Journal of Energy

VOLUME 68 Number 2-3 | 2019 | Special Issue

journal homepage: http://journalofenergy.com/

Comparing Analysis of Loss of Coolant Accident on Bethsy Facility with Apros 6.05 and 6.06

Klemen Debelak, Luka Štrubelj
GEN energija, d.o.o
Vrbina 17, 8270 Krško, Slovenija
klemen.debelak@gen-energija.si, luka.strubelj@gen-energija.si

ABSTRACT

In this paper, the comparison of analysis of international standardized problem ISP 27 using two versions of APROS process simulation software 6.05 and 6.06 is presented. Numerical simulation of experiment Bethsy 9.1b, also known as ISP 27 was performed on a scaled down model of a three loop, 900 MWe Framatome PWR. In the test a small LOCA, with 2-inch cold leg break, combined with High pressure Injection System (HPIS) failure is simulated. State oriented approach, which requires operators to start an Ultimate Procedure were used. Model was first built in APROS 6.05 using standard modules in order to describe the volumes, heat structures and regulation of the test facility and was then exported to APROS 6.06.

The results from both versions showed all the processes such as loop seal clearing, core uncover and rise of cladding temperature and other processes taking place in the experiment were in a good agreement with experimental data. However even though results were similar some differences were noticeable. The differences in core cladding temperature, time integrated break mass flow, core liquid level and pressurized pressure were analysed in more detail in this paper.

Keywords: *APROS, Loss of Coolant Accident, Bethsy, ISP 27*

1 INTRODUCTION

Betsy is an integral test facility which was constructed for research of PWR accident transients. It is placed at the Nuclear Center of Grenoble in France. The Bethsy design aims to contribute to validating computer safety code and to check the relevance of the physical bases of the Emergency Operating Procedures (EOP). It represents a scaled down Framatome PWR, with three loops and thermal power of 2775 MW (900MWe) [1].

In this paper, the comparison of results of simulation of the test 9.1 b, using APROS 6.05 and APROS 6.06 computer code are presented. The test 9.1 b (ISP-27) involves a 2-inch cold leg break, combined with the High Pressure Injection System (HPIS) failure. The model for the facility was first built in APROS 6.05 and was latter exported to APROS 6.06. The expected differences in results were investigated in more detail.

2 BETHSY MAIN FEATURES

BETHSY facility is a 3-loop replica of a reference 2857 MW thermal (900 MWe) FRAMATOME PWR, with following characteristics [2], [3]:

- 428 heater rod core simulation, electrically heated,
- 3 secondary steam generators designed with 34 U-tubes of original dimensions,
- primary system pressure up to 17.2 MPa, secondary side pressure up to 8 MPa,

• initial power level of test section allows for 10 % of scaled nominal full power,
• heat losses controlled by external heater system,
• HPIS and LPIS available (HPIS not available in test 9.1b).

Scaling Information:
• power and volume scaling is 1/100,
• full length core simulator, decay power level and nominal flow rates scaled are 1/100,
• geodetical elevations of all components preserved 1/1 to simulate gravitational head
• loop piping diameter of hot legs dimensioned to preserve FROUDE number criterion of full size plant

3 APROS MODEL DESCRIPTION

The thermohydraulcal model consists of: 760 Points, 60 Nodes, 71 Branches, 159 Heat structures X (1D heat structures), 48 Heat pipes (Thermal-hydraulic large volumes divided into many smaller volumes in one direction with pipe walls heat structures), 18 Pipes (Thermal-hydraulic large volumes divided into many smaller volumes in one direction), 38 Heat transfer modules (Heat transfer coefficients defined), 3 pumps with defined head curve, 5 valves, 2 Accumulators and 3 Steam generators. Volume is represented by 293 volumes with 6-equation model.

Reactor pressure vessel

The volumetric model of Reactor pressure vessel was built using nodes and branches. Wall materials are represented with HEAT_STRUCTURE_X module. Core, which are electrical heaters at Bethsy facility are also represented with HEAT_STRUCTURE_X. Their relative power is regulated according to events and time tables in order to follow the power of the experiment.

Reactor cooling system

Reactor cooling system consists of three loops. In comparison to loop one, loops two and three have accumulator and low pressure injection, whereas pressurizer is connected to loop one. The break is located 332 mm downstream of the outlet flange of the pump in loop one. For the break, which is represented by a branch, critical flow feature was enabled. Reactor coolant pumps are represented with common pipe module in combination with calculation level modules for electrical motor and pump. Heat structures are simulated within heat pipes and are connected with heat transfer coefficient module to point that represents environment. Accumulators are modelled using ACCUMULTOR module and are using Calculation mode 1 of node velocity.

Pressurizer

Pressurizer volumetric model was built using nodes and branches. Wall materials and electrical heaters are represented with HEAT_STRUCTURE_X module. Spray system is not modelled.

Steam generator

The model consist of three advanced steam generator modules. Heat structures (except for u-tubes) are modelled using HEAT_STRUCTURE_X. Due to limitations of the module advanced steam generator additional two branches and one node was added to simulate upper part of the node. This was done in order to minimize the difference of volumes that are above the riser, compared to the real Bethsy steam generator.

Feedwater and auxiliary feedwater

Feedwater and auxiliary feedwater are modelled using pipes and pipes with heat structures.

Main steam and steam dump

Main steam and steam dump are modelled using pipes, pipes with heat structures and basic valves.

Regulation

Regulation was built in order to initiate and simulate events in timely manner that is in compliance with experiment. There are three separate automations: for pressurizer power, for core power and one that is responsible for controlling all other system. The last is responsible for control of feedwater, auxiliary feedwater, accumulator injection, reactor coolant pump trip, low pressure injection, main steam, steam dump and safety valves on main steam.

Regulation for pressurizer power is used only for achieving steady state. After the simulation start the pressurizer heaters are switched off. Core power regulation enables to simulate decay heat according to the table that was obtained during experiment [2], [3], [4].

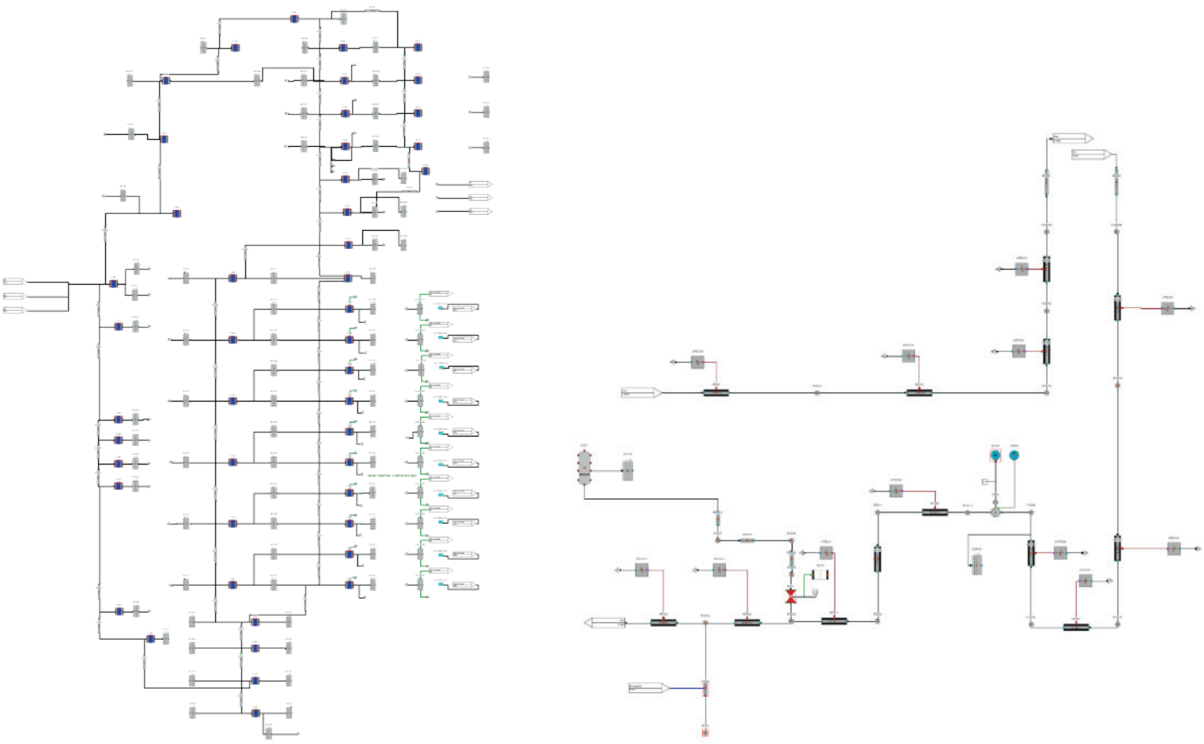

Figure 1: Reactor pressure vessel (left); Cooling loop 2 (right)

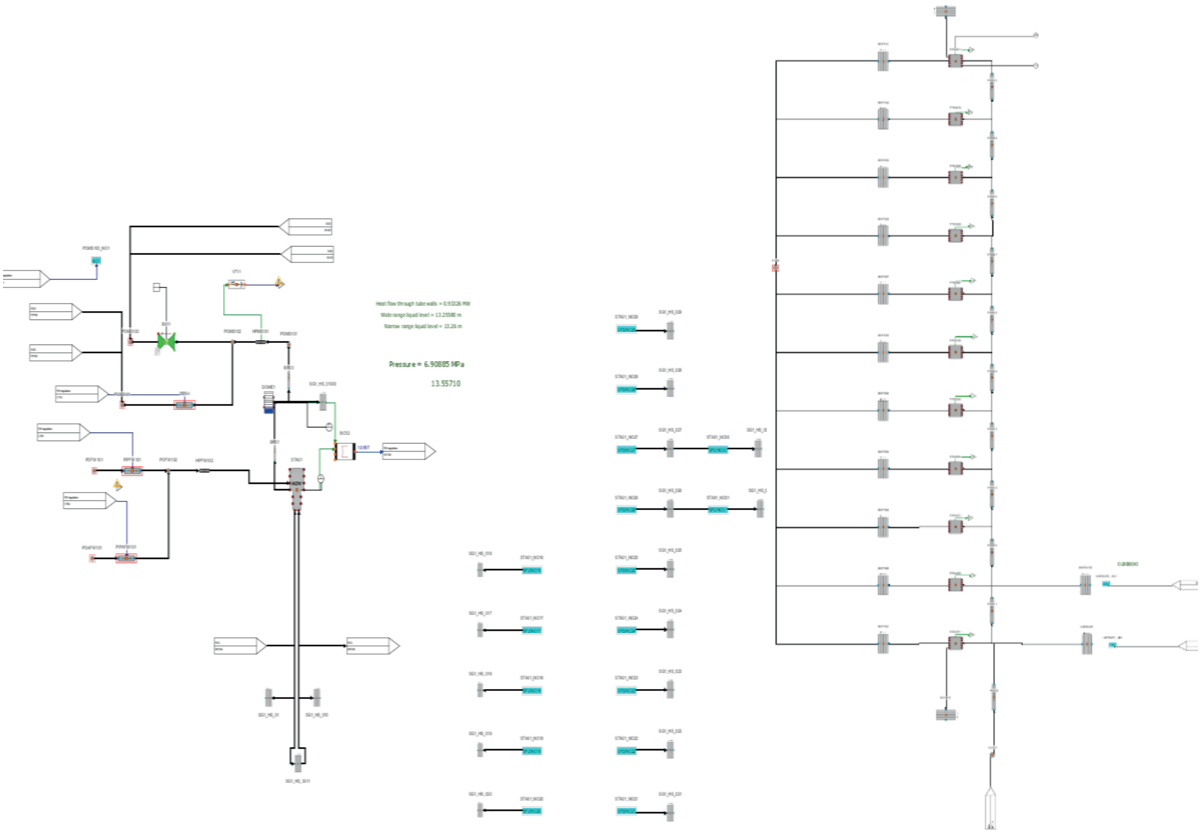

Figure 2: Steam generator with main steam, Feedwater and Auxiliary feedwater system (left); Pressurizer (right)

The verification of APROS model was made on heights, volumes and mass of heat structures.

4 BETHSY 9.1B TEST DESCRIPTION

Test 9.l b is categorized as multiple failure transient (Beyond Design Basis Accident), and is involved in Accident Management studies. According to newer (IAEA, EUR) terminology the transient is categorized as Design Extension Condition A – complex sequence without core damage. The test begins with a 2 inch cold leg break, while high pressure safety injection system (HPIS) is assumed to be unavailable. This leads to a large core uncovery and fuel heat-up, requiring the implementation of an Ultimate Procedure.

In the 9.1b scenario, the start of the procedure is delayed. When the maximum heater rod cladding temperature reaches 723 K (trigger criterion), the 3 steam generator steam dumps to atmosphere are fully opened (condenser is unavailable). This cause the depressurization of the primary coolant circuit, up to the accumulator injection threshold, then to LPIS actuation. The test ends as soon as a safe state of the primary coolant circuit is recovered, i.e. when the conditions required for the actuation of the Residual Heat Removal System (RHRS) are obtained [1].

Electrical trace heating in experiment, located on almost every component and piping of the primary coolant system is provided until accumulator injection starts. In model trace heating is considered in the way heat transfer to the environment starts after injection (before there is no heat transfer to the environment).[2]

5 COMPARISON OF RESULTS

The model was first brought to steady state in APROS 6.05 and was in good agreement with the experimental data. When imported in APROS 6.06 the model did not show any deviation from the previous version.

The simulation results of both version of APROS were in a good agreement with the experimental data. Comparison of timing of major events is shown in Table 1. Processes such as loop seal clearing, core uncover and rise of cladding temperature, which are taking place in the experiment can also be seen in both simulations. However a minor deviations of results from experimental data can be seen in both cases (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8). The simulation results are almost identical to the time of maximum core clad heatup (Figure 5) and minimum primary mass inventory (Figure 8). After the behaviour is a bit different.

Table 1: Table of events

Events	Time		
	Experiment	APROS 6.05	APROS 6.06
Transient initiation : Break opening	0 s	0 s	0 s
* P+P = 13.1 MPa : Scram Signal (AU)	41 s	32 s	32 s
Pressurizer is empty	50 s	82 s	82 s
* P+P = 11.9 MPa : Safety Injection Signal (IS)	54 s	62 s	62 s
Main feedwater off, turbine bypass	59 s	67 s	67 s
Core power decay starts (17 s after AU signal)	58 s	49 s	49 s
Auxiliary feedwater on (30 s after IS signal)	82 s	92 s	92 s
Pump coastdown starts 300 s after IS signal	356 s	362 s	362 s
Start of the first core level depletion	1830 s	1800 s	1800 s

First loop seal clearing in loop 2	1944 s	1874 s	1874 s
Start of the second core uncovery	2180 s	1968	1964 s
• Ultimate procedure initiation by	2562 s	2453	2453 s
atmospheric steam dump opening (3 SG)	2567 s	2458 s	2458 s
Loop seal reformation in loop 2	2750 s	2510 s	2510 s
• P+P = 4.2 MPa : Accumulator injection starts	2962 s	2890 s	2894 s
Primary mass inventory is minimum	2970 s (400 kg)	2890 s (465 kg)	2890 s (465 kg)
Second loop seal clearing in loop 2	3040 s	3036 s	3041 s
Maximum core clad heatup	3053 s (995 K)	3013 s (1031 K)	3027 s (1038 K)
Loop seal reformation in loop 2	3680 s	3593 s	3605 s
• P+P = 1.5 MPa : Accumulator isolation	3831 s	3817 s	3849 s
* P+P = 0.91 MPa : LPIS starts	5177 S	5209 s	5357 s
* End of the test (RBRS stable operating condition)	8200 s	8537 s	8566 s

The pressurizer pressure is almost identical with both versions of results. As it can be seen from Figure 3 the simulation results are in good agreement with the experiment. Only the pressure drop between time 500 s and 1100 is not big enough.

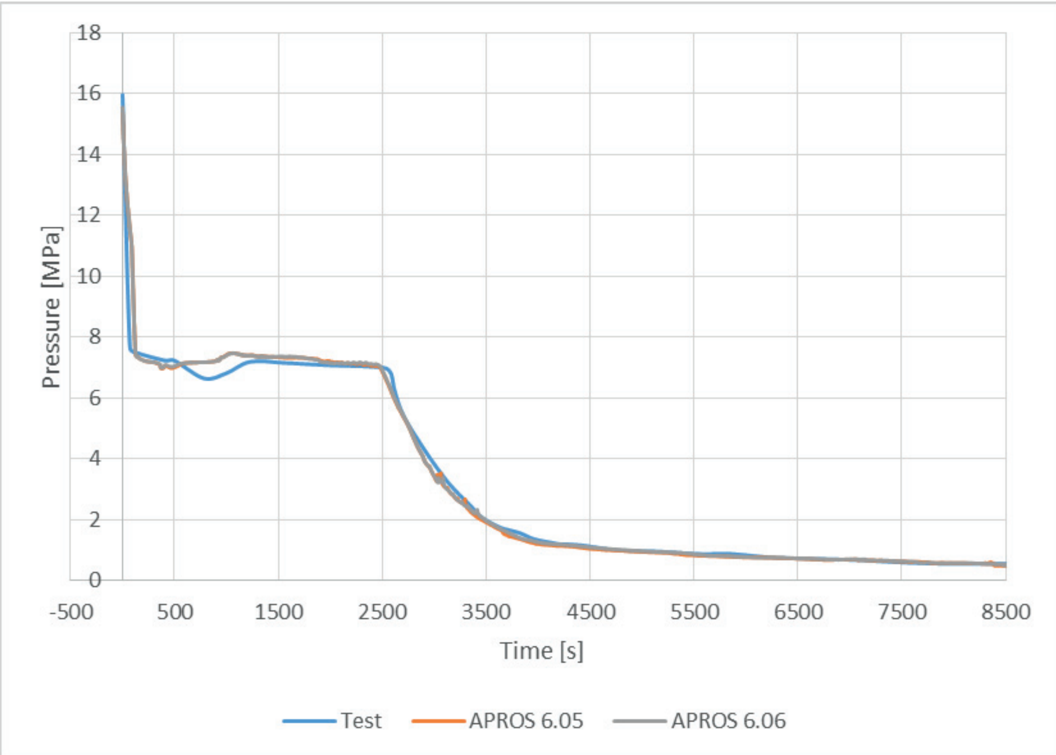

Figure 3: Pressurizer pressure

The minimal core liquid level and the maximum cladding temperature of core is higher in both versions of APROS compared to experiment (Figure 4, Figure 5). The difference between APROS 6.05 and 6.06 core liquid level can be seen between 3000 s and 3500 s. Higher core liquid level in APROS 6.05 results in faster cooldown of the maximum cladding temperature (Figure 5) and better alignment with experiment. The temperature rise of the core cladding begins earlier in both simulation cases (Figure 5).

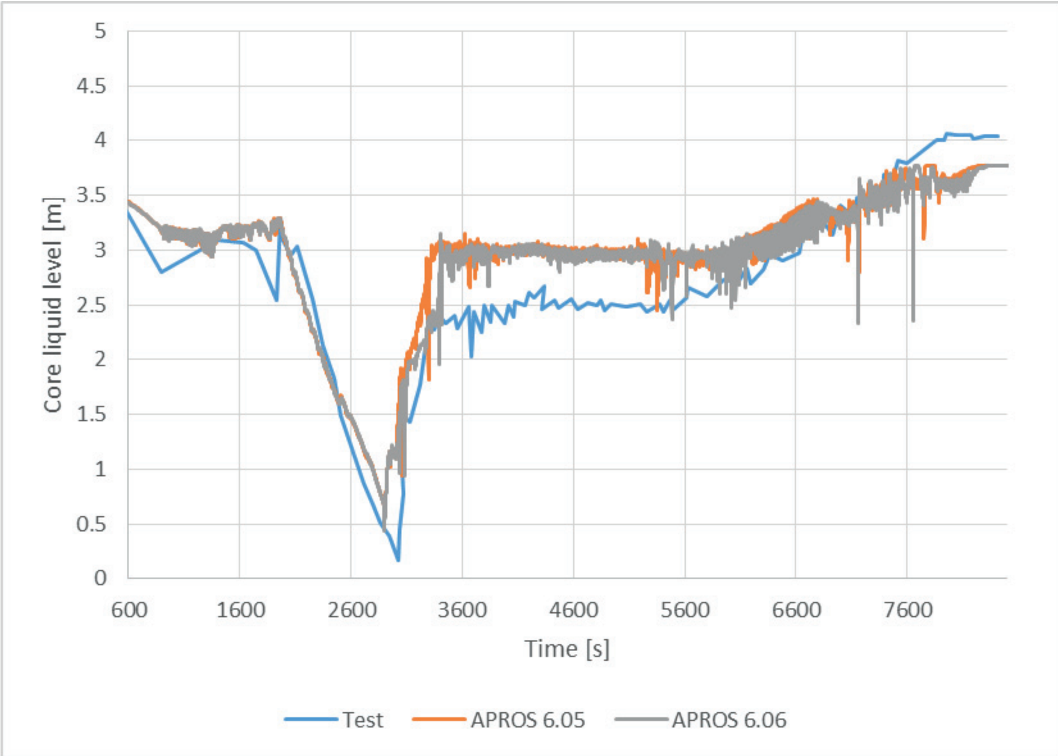

Figure 4: Core liquid level

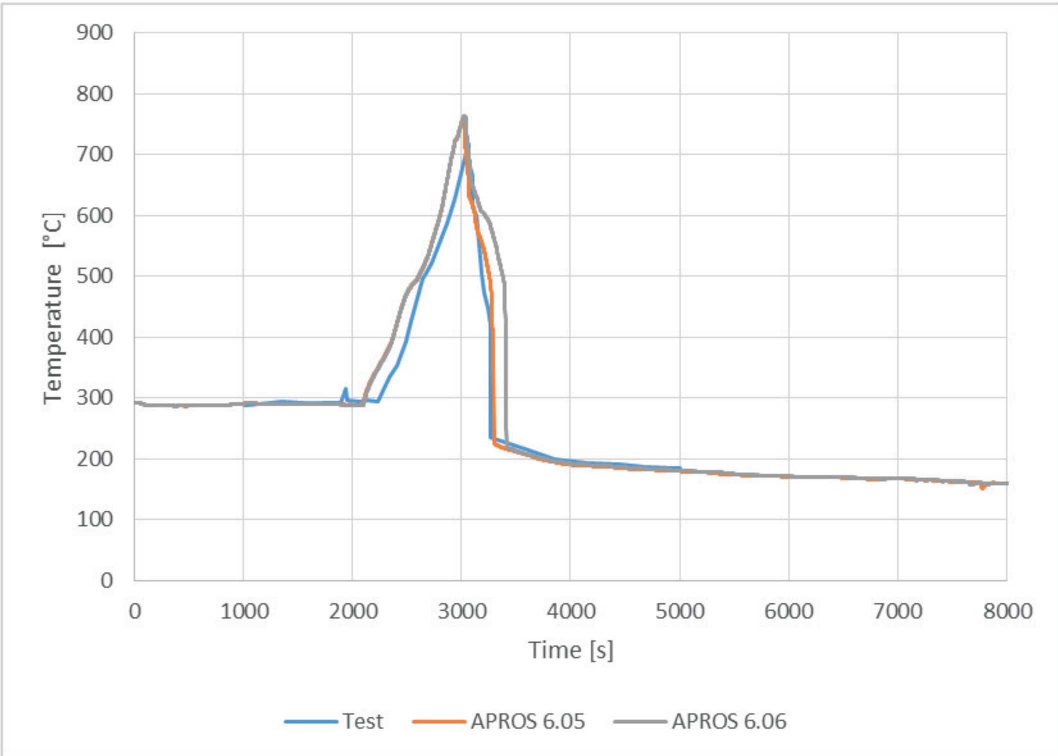

Figure 5: Maximum cladding temperature

The integral break flow in APROS 6.05 is in very good agreement with the experiment up to time 3300 s and is also identical to APROS 6.06 results (Figure 6). From this point the flow in AROS 6.05 is higher but becomes almost identical to test results at the end of the experiment. Integral break flow in APROS 6.06 is in very good agreement with the experiment up to time 5400 s, but after it is too small compared to the test.

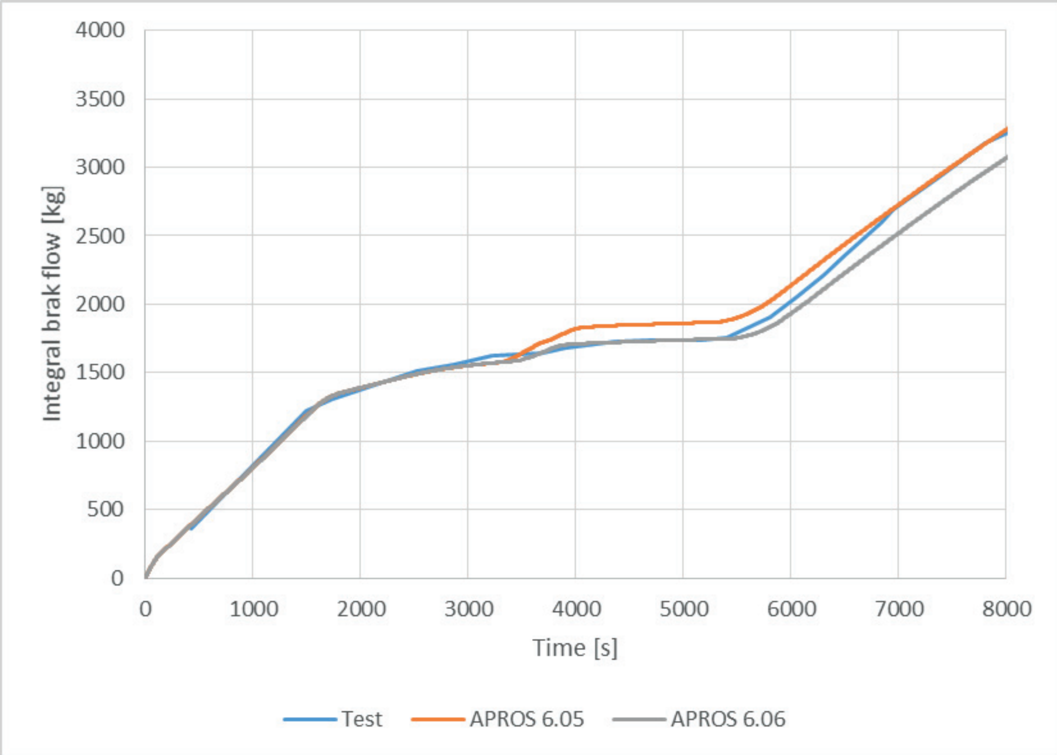

Figure 6: Integral break flow

The Simulation results for the steam generator 2 mass of both APROS versions are almost the same (Figure 7). However there is a difference compared to the experiment in steam generator mass inventory in time between 500 s and 3000 s. This is the consequence of limitation of advance steam generator module, which has a displacement of volumes above riser in regard to experiment steam generator.

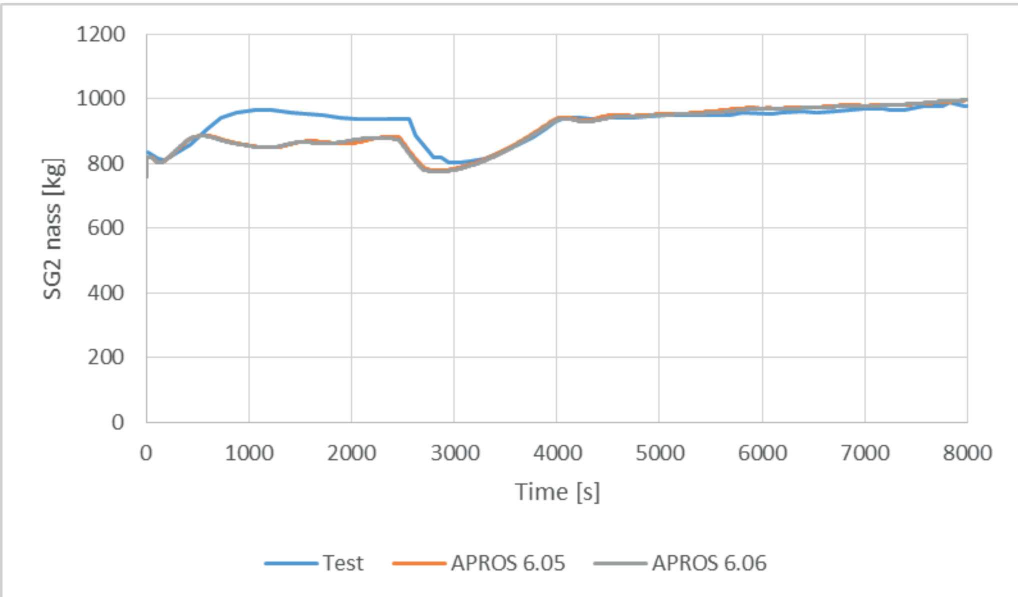

Figure 7: Steam generator 2 mass

The biggest deviation in the primary mass inventory can be observed in APROS 6.05 results between time 3600 s and 4100 s (Figure 8).

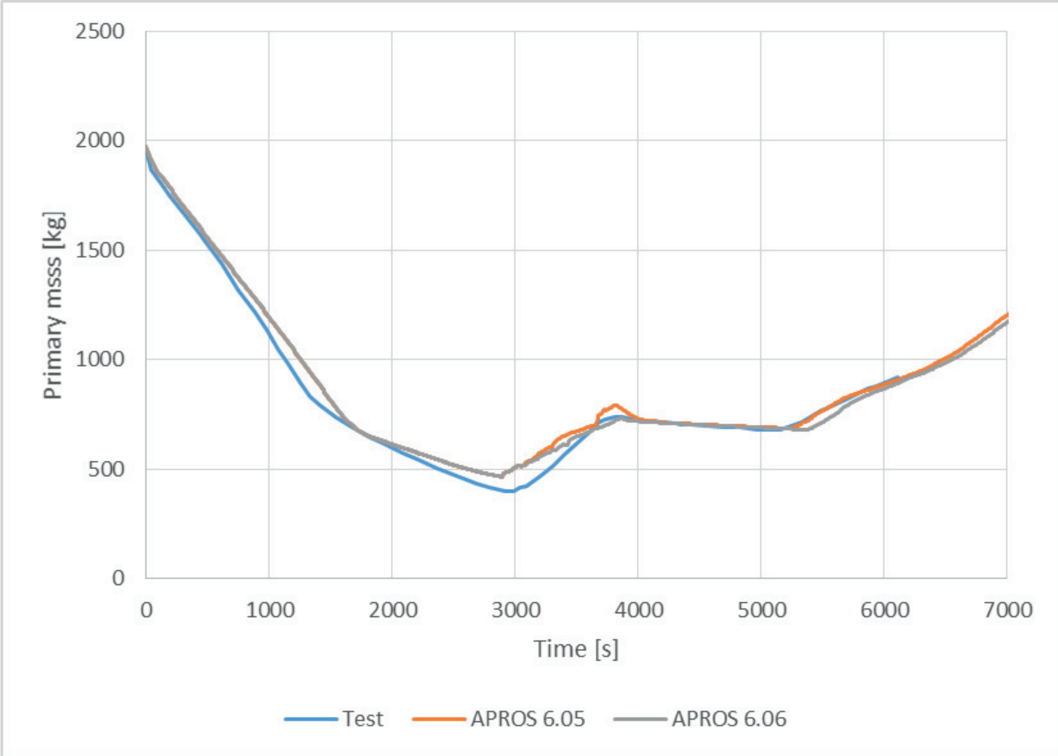

Figure 8: Primary mass inventory

6 CONCLUSION

In this paper, the comparison of analysis of international standardized problem ISP 27 using two versions of APROS process simulation software 6.05 and 6.06 is presented. Numerical simulation of experiment Bethsy 9.1b, also known as ISP 27 was performed on a scaled down model of a three loop, 900 MWe Framatome PWR. Model was first built in APROS 6.05 using standard modules in order to describe the volumes, heat structures and regulation of the test facility and was then exported to APROS 6.06.

The results from both versions showed all the processes such as loop seal clearing, core uncover and rise of cladding temperature and other processes taking place in the experiment were in a good agreement with experimental data. The simulation results were very similar to the point of maximal cladding temperature. After some differences were observed. When comparing the APROS 6.05 results to the APROS 6.06 results, it is not obvious which is in better alignment with the experiment. In some cases one is better in others the other one, however both are in relative good agreement with the experiment and can be used for simulations of such scenarios in nuclear power plants

REFERENCES

[1] CEA, "BETHSY, General Description," Note SETh/LES/90-97, CEA (Commissariat `a l'´energie atomique et aux ´energies alternatives), Grenoble, France, April 1990

[2] Klemen Debelak, Luka Štrubelj, Modeling of Loss of Coolant Accident on Bethsy Facility with Apros Software, NENE 2017 – 26th International Conference Nuclear Energy for New Europe, 2017

[3] NEA/OECD, CSNI0076 BETHSY/6.9C., WWW: http://www.oecd-nea.org/tools/abstract/detail/csni0076/, Accessed on 2.2.2016.

[4] APROS 6 Nuclear documentation, VTT and Fortum, 2015