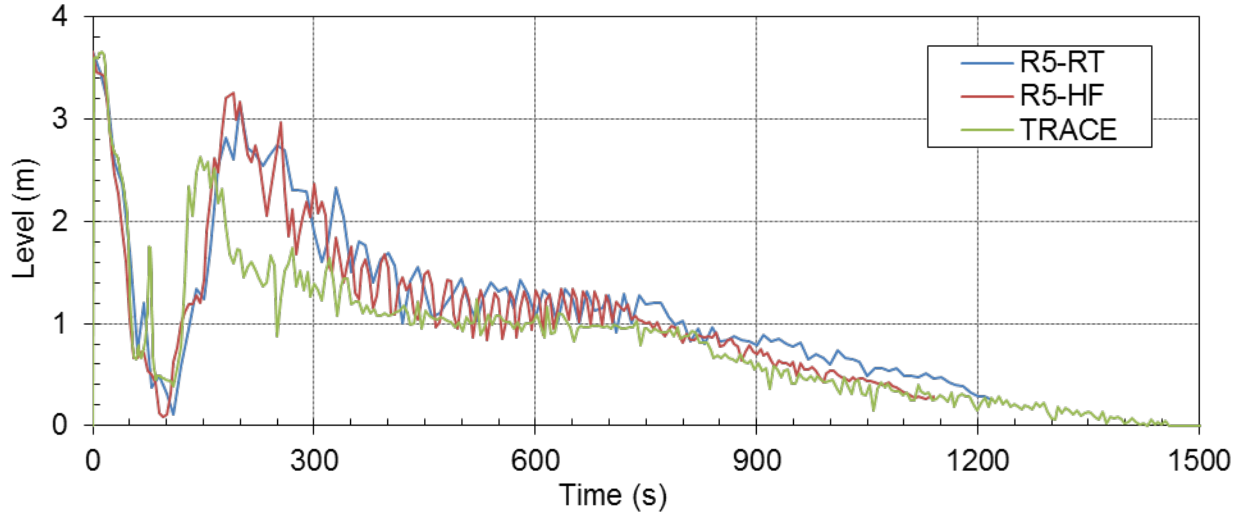

Figure 43 Core Collapsed Liquid Level (20.32 cm)

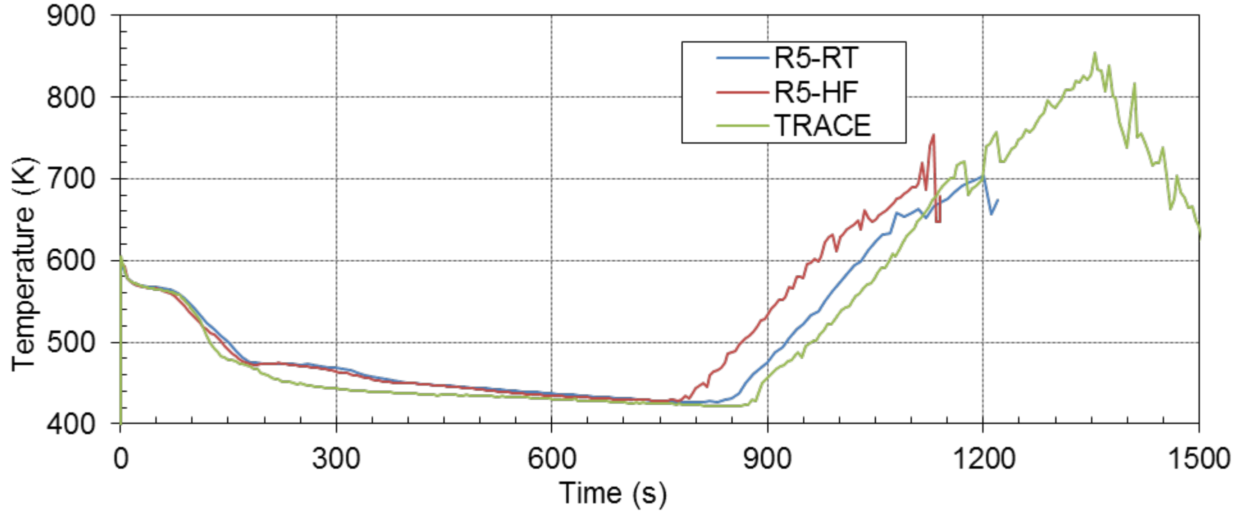

Figure 44 Core Exit Temperature (20.32 cm)

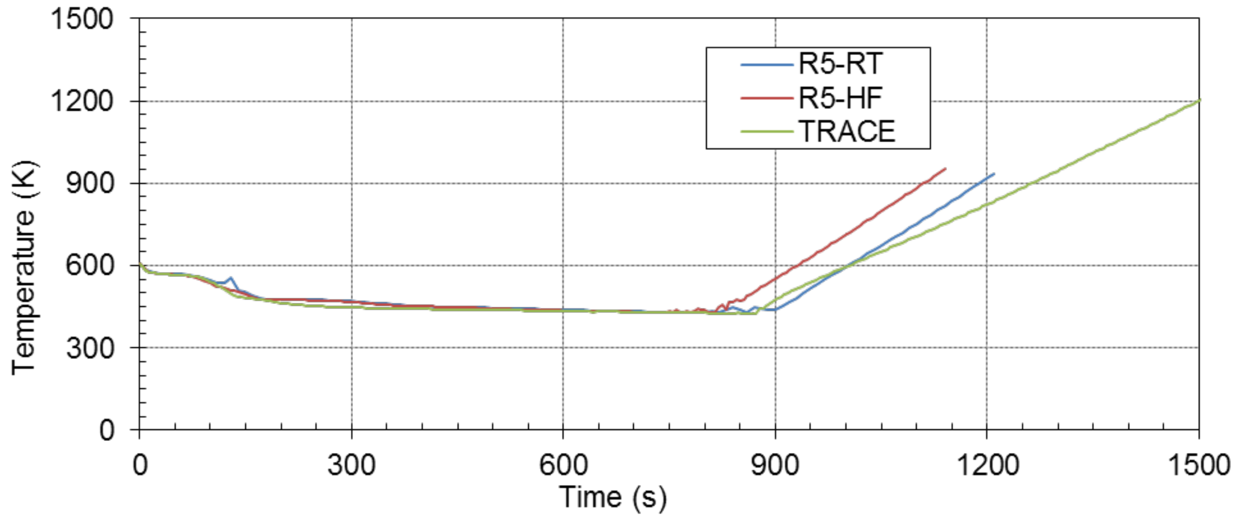

Figure 45 Fuel Cladding Temperature (20.32 cm)

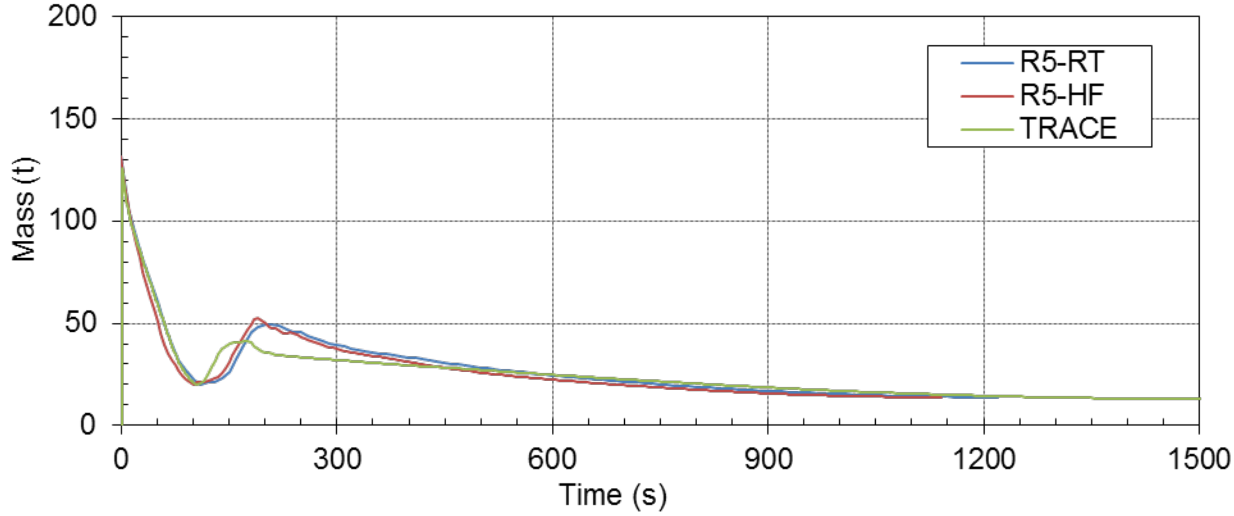

Figure 46 RCS Mass (20.32 cm)

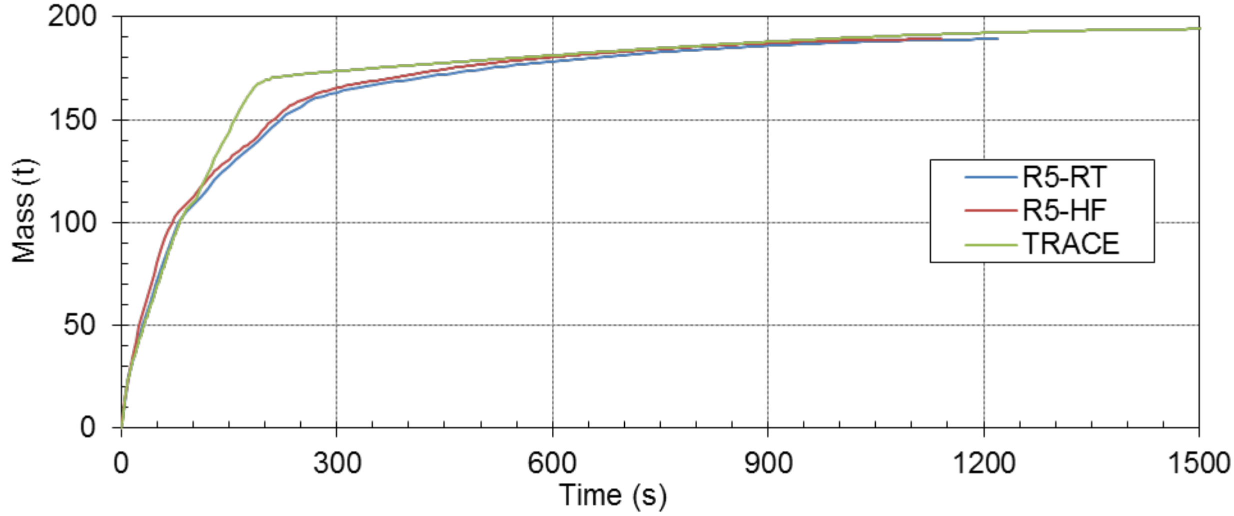

Figure 47 Integrated Break Flow (20.32 cm)

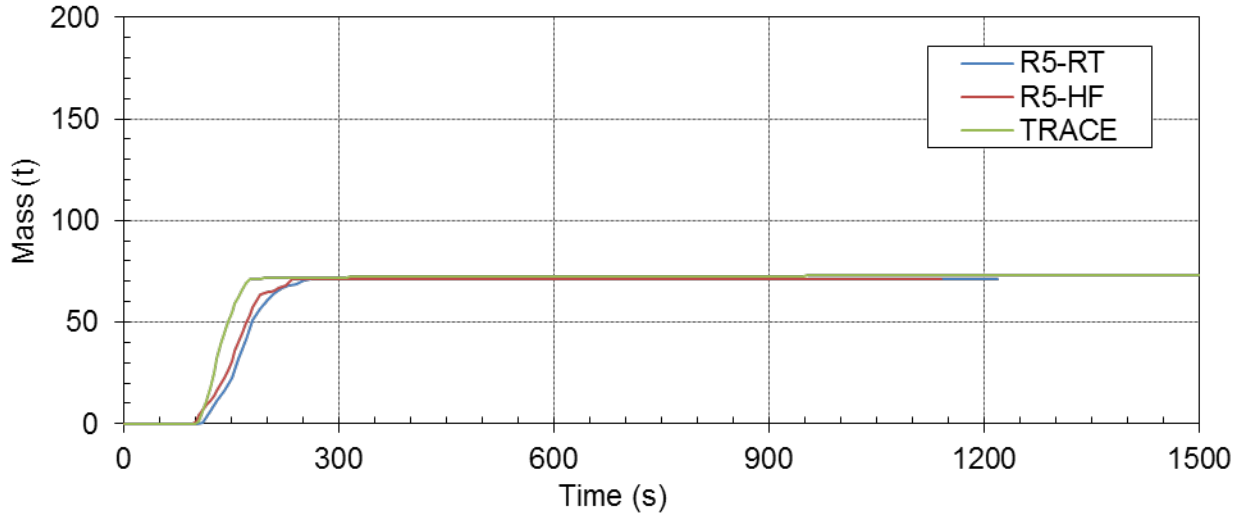

Figure 48 Mass Injected by Accumulators (20.32 cm)

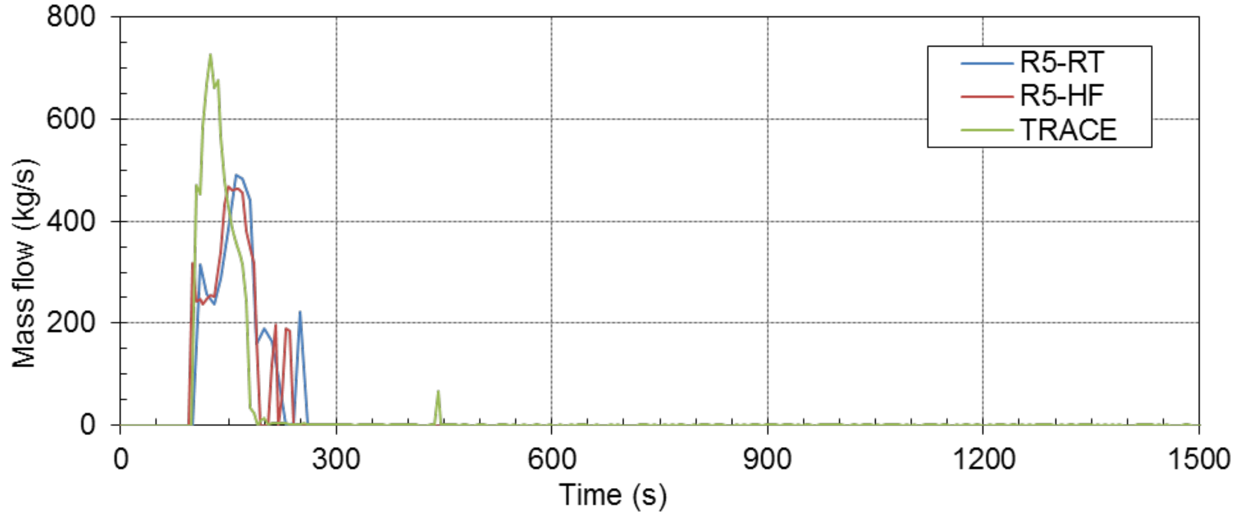

Figure 49 Accumulator no. 1 Flow (20.32 cm)

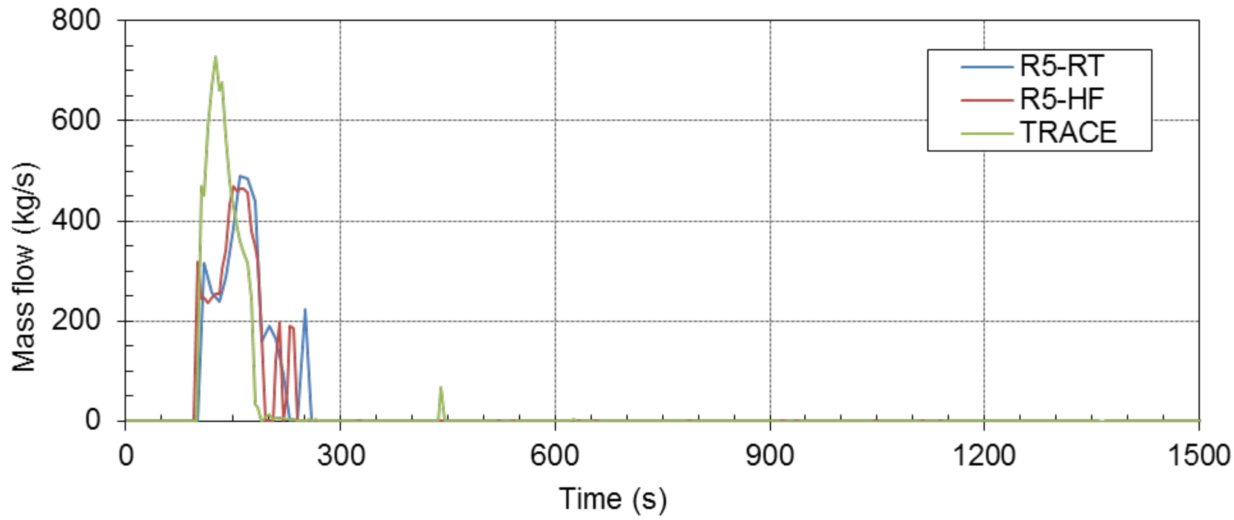

Figure 50 Accumulator no. 2 Flow (20.32 cm)

3.5 LOCA with 30.48 cm Break Size

Looking results for smaller breaks, it would be expected that TRACE results for 30.48 cm (see Figures 51 through 62) would be even closer to RELAP5 results. However, in original TRACE calculation faster accumulator discharge so much influences the break flow that RCS mass (see Figure 58) was so low after the accumulators are emptied that another core heatup starts 1 minute after break occurrence and the TRACE results are qualitatively very much different from RELAP5 results. Therefore it was decided to reduce the accumulator flow area in such a way to get comparable accumulator discharge between TRACE and RELAP5 (see Figures 60, 61 and 62). As can be seen from Figure 54 showing results for 30.48 cm break size for reduced accumulator line area (label "TRACE (ACC)"), the TRACE break flow (and its integrated value shown in Figure 59) is now similar to RELAP5 calculations with some differences in the time of core heatup start. Slightly smaller break flow (Figure 54) means less RCS mass discharged (Figure 58) and by this the core heatup is delayed (Figure 57).

In case of RELAP5 using RT and HF critical flow model the core heatup occurred in 6 minutes and 8 minutes, respectively, while in TRACE in 11 minutes after break occurrence (not seen from Figure 57, but TRACE calculated results are available until 905 s). The results showed that accumulator emptying should be further studied.

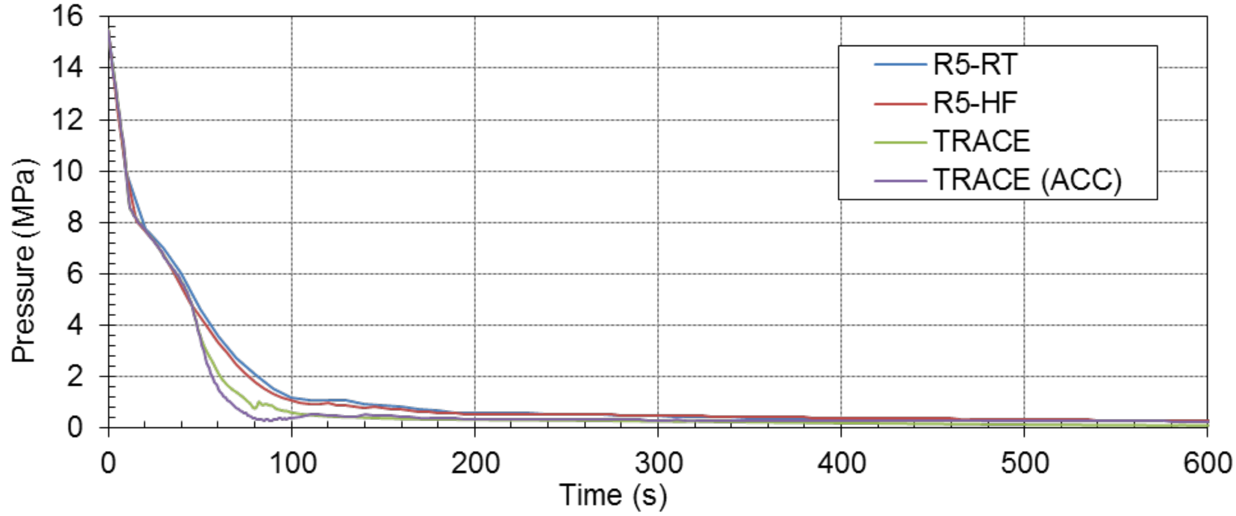

Figure 51 Pressurizer Pressure (30.48 cm)

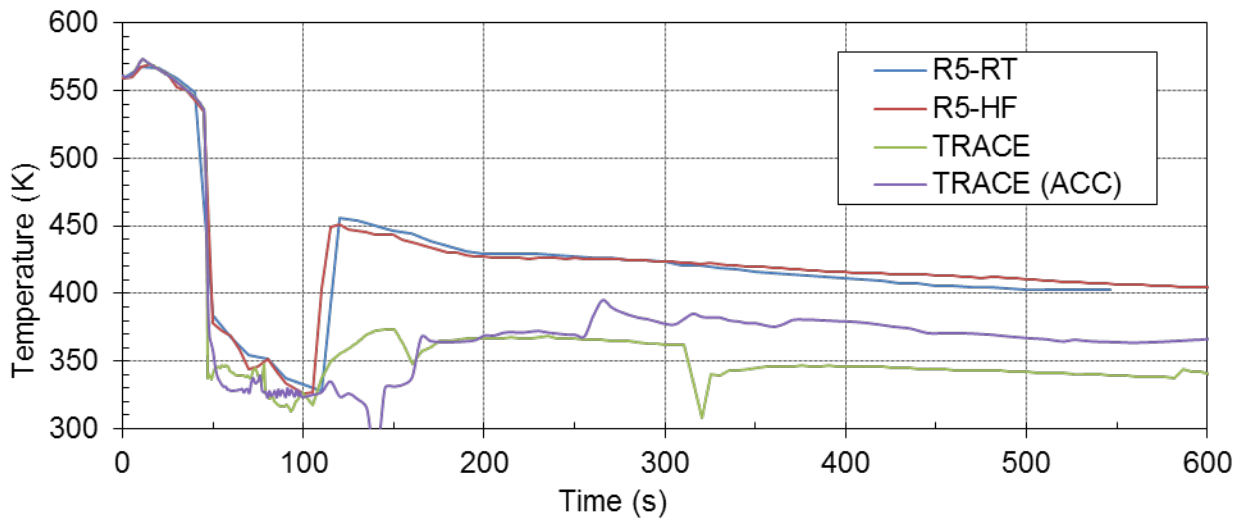

Figure 52 Cold Leg no. 1 Temperature (30.48 cm)

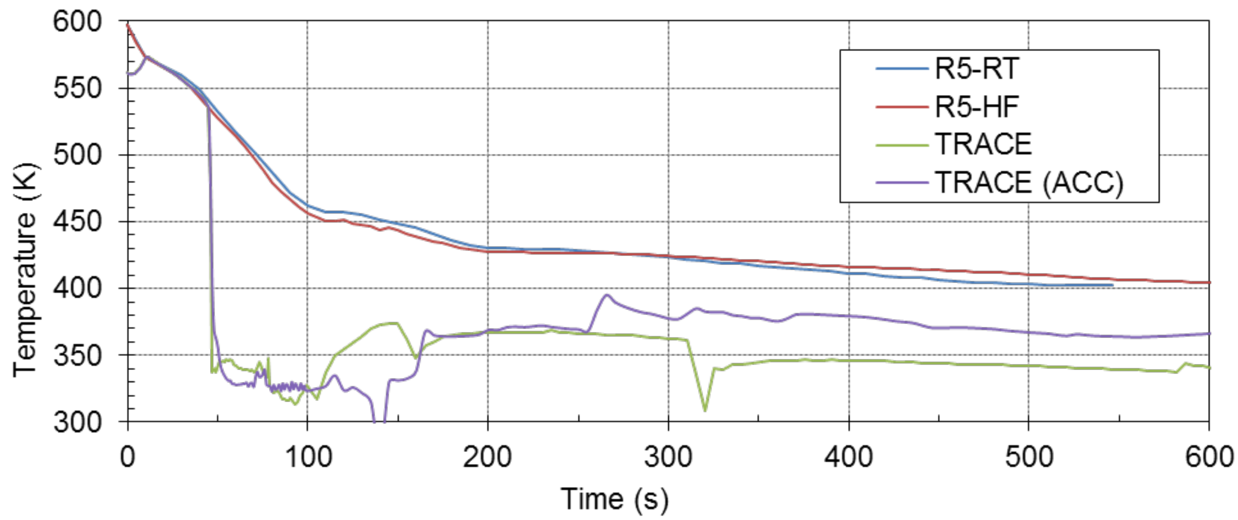

Figure 53 Hot Leg no. 1 Temperature (30.48 cm)

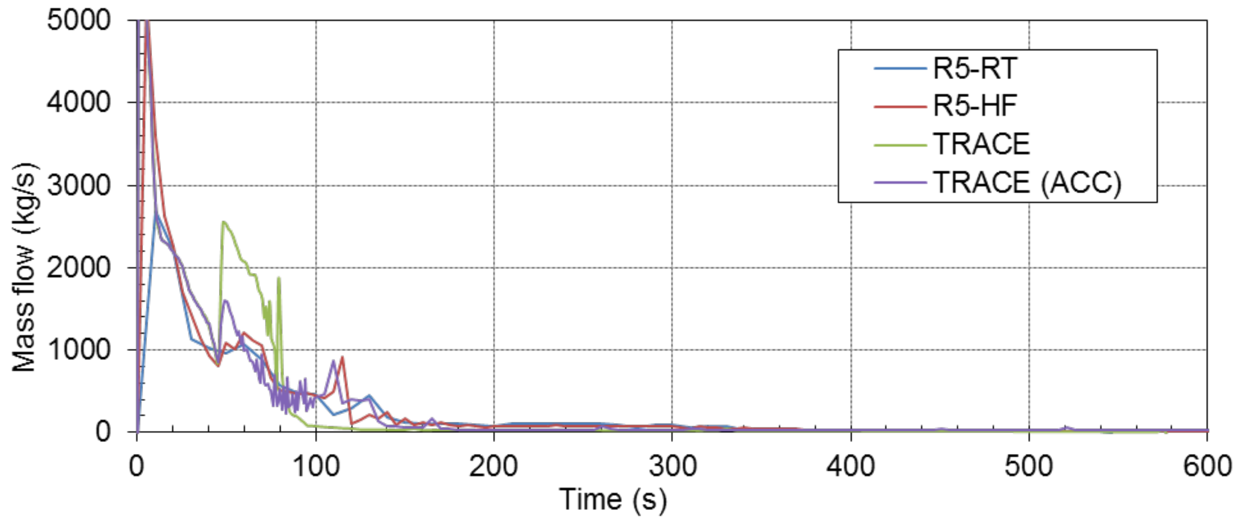

Figure 54 Break Flow (30.48 cm)

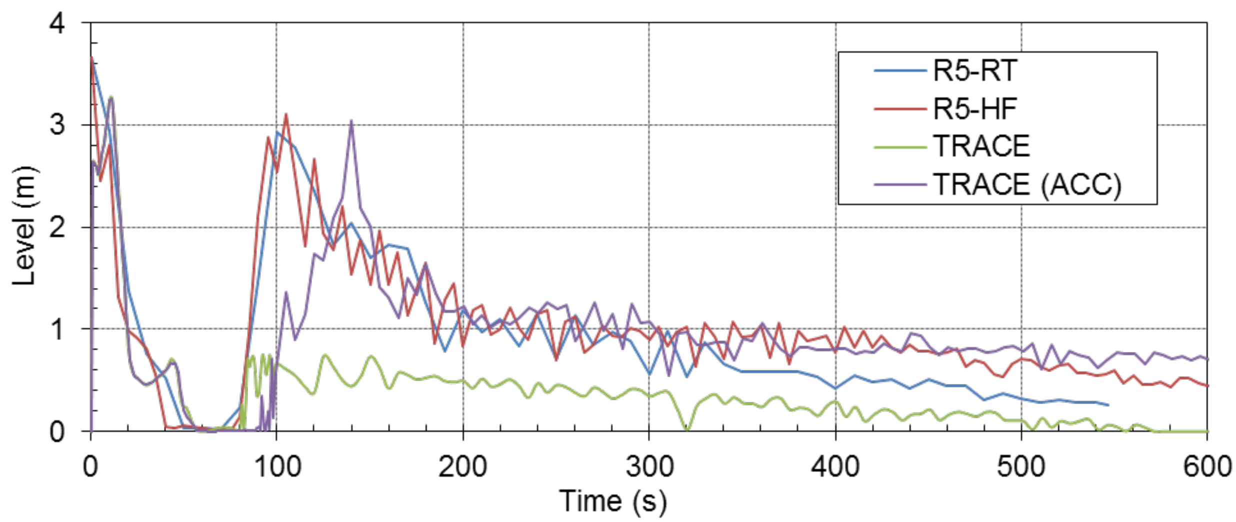

Figure 55 Core Collapsed Liquid Level (30.48 cm)

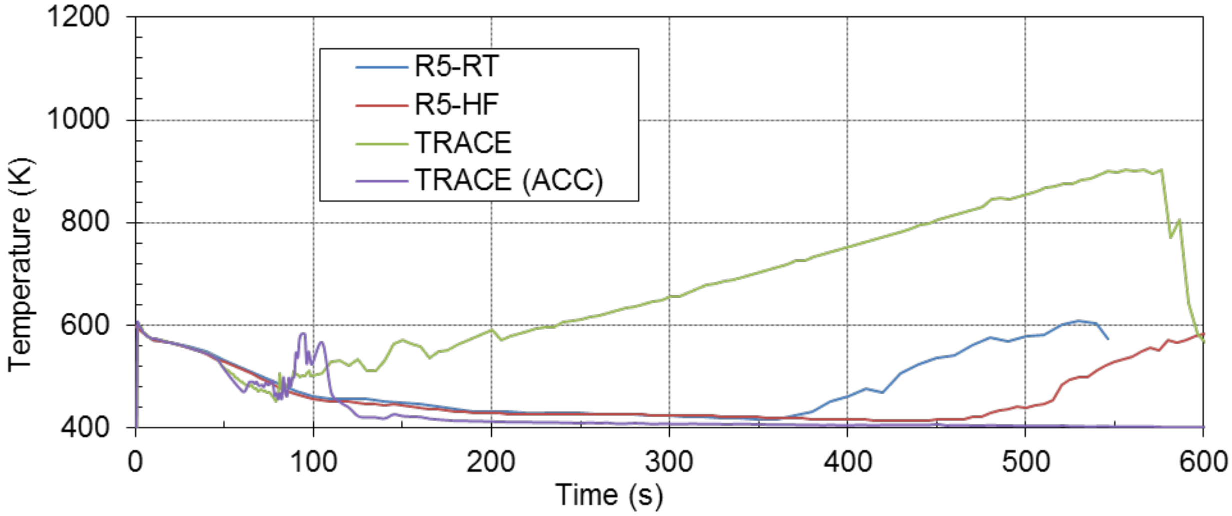

Figure 56 Core Exit Temperature (30.48 cm)

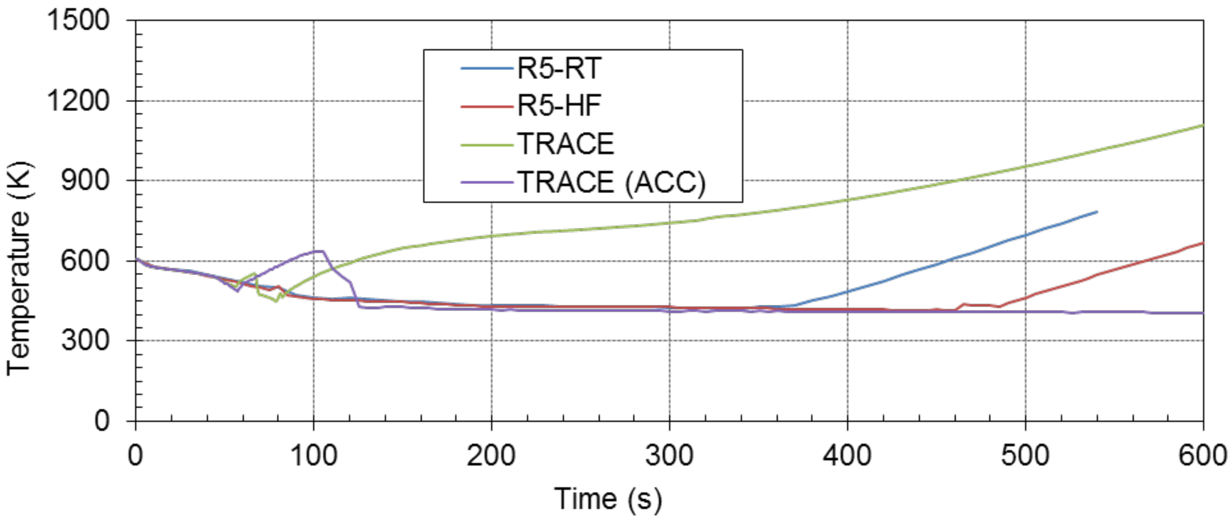

Figure 57 Fuel Cladding Temperature (30.48 cm)

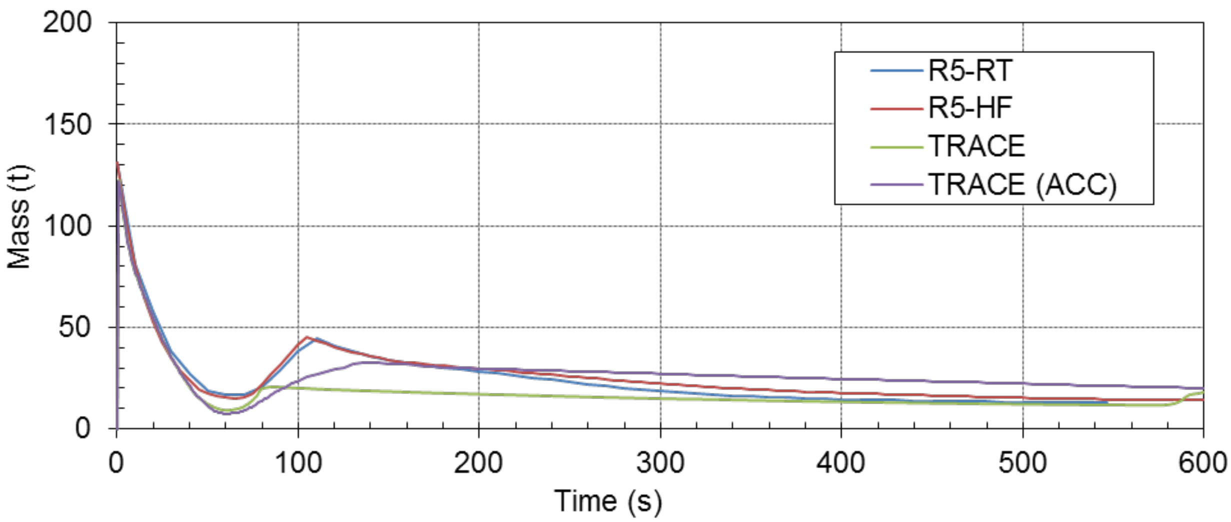

Figure 58 RCS Mass (30.48 cm)

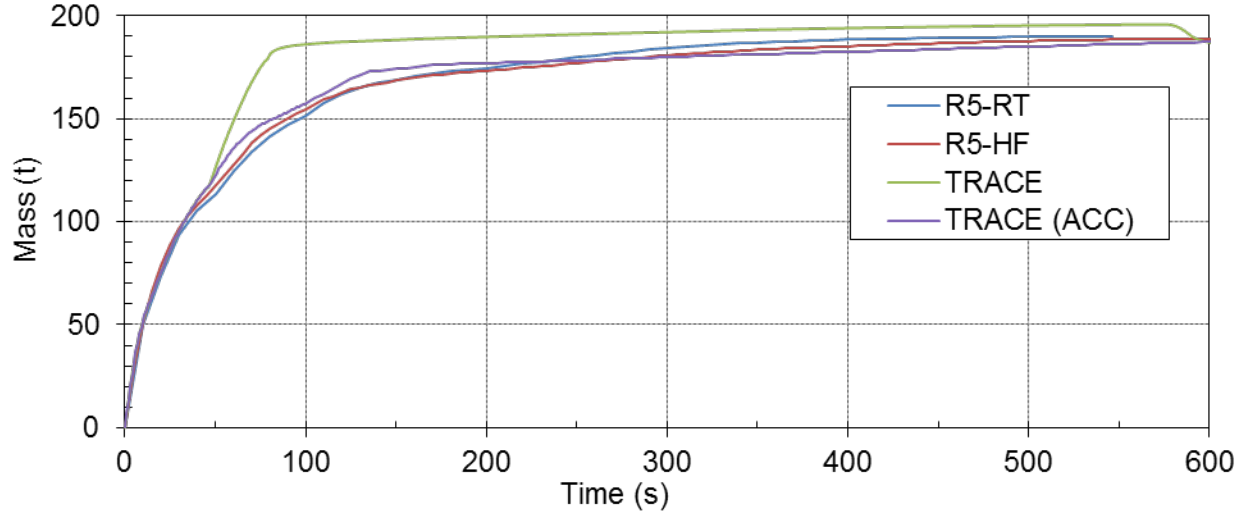

Figure 59 Integrated Break Flow (30.48 cm)

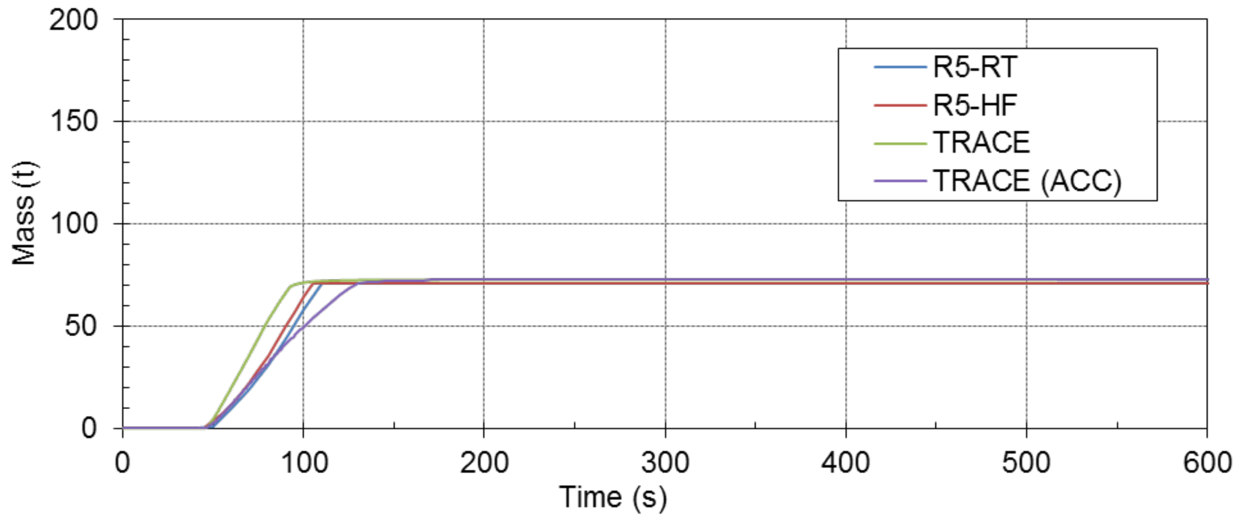

Figure 60 Mass Injected by Accumulators (30.48 cm)

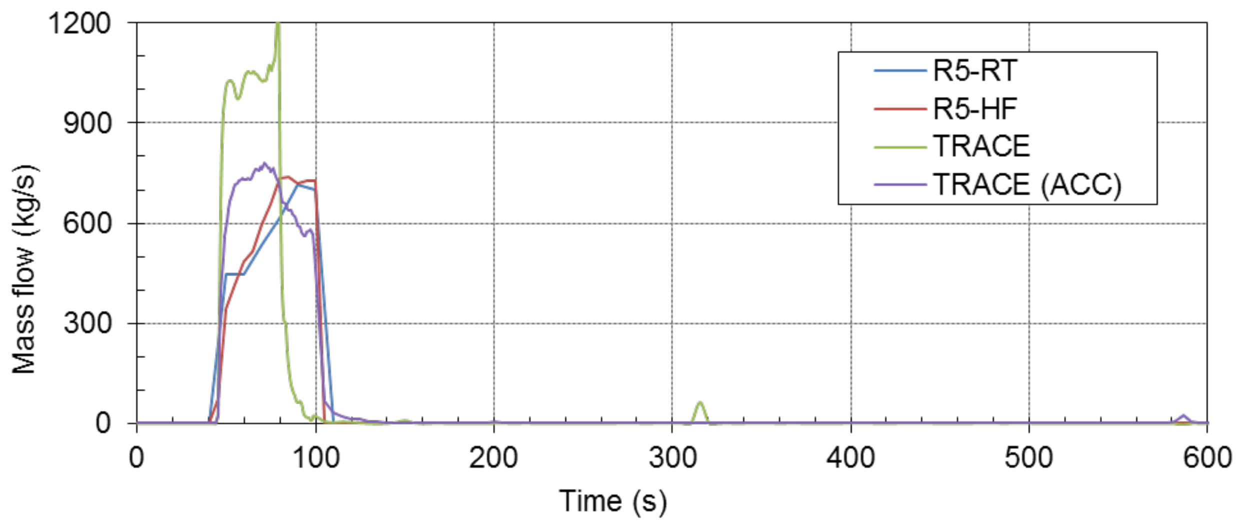

Figure 61 Accumulator no. 1 Flow (30.48 cm)

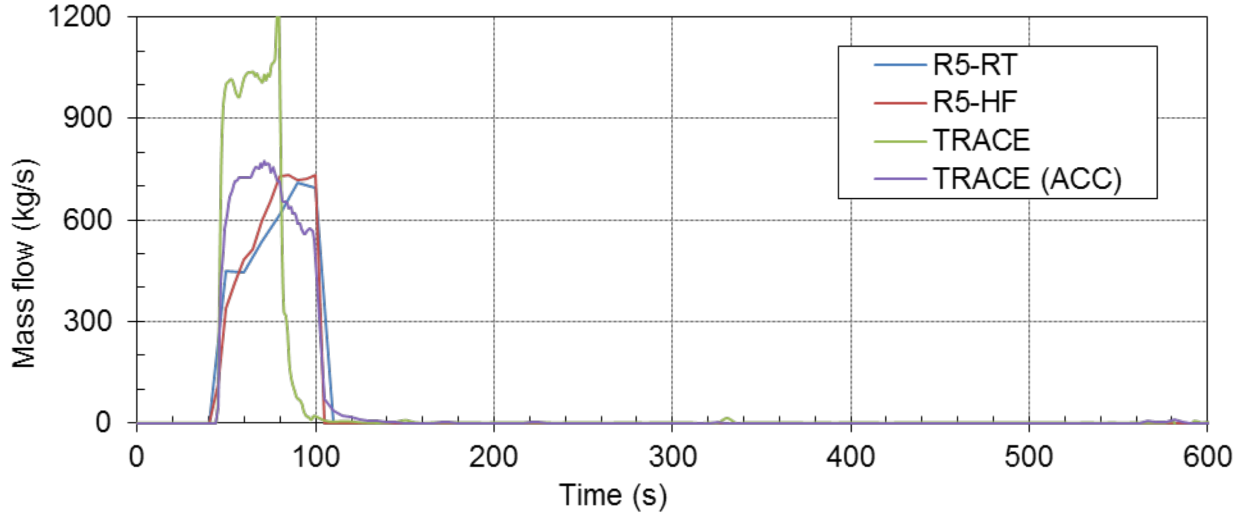

Figure 62 Accumulator no. 2 Flow (30.48 cm)

3.6 Discussion of Results

In the performed TRACE LOCA analysis of 30.48 cm (case labeled “TRACE”) faster accumulator discharge (see Figure 60) so much influences the break flow (see Figure 54) that RCS mass was so low that heatup starts after 1 minute and is qualitatively very much different from RELAP5 calculation. Therefore it was decided to reduce the accumulator flow area in such a way to get comparable accumulator discharge between TRACE and RELAP5. As can be seen from Figures 61 and 62 showing results for 30.48 cm break size for reduced accumulator line area (label “TRACE (ACC)”), the TRACE break flow is now similar to RELAP5 calculations with differences in the time of core heatup start. In case of RELAP5 using RT and HF critical flow model the core heatup occurred in 6 minutes and 8 minutes, respectively, while in TRACE in 11 minutes after break occurrence.

As was already indicated the results showed that accumulator emptying should be further studied. Therefore the BETHSY 6.2TC calculation (Refs. 7 and 11) has been checked as shown in Figure 63. The accumulator discharge was faster in the case of TRACE comparing to RELAP5 calculation, which was in reasonable agreement with experimental data. The TRACE calculation of the same BETHSY 6.2TC test described in the TRACE code development assessment manual (Ref. 12) similarly shows that TRACE calculated accumulator discharge is faster than in the experiment as can be seen from Figure 64. In the Reference 12, page C-491 it is further explained:
“*Calculated and measured integrated accumulator injection flows into both loops are shown in Figure C.8-65. In the test, the accumulator injection starts at 345 seconds and is isolated at approximately 950 seconds. In the calculation, the accumulator injection begins at about 350 seconds and is isolated at about 650 seconds. As indicated in Reference 9, the combination of the larger amount of water inventory loss out the break and the earlier time that the accumulators complete their injection results in the earlier calculated core heatup at approximately 1330 seconds.*”

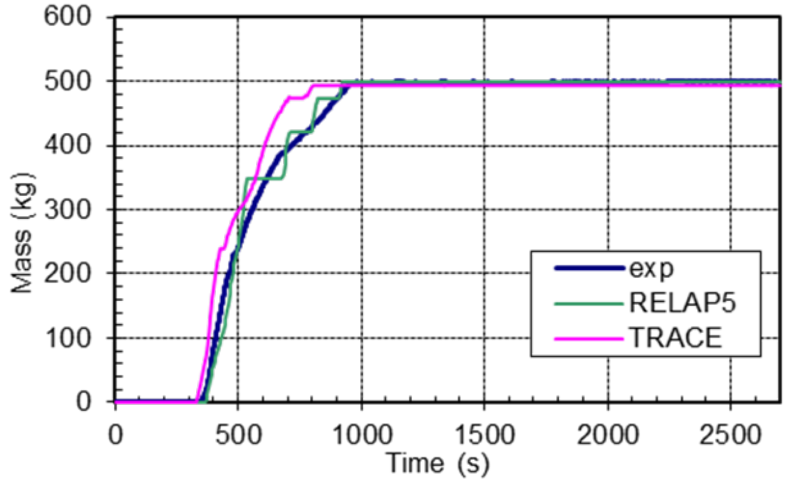

Figure 63 Mass Discharged by Accumulators (Ref. 7)

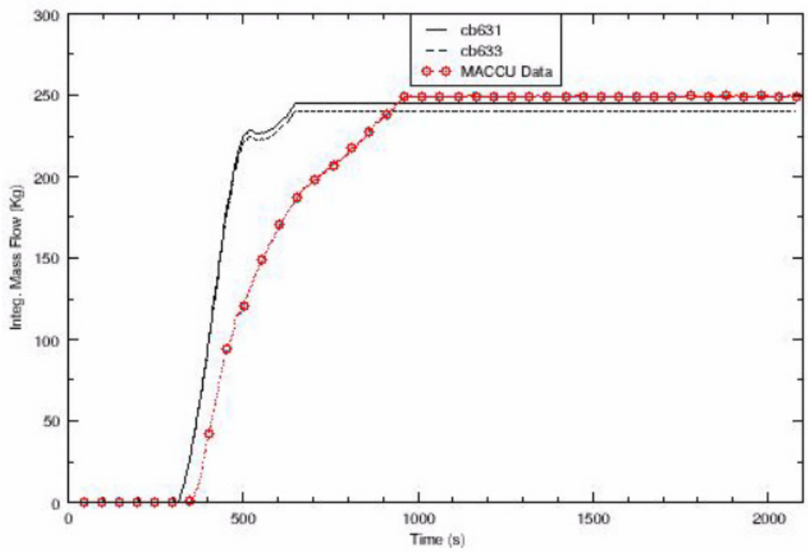

Figure 64 Integrated Accumulators Injection Flow (Fig. C.8-65 from Ref. 12)

When comparing TRACE predictions in Figures 63 and 64, it can be seen that also in the case of TRACE assessment using TRACE Patch 01 code (Ref. 12), the accumulator discharge was predicted faster than in case of BETHSY 6.2TC experiment. Calculated accumulator water flow over prediction of TRACE for integral experiments presented in the Assessment Manual, Appendix C (Ref. 12), is seen in Figures C.5-99, C.5-100, C.5-204, C.5-205, C.6-16, C.6-17 and C.6-37 of Reference 12, and indirectly from integrated accumulator flow in Figure C.8-65 of Reference 12.

4. CONCLUSIONS

In the study it was demonstrated that developed input model of two-loop pressurized water reactor (PWR) for TRACE thermal-hydraulic systems code has the capability for independent assessment of RELAP5 computer code calculations. For demonstration the response of PWR to loss-of-coolant accident (LOCA) was simulated for five break sizes ranging from 10.16 cm to 30.48 cm equivalent diameter break size in cold leg. Two RELAP5 code calculations were performed to see the influence of critical flow break model, while in case of TRACE default critical flow model was used.

The results showed that RELAP5 calculations using different break flow models are rather similar between each other, therefore also other parameters are similar. The accumulators discharge was faster in TRACE calculations than in RELAP5 calculations for whole LOCA spectrum. Therefore the calculated TRACE break flow was also larger than RELAP5 calculated break flow during this period. This further influences the accident progression. In the case of smaller breaks also secondary side more significantly influences the primary pressure, but this could not be properly simulated with TRACE due to problems with separator component. It can be concluded that different accumulator discharge influencing the break flow seems to be the largest contributor to the differences between RELAP5 and TRACE for the performed LOCA calculations.

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10. SUPPLEMENTARY NOTES

K. Tien, NRC Project Manager

11. ABSTRACT (200 words or less)

The accident at the Fukushima Dai-ichi nuclear power plant in 2011 demonstrated that external events could cause loss of all safety systems. In the Europe stress tests were performed and the need was identified to further improve the safety of the existing operating reactors. Therefore the safety upgrade programs were started. The objective of this study was to demonstrate that developed input model of two-loop pressurized water reactor (PWR) for TRACE thermal-hydraulic systems code can be used for independent calculations to be compared with RELAP5 computer code calculations. For demonstration the response of PWR to loss-of-coolant accident (LOCA) break spectrum from 10.16 cm (4 inch) to 30.48 cm (12 inch) was simulated. Only passive accumulators were assumed available. For calculations the latest TRACE Version 5.0 Patch 4 and RELAP5/MOD3.3 Patch 4 using both break flow models were used. The results showed that RELAP5 calculations using different break flow models are rather similar, therefore also other parameters are similar. The accumulators discharge was faster in TRACE calculation than in RELAP5 calculations. It can be concluded that different accumulator discharge influencing the break flow seems to be the largest contributor to the differences in the results between RELAP5 and TRACE.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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Loss of Coolant Accident (LOCA)
Passive Accumulators
Fukushima Dai-ichi NPP Accident

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