The 14th International Topical Meeting on Nuclear Reactor Thermalhydraulics, NURETH-14
Toronto, Ontario, Canada, September 25-30, 2011

NURETH14-150

BETHSY 6.2TC TEST CALCULATION WITH TRACE AND RELAP5 COMPUTER CODE

A. Prošek[1], A. Berar[1]
[1] Jožef Stefan Institute, Ljubljana, Slovenia

Abstract

The TRACE code is still under development and it will have all capabilities of RELAP5. The purpose of the present study was therefore to assess the accuracy of the TRACE calculation of BETHSY 6.2TC test, which is 15.24 cm equivalent diameter horizontal cold leg break. For calculations the TRACE V5.0 Patch 1 and RELAP5/MOD3.3 Patch 4 were used. The overall results obtained with TRACE were similar to the results obtained by RELAP5/MOD3.3. The results show that the discrepancies were reasonable.

Introduction

The TRAC/RELAP Advanced Computational Engine (TRACE) is the latest in a series of advanced, best-estimate reactor systems codes developed by the U.S. Nuclear Regulatory Commission [1]. The advanced TRACE comes with a graphical user interface called SNAP (Symbolic Nuclear Analysis Package) [2], which is intended for pre- and post-processing, running the codes, RELAP5 to TRACE input deck conversion, input deck database generation etc. The TRACE code is still under development and it will have all capabilities of RELAP5. The TRACE has superior capabilities and accuracy for most applications compared to RELAP5. Although the TRACE is the future of U.S Nuclear Regulatory Commission (NRC), its use in countries members of Code Applications and Maintenance Program (CAMP) it is still not dominant against the RELAP5 computer code. However, TRACE it is now more and more used by the RELAP5 code users, in a great deal also because of better RELAP5 to TRACE conversion capability. The typical RELAP5 users start with RELAP5 legacy input decks, which are first automatically converted to TRACE input decks using SNAP and then manual corrections are done. Namely, much of efforts were done in the past to develop the RELAP5 input decks. Although much work has been done to date on TRACE assessment, important part is also independent assessment performed by wide community. The purpose of the present study was therefore to assess the accuracy of the TRACE calculation of BETHSY 6.2TC test using the converted and adapted RELAP5 nodalization, which was developed in the past for international standard problem no. 27 (ISP-27) at Jožef Stefan Institute [3]. The RELAP5 legacy input deck has different origin than the one, which has been used for conversion to TRACE in the original TRACE code assessment study [4]. When comparing the TRACE calculation to the RELAP5 calculation and to TRACE calculation described in the code assessment manual [1], one can more easily see the peculiarities of the TRACE code. Finally, both RELAP5 and TRACE calculations were compared to the experimental data.

1. Methods

The selected BETHSY 6.2TC test was 15.24 cm (6 inch) equivalent diameter horizontal cold leg break in the reference pressurized water reactor without high pressure and low pressure safety injection. The transient was ended at 2179 s when primary pressure dropped below 0.7 MPa. BETHSY facility was a 3-loop replica of a 900 MWe FRAMATOME pressurized water reactor. For better presentation of the calculated physical phenomena and processes, an animation model using SNAP was developed. For calculations the RELAP5/MOD3.3 Patch 4 [5] and TRACE V5.0 Patch 1 computer codes were used [1]. In the following subsections the BETHSY facility and test scenario are described first. Then the RELAP5 and TRACE input models are described. For the RELAP5 and TRACE computer code description the reader can refer to Ref. [5] and [1], respectively.

1.1 BETHSY facility description

BETHSY is an integral test facility, which was designed to simulate most pressurized water reactor accidents of interest, to study accident management procedures and to validate the computer codes. BETHSY facility was located at Centre D'Etudes Nucleaires de Grenoble (France). It was a scaled down model of three loop Framatome nuclear power plant with the thermal power 2775 MW. Six important choices have been made which characterize indeed the general design of the BETHSY facility. They concern: the number of loops, the rated pressure of both the primary and the secondary side, the maximum core power level, the maximum flow rate of primary pumps, the general scaling factors and the connected circuits and systems. Volume, mass flow and power were scaled to 1:96.9, while the elevations and the pressure of the primary and secondary system were preserved [6]. The design pressure on the primary side was 17.2 MPa and on the secondary side 8 MPa. The power was limited to the decay heat level; therefore the transient without reactor trip could not be simulated. The facility was equipped with all important systems and measurement system, needed for performance and observing the analyzed transients. The facility consisted of pressure vessel, reactor coolant pumps and piping, heat tracing system, the system for break simulation, instrumentation and the control systems. The core power was 3 MW, what is 10% of the reference power considering scaling. The break system enabled simulation of the break in different locations, i.e. in the cold leg, the lower plenum, the pressurizer, the steam generator U tubes and the feedwater pipe. The instrumentation data system measured all data needed for the transient analysis. The control system could simulate the plant control systems and operator actions.

1.2 BETHSY 6.2TC test description

BETHSY 6.2TC test was a 15.24 cm (6 inch) cold leg break in the loop one without available high pressure and low pressure safety injection system [6]. Accumulators were available in the intact loops. The main aims of this test were to compare the counterpart test data from BETHSY and LSTF facilities and qualification of CATHARE 2 computer code. The experiment scenario was the following: opening of the valve simulating the break in the cold leg no. 1, accumulator injection in the intact loops when a primary circuit pressure was lower than 4.2 MPa and end of transient, when the primary circuit pressure was below 0.7 MPa.

1.3 RELAP5 input model description

The RELAP5/MOD2 input model was developed, when participating to ISP-27. It was initialized according to the specified data for each test. Each of the three coolant loops were represented explicitly without taking into account the small asymmetry between the loops. The base RELAP5/MOD2 input model of BETHSY facility for pre-test calculations contained 196 volumes, 207 junctions and 191 heat structures. This base RELAP5/MOD2 input model was later upgraded to RELAP5/MOD3.1 and RELAP5/MOD3.1.2. Also, during the post-test analyses, the base input model was renodalized. The number of nodes was increased in reactor coolant system piping, reactor coolant pumps, core bypass section, reactor vessel downcomer and steam generators. The elevations of parallel volumes of the reactor downcomer, in bypass, reactor core, hot leg and cold leg were preserved. Nodalization of the reactor core, pressurizer, reactor head, upper plenum and lower plenum remained the same. This model consisted from 398 volumes, 408 junctions and 396 heat structures. This model was then used separately for BETHSY 6.9c [7] and BETHSY 6.2TC [8] test calculations by RELAP5/MOD3.2. Therefore in 2000 a common RELAP5/MOD3.2 model was developed for all available BETHSY tests consisting from 398 volumes, 408 junctions and 402 heat structures [9], [10]. This model was in 2010 adapted for the use with the RELAP5/MOD3.3 computer code. No changes were made to the geometry and the number of hydrodynamic components and heat structures. From the RELAP5/MOD3.3 ASCII input model the hydrodynamic view was generated by SNAP, requiring also manual editing in Model Editor of SNAP.

1.4 TRACE input model description

The TRACE input model converted from RELAP5/MOD3.3 input model mostly preserved the numbering of components from RELAP5 (see reference [1]). There are 157 hydrodynamic components and 57 heat structures. The converted input model required several manual corrections, adaptations of components and introduction of components needed for transient. The final view of adapted TRACE input model for transient calculation is shown in Figure 1.

All converted hydraulic diameters were replaced manually with the hydraulic diameters obtained from the RELAP5/MOD3.3 output file. The nitrogen vessel represented by an Accumulator component in the RELAP5 input model was automatically converted to Liquid separator type instead of Accumulator type of Pipe component. It was then manually changed to Accumulator type of pipe. SNAP 1.2.6 conversion tool failed short in the respect of converting the wall-roughness for some hydraulic components from RELAP5 to TRACE. The data for the wall-roughness for these components were therefore manually added to the TRACE input model. Problems were also with Separator component – RELAP5 liquid carryover and carryunder value were converted to minimum and maximum barrel void fraction, while to liquid carryover and carryunder other values were assigned.

For TRACE input model the calculated area of adjacent volumes are also compared in the SNAP. If the volumes differ by more than a user-modifiable ratio, the volumes are determined to involve an area change. An error is reported if the intervening edge between the two volumes does not have either friction defined, or the abrupt area change model enabled. Solution was to input very small values of loss coefficients. This was needed for areas of components converted from the RELAP5 servo valves and accumulators.

Several important side junctions resulting from RELAP5 Branch components converted to Pipe components were renodalized using Tee components (e.g. break, accumulator injection point, steam generator dome). These specific adaptations were important for the calculation results. The break modeled by originally converted side junction produced different results in the steady state of BETHSY 9.1b test [11]. Similar was true for the accumulator injection. In the case of RELAP5 time dependent junctions converted to TRACE Pump (type mass flow controlled single junctions) such adaptations were not needed. Nevertheless, such pump components were replaced by Fill components. Also, much of adaptation was needed for heat structures. In the RELAP5 input model the source of heating was realized by control variables. Therefore in the converted TRACE input model several Power components were generated.

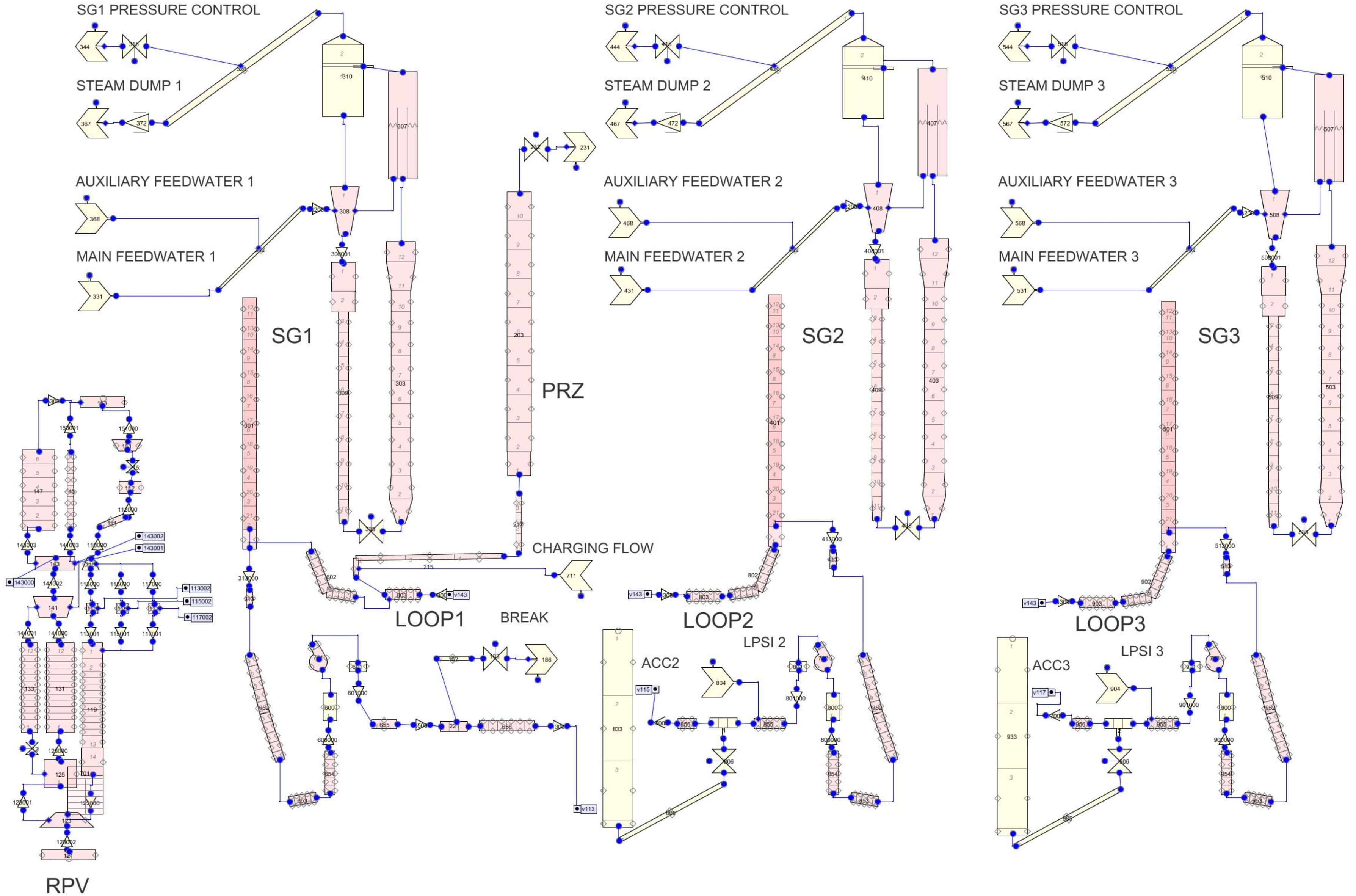

Figure 1 SNAP hydrodynamic component view for adapted TRACE input model of BETHSY facility.

Unfortunately, by Power components only the positive power can be modeled, while to model heat losses the heat structures should be powered by negative power. Therefore heat fluxes were assigned to the outer surfaces (the desired power divided by heat structure outer surface area), while Power components were deleted all except the one representing the core heating.

Finally, the RELAP5 restart input model consisting of break, safety systems and controls needed during transient could not be converted by SNAP to TRACE restart input model. Therefore this part was converted manually. Finally, this lesson learned will be built into the RELAP5 to TRACE conversion procedure, which is being developed.

2. Results

The results of steady-state and transient calculations of BETHSY 6.2TC test using TRACE V5.0 Patch 1 and RELAP5/MOD3.3 Patch 4 computer code are presented in the following subsections.

2.1 Steady-state calculation

Table 1 shows the initial and boundary conditions for BETHSY 6.2TC test. The RELAP5 and TRACE input model were initialized to the cold leg temperature. In the case of TRACE the secondary pressure is not exactly matched. The difference comes from the geometry and the code models. In the TRACE assessment report [4] the cold leg temperature was not matched for the sake of matching secondary pressure. The steam generator levels and masses were matched to average measured values both for RELAP5 and TRACE. The pressurizer pressure and level were also matched to average measured values. The core power was boundary condition. In the experiment the electrical trace heating system was installed of the power of 54.82 kW and was operating till the transient start. Therefore in the calculations the heat losses were modeled after the electrical heat system was off.

Table 1 Comparison of initial conditions for BETHSY 6.2TC test.

Parameter	Measured	RELAP5	TRACE
core thermal power (kW)	2863 ± 30	2864	2863
pressurizer pressure (MPa)	15.38 ± 0.15	15.38	15.38
pressurizer level (m)	7.45 ± 0.2	7.45	7.45
total flow (kg/s)	16.81 (calculated from core power)	16.84	16.61
core inlet temperature (K)	557.2 ± 0.4	557.2	557.2
core outlet temperature (K)	588.2 ± 0.4	588.1	588.8
reactor coolant system mass (kg)	1984 ± 50	1948	1948
secondary side pressure - per SG (MPa)	6.84 ± 0.07	6.83	6.69
steam generator level - per SG (m)	11.1 ± 0.05	11.1	11.1
feedwater temperature (K)	523.2 ± 4	523.2	523.2
heat loss (kW)	54.82	N.A.	N.A.
downcomer to upper head flow (kg/s)	0.047	0. 47	0.047

For TRACE input model initialization artificial controls were built in. The primary pressure was set by boundary condition, while the pressurizer level was set by an artificial Fill component. The controller was built to set the cold leg temperature and according to it the secondary pressure was adjusted. For steam generator level the Fill component was used (using Fill component for auxiliary feedwater). The primary mass flow was adjusted by the pump speed.

2.2 Transient calculation

The main sequence of events is shown in Table 2. The graphical comparison between the experiment, RELAP5 and TRACE for main variables is shown in Figures 2 thorough 13. The calculation results showed that occurrences and trends of key transient phenomena are reasonably predicted by both computer codes.

As shown in Table 2 most of times were reasonably captured. The times of reactor trip and safety injection signals are similar for both RELAP5 and TRACE calculation. As the pressure drop in TRACE calculation is slower, the primary to secondary pressure reversal is delayed in case of TRACE. The main reason is probably the secondary side behaviour. Namely, the mass released through atmospheric relief valves in the initial period greatly influenced the primary pressure drop. Higher secondary pressure indicated that in first 100 s the atmospheric relief valves were open few tens of seconds. The overall accumulator time performance is better by TRACE than by RELAP5.

Table 2 Main sequence of events

Events	Time (s)		
	Experiment	RELAP5	TRACE
Break opening	0	0	0
Scram signal (13.1 MPa)	8	2	3
Safety injection signal (11.9 MPa)	11	8	9
First core uncovery	92	90	136
Loop seal clearing	134	155	173
Primary/secondary pressure reversal	172	175	203
Second core uncovery	334	280	253
Accumulator injection starts (4.2 MPa)	363	365	329
Accumulator isolation (1.5 MPa)	895	1125	801
Pressurizer pressure < 0.7 MPa	2065	2230	2167

The timing of the transient very much depends on the break mass flow. For RELAP5 original Ransom-Trapp break flow model the values of 0.85, 1.25 and 0.75 were used for subcooled, two phase and superheated discharge coefficients, respectively. For TRACE break model the values of 0.8 and 0.9 were used for subcooled and two phase discharge coefficients, respectively. The values for TRACE were selected after some sensitivity studies. In Figures 2 and 3 are shown the break flow and the integrated break mass flow. It can be seen that the calculated break flows are quite well matched, in the range of 10% uncertainty. The integrated break flow better agree for the TRACE calculation. Primary pressure is shown in Figure 4. In spite of larger RELAP5 break flow than TRACE break flow the pressure drop is faster in case of TRACE calculation. Secondary pressure is shown in Figure 5. Already it was noted, that experimental values indicated that atmospheric relief valves were open a few tens of seconds. Later, the agreement between experiment and calculation is better for TRACE than for RELAP5. This is due to better heat losses modelling in the case of TRACE. However, in general after initial period the secondary side has small influence on the primary side and by this on the overall calculation. Figures 6 and 7 show the heater rod surface temperatures in the middle and at the top of the core, respectively. The core heatup corresponds by the minimum core collapsed liquid level shown in Figure 8. Both calculations predicted with delay the first peak of heater rod surface temperature at the middle of the core. The second rod heatup was better calculated by TRACE. In the case of heater rod surface temperature at the top of the core the timing of heatup prediction was better in the case of TRACE, while heatup rate was better in the case of RELAP5. The primary mass is shown in Figure 9. In spite of correct TRACE calculated mass discharged through the break the TRACE calculated primary mass is smaller than the experimental. Similar is the situation in the case of RELAP5 calculation. The information on the loop seal clearing can be obtained from Figures 10 and 11, showing the differential pressures on the steam generator and pump side, respectively. It may be seen that some further adjustment is needed for TRACE pressure drop on the pump side. Finally, the accumulator behavior is shown in Figure 12 showing the accumulator pressure and Figure 13 shown the integrated accumulator injected mass. Again the accumulator injected mass was very close to measurement value in the case of TRACE. The trend for RELAP5 is very good with exception that approximately 10% more mass was discharged. The difference in the calculated masses originates partly from a bit smaller initial primary mass, while the rest of difference may be attributed to the measurement uncertainty.

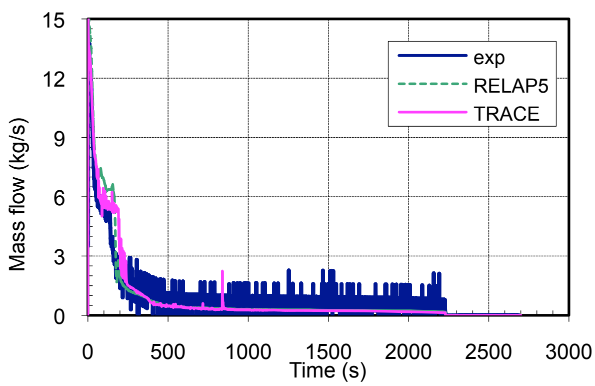

Figure 2 Break mass flow

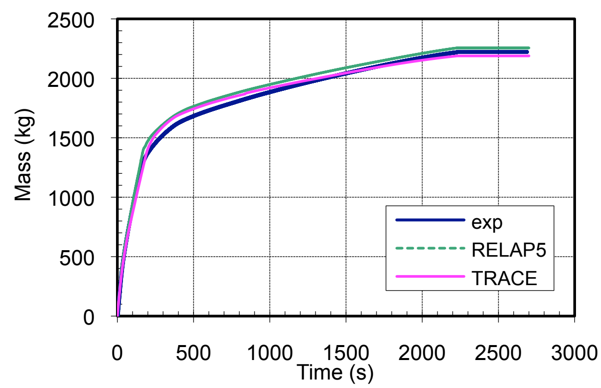

Figure 3 Integrated break mass flow

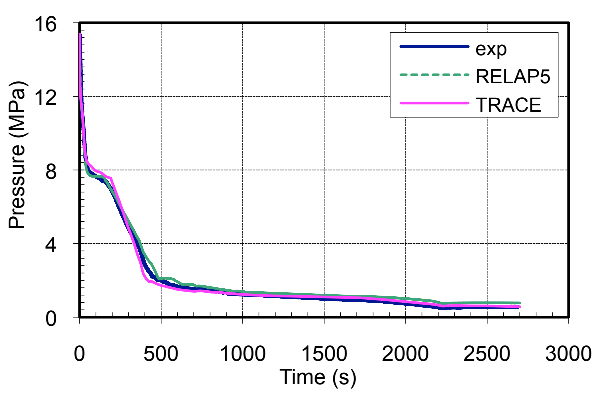

Figure 4 Pressurizer pressure

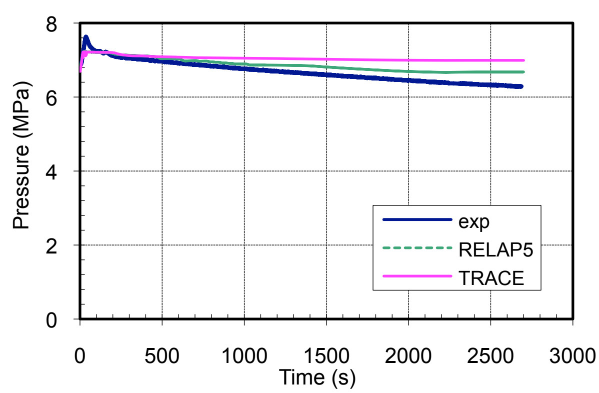

Figure 5 Steam generator 1 pressure

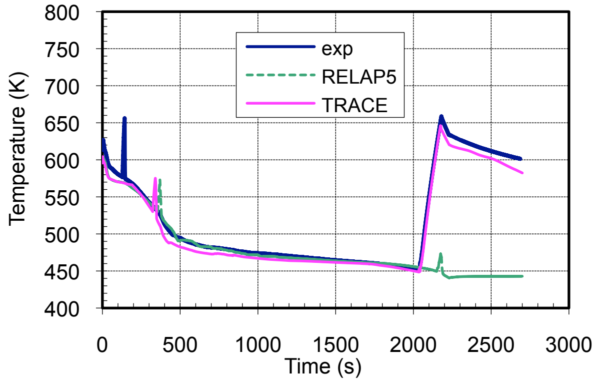

Figure 6 Heater rod surface temperature at the middle of the core

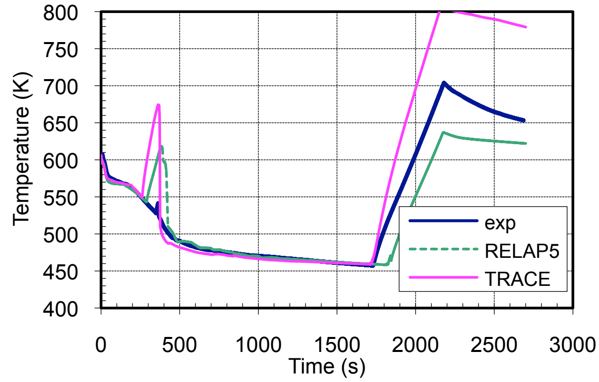

Figure 7 Heater rod surface temperature at the top of the core

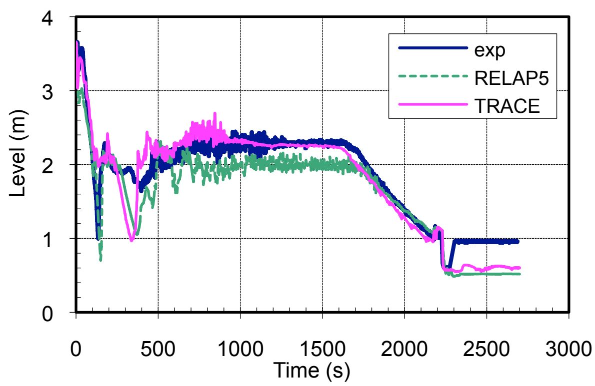

Figure 8 Core collapsed liquid level

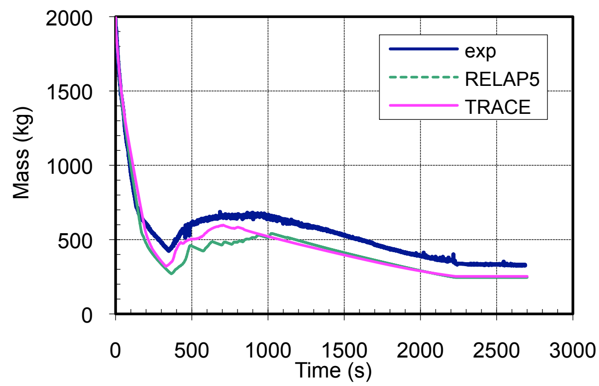

Figure 9 Total primary mass

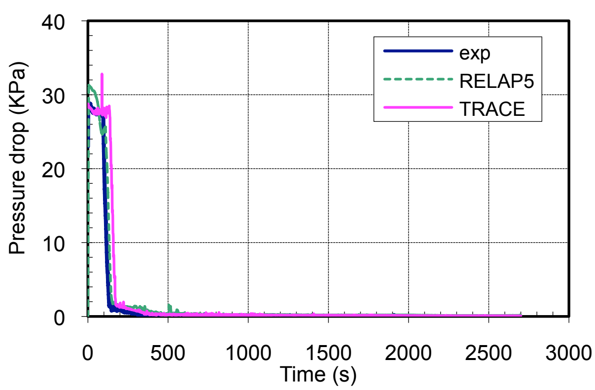

Figure 10 Intermediate leg 1 DP (SG side)

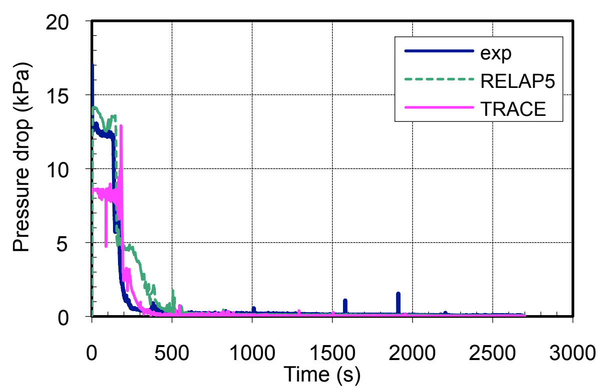

Figure 11 Intermediate leg 1 DP (pump side)

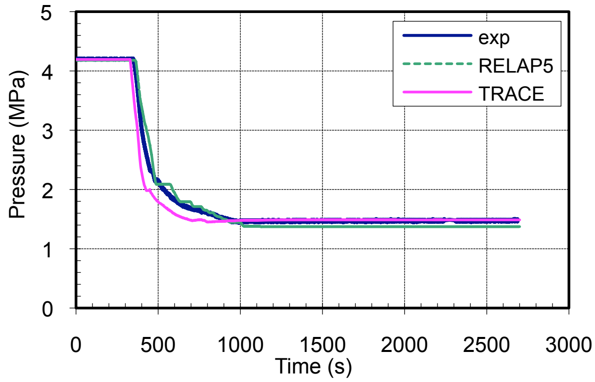

Figure 12 Accumulator no. 2 pressure

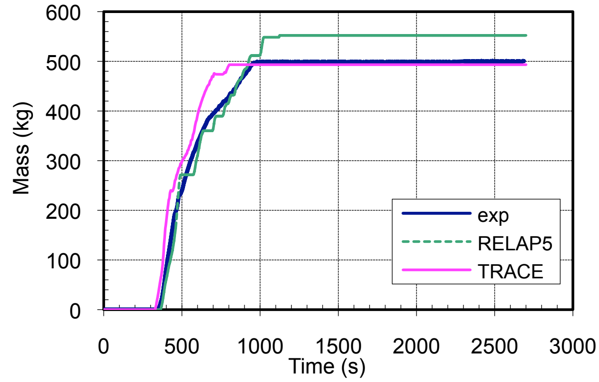

Figure 13 Integrated accumulators injected mass

Comparison of TRACE and RELAP5 calculations show that in general there are very similar. Again it was confirmed that the TRACE using the converted input model from RELAP5 produces results comparable to RELAP5. The first time this was shown in study of BETHSY 9.1b test [11], being TRACE even slightly better. When looking the timing of accumulator injection and core heatup in the presented BETHSY 6.2TC test, the TRACE calculation was better than reported in assessment manual [1]. Nevertheless, this study showed that additional adaptations of the TRACE input model may be done, including 3D reactor vessel model.

3. Conclusion

The overall results obtained with TRACE V5.0 Patch 1 were similar to the results obtained by RELAP5/MOD3.3 Patch 4. The results show that the main discrepancies in case of TRACE calculation are connected with the predictions of primary pressure and break flow in the first 200 s, influencing the accumulator emptying and primary mass inventory. Both the TRACE and RELAP5 code predicted first core uncovery until accumulators started to inject and after emptying accumulators the second core heatup was predicted due to second core boil off. It was shown that TRACE calculations obtained by converted input model from RELAP5 to TRACE are as good as the RELAP5 calculations obtained by the original RELAP5 input model. In future some further improvements in TRACE input model may still be done, e.g. 3D vessel, hopefully contributing to even better results.

4. References

[1] U. S. Nuclear Regulatory Commission, TRACE V5.0 User Manual, Division of Risk Assessment and Special Projects, Office of Nuclear Regulatory Research, Washington, DC.

[2] APT, Symbolic Nuclear Analysis Package (SNAP), User's Manual, Applied Programming Technology (APT), Inc., 2007.

[3] S. Petelin, B. Mavko, O. Gortnar, I. Ravnikar, G. Černe, “Result of BETHSY test 9.1.b using RELAP5/MOD3”, International agreement report NUREG/IA-0141, U.S. Nuclear Regulatory Commission, Washington, U.S.A, 1998.

[4] U. S. Nuclear Regulatory Commission, TRACE V5.0 Assessment Manual, Division of Risk Assessment and Special Projects, Office of Nuclear Regulatory Research, Washington, DC.

[5] USNRC, “RELAP5/MOD3.3 code manual”, Patch 04, Vols. 1 to 8, Information Systems Laboratories, Inc., Rockville, Maryland, Idaho Falls, Idaho, prepared for USNRC, 2010.

[6] CEA, "BETHSY, General Description", Note SETh/LES/90-97, CEA (Commissariat à l'énergie atomique et aux énergies alternatives), Grenoble, France, April 1990.

[7] S. Petelin, B. Mavko, M. Jurkovič, "BETHSY - loss of the residual heat removal system during mid-loop operation", Proceeding of 5th International Conference on Nuclear Engineering, May 26-30, Nice, France, 1997.

[8] S. Petelin, and B. Končar, "RELAP5/MOD3.2 Assessment on the BETHSY 6.2TC SBLOCA Test", Proceeding of 4th Regional Meeting, Nuclear Energy in Central Europe, Bled, Slovenia, September 7-10, 1997.

[9] S. Hrvatin, A. Prošek, I. Kljenak, "Quantitative assessment of the BETHSY 6.2 TC test simulation" Proceedings of the Eighth International Conference on Nuclear Engineering, The American Society of Mechanical Engineers, New York, U.S.A., 2000.

[10] S. Hrvatin, A. Prošek, "Quantitative assessment of the BETHSY 6.9c test simulation", Proceedings of International Conference Nuclear Energy in Central Europe 2000, Bled, Slovenia, September 11-14, 2000.

[11] A. Prošek, O.A. Berar, "Analysis of small-break loss-of-coolant accident test 9.1b at BETHSY facility with TRACE and RELAP5", Proceedings of ICAPP 2011, International Congress on Advances in Nuclear Power Plants, Nice, France, May 2-6, 2011.

[12] S. Petelin, B. Končar, S. Hrvatin, "Influence of the upper head nodalization on the "BETHSY" 6.2 TC test", Proc. of International Conference Nuclear Energy in Central Europe '99, Portorož, Slovenia, September 6-9, 1999.