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PERSEO No.7 Part-1 Benchmark Calculation using SPACE Code

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1. Introduction

In the framework of the OECD/NEA/CSNI/WGAMA group, a new activity on the “Status report on thermal-hydraulic passive systems design and safety assessment” has been started. ENEA has hosted the benchmark problem of PERSEO (in-Pool Energy Removal System for Emergency Operation) [1]. The SPACE code team in KAERI has joined this benchmark program to validate the SPACE code for the passive pool-type heat removal system. In this study, preliminary calculation results will be discussed.

2. PERSEO Test

The PERSEO facility is built at SIET laboratory by modifying the existing PANTHERS IC-PCC facility, utilized in the past for testing a full-scale module of the GE-SBWT in-pool heat exchanger [2]. The main purpose of the PERSEO is the assessment of the performance and efficiency of a new in-pool heat exchanger for decay heat removal, implementing natural circulation.

2.1 PERSEO Facility

Main components of the PERSEO are pressure vessel (PV), heat exchanger (HX), heat exchanger pool (HXP), overall pool (OP), line connecting the OP and the HXP with the triggering valve, steam duct connecting the two pools, steam line from the PV to the HX upper header, and condensate line from the HX lower header to PV, as shown in Fig.1. Table I shows design specification of major components in the PERSEO [3].

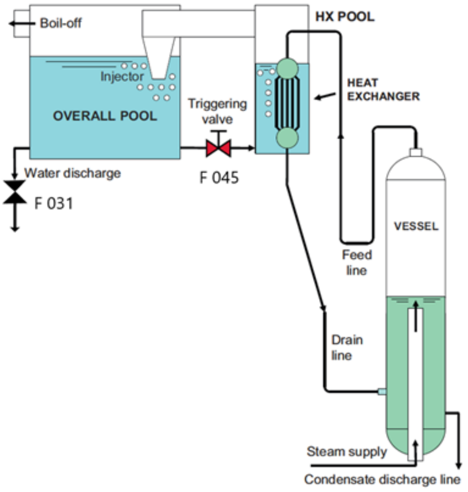

Fig. 1. Schematic of the PERSEO Facility

Table I: PERSEO Geometrical Information

Component	Volume[m^3]	Height [m]	Remark
PV	43	13	-
HXP	29	5.7	-
OP	173	5.8	-
HX[1]		1.8	120 tubes

[1]outer diameter = 50.8 mm, thickness = 2.3 mm

The test is initiated with opening of the triggering valve. Then, HXP is flooded by cold water. The primary side steam condensation in the HX occurs soon after the HXP flooding and heat is transferred from the primary-side to the pool-side. The steam produced in the HXP is driven to the OP through the steam duct and the injector contributes to mix the OP water and avoid a temperature stratification. When the OP water reaches the saturation temperature, the produced steam flows outside through the boil-off pipe. When the OP water level decrease and the injector is uncovered, no mixing effect is present anymore and the water reserve decreases according to the heat transfer rate in the HXP.

2.2 Test No.7 Description

The PERSEO test No. 7 is chosen for the benchmark problem [1]. It is a full pressure (7 MPa) test that investigates both the system stability and the long-term cooling capability. The test is divided into two part:

- Part-1: stability test to verify the behavior of the system with two different water level. Water level increase at 1.4 m and 3.5 m in the HXP.
- Part-2: test to verify the long term cooling of the system. In this part, the water level reduction in the pool is accelerated by opening a dedicated valve to drain water from the OP.

In this study, SPACE validation focused on the Part-1. Table II shows main thermal-hydraulic aspect related. Initially, during the Part-1, the HXP and OP are filled with air. At the beginning of test, the triggering valve begins to be opened two times. This period represents the first phase of water injection. The flow rate from the OP to the HXP is increased, thus, the HXP water level increased and the OP water level decreased. At this time, the maximum water level reached to about 1.4 m. Therefore, the heat transfer from the primary to the pool side slightly increase by around 3.5 MW. In the steam

Table II: Major TH Aspect during PERSEO No.7 Part-1

Thermal-hydraulic Aspect	Time [sec]	Quantity
1st triggering valve opening and closure	475 - 608	
2nd triggering valve opening and closure	621 - 655	
1st maximum level in the HXP	683	1.41 m
Small heat removal	600 – 1000	3.5 MW
Slow water consumption in the HXP	1049	1.41 m - 1.4 m
Instabilities for steam condensation in the injector	930 – 1290	Negative pressure of HXP
3rd triggering valve opening and closure	1039 - 1260	
2nd maximum level in the HXP	1050	3.4 m
Maximum heat transfer rate	1260 - 1845	21.5 MW
HXP minimum level	4800	1.25 m
OP temperature	3000	55 °C

duct, an interface between cold water and steam is present, and strong condensation shocks take place.

The second phase of water injection occurs at 1039 sec. At time 1050 sec, HXP level reaches the maximum value of 3.4 m. And, the fluid temperature in the HXP decrease rapidly due to the cold water covering of the HXP. In this period, the heat transfer through the HX is heavily increased to the maximum of 21.5 MW, since the tubes in the HX is fully covered by higher HXP water level. When the maximum level of the HXP is reached, the quasi-steady operation of the system begins. In this case, the triggering valve is closed during the quasi-steady operation, thus the maximum heat removal is maintained for around 600 secs. The maximum steam flow rate condensed in the HX is about 13 kg/s.

After 1845 sec, owing to the boil-off, the HXP water level is reduced, and the HX is uncovered. Therefore, the heat removal rate in the HX is gradually reduced. With the same reason, the steam and condensate flow rate are reduced. The OP level is increased due to the condensation of steam from the HXP. In addition, the thermal stratification in the OP starting from 2500 sec when the steam flow rate from the injector is no longer sufficient to promote mixing.

3. SPACE Benchmark Calculation

3.1 Modeling and Nodalization

Fig. 2 shows the PERSEO nodalization for SPACE code. To consider a recirculation in the pools, the pools are modeled with two PIPE components with cross-junction connections. To maintain the water level in the PV, the water supplier (151) is controlled. Steam boundary condition (150) is modeled with saturated steam of transient pressure. The HX tube-side and heat structure are modeled with averaged single tube for 120 tubes. The triggering valve is modeled with the control valve and the valve opening area is adjusted according to the measured flow rates. The tube and shell-side of the HX are modeled with 17 axial nodes. The heat structure are modeled with appropriate heat transfer area, which is adjusted corresponding to the measured heat transfer rate during the quasi-steady state condition. The HXP pressure is controlled with constant pressure boundary (515) during the initial steady-state. The OP are modeled with two-parts consisted of 24 axial nodes. The top of the

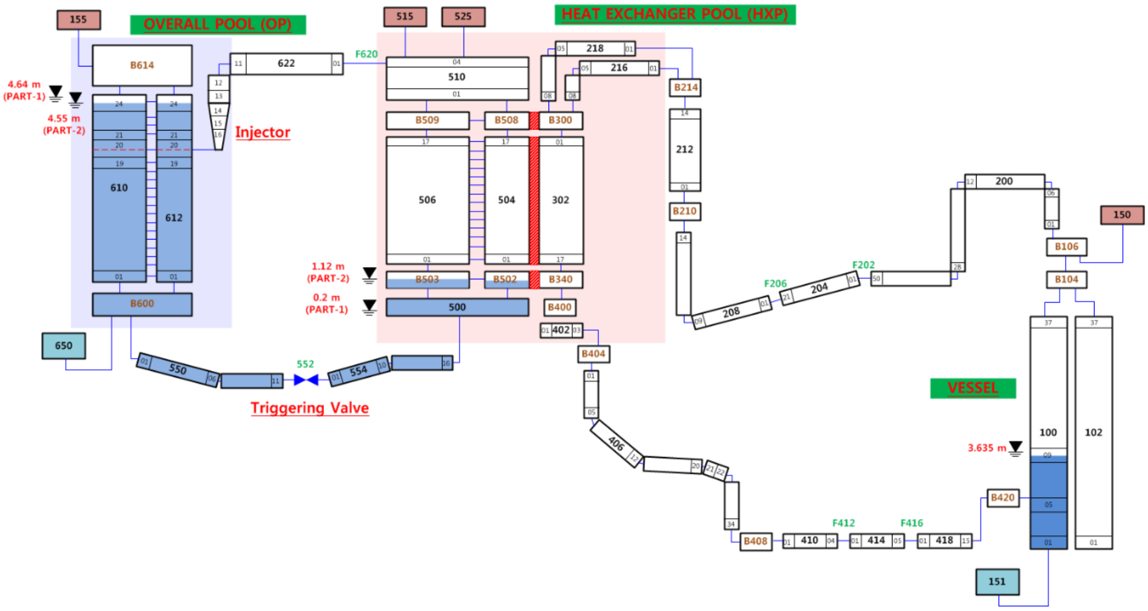

Fig. 2. PERSEO Nodalization for SPACE

OP is connected to pressure boundary (155) for the boil-off. The connection between the injector and the OP is modeled with cross-direction for the calculation to avoid some instability.

3.2 Initial and Boundary Conditions

The initial and boundary conditions for PERSEO No.7 Part-1 are summarized in Table III. Before initiating the transient, the null transient for 475 secs is calculated to make sure the steady state like to the experiment. Initially controlled HXP pressure is deactivated during the transient.

Table III: Initial and Boundary Conditions for PERSEO No. 7 Part-1

Parameter	Quantities	Remark
Initial conditions		
PV pressure	7.02 MPa	Saturated
HXP pressure	0.105 MPa	Air, water
OP pressure	0.1 MPa	Air, water
PV level	3.635 m	Saturated water
HXP level	0.2 m	~ 80 °C(water) ~200 °C(Air)
OP level	4.64 m	15°C (Air, Water)
Boundary Conditions		
PV pressure	Time dependent	Measured value (saturated)
OP pressure	0.1 MPa	Constant

3.3 Validation Results

The heat transfer for in-tube condensation is multiplied by factor of 3 based on the measured heat transfer rate of 20.0 MW during quasi-steady (Fig.3). Figs. 4~9 show comparisons between experimental data and SPACE results. The flow rates through the triggering valve with three times open and closure are well predicted (Fig.4), which is achieved by adjusting the opening area. Fig. 5 shows the HXP and OP water levels during the test. Except the HXP water level during the long-term reduction, SPACE results shows good prediction. The heat removal rate in the HX follows experimental results, although there are some fluctuations (Fig.6). The maximum heat removal rate are well predicted using the multiplication factor of 3, which means the existing condensation heat transfer is under-estimated.

Fig. 7 and Fig. 8 shows the bottom temperatures of the HXP and OP, respectively. Overall trends are well predicted by SPACE code. The time for the saturation of the water in the HXP and temperature rise of the water in the OP show good prediction. However, the initial temperature in the HXP is over-estimated, which is calculated during the null transient. It can be difficult to match the initial conditions of experiment, since the HXP has strong multi-dimensional behavior. However, the initial temperature in the OP is steady due to no heat transfer at all.

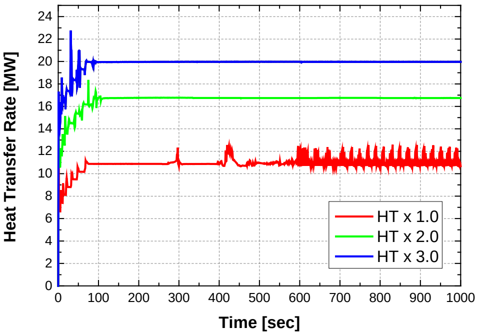

Fig. 3. Heat Transfer Rates in the HX with Different Multiplication Factors (quasi-steady state condition)

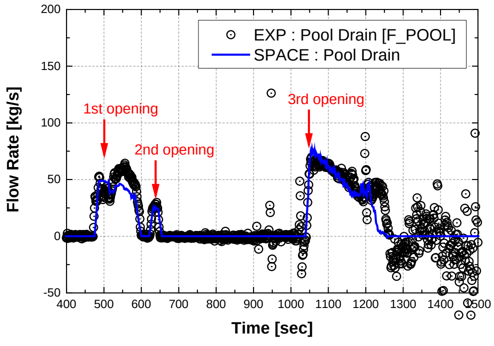

Fig. 4. Flow Rate through the Triggering Valve

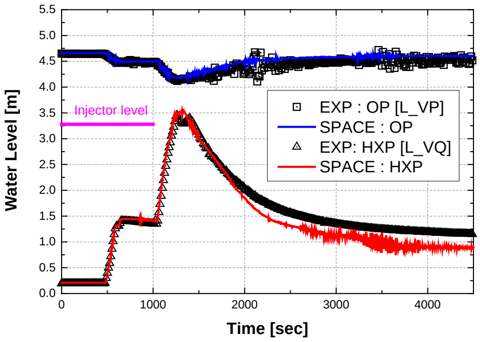

Fig. 5. OP and HXP Water Levels

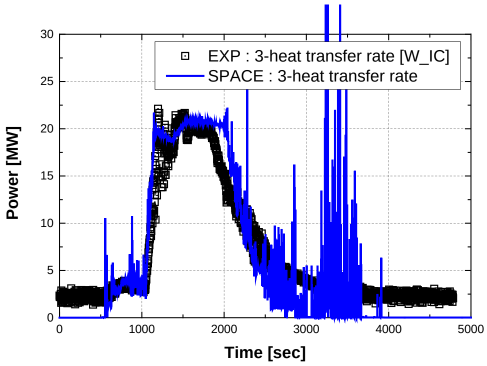

Fig. 6. Heat Transfer Rate through the HX

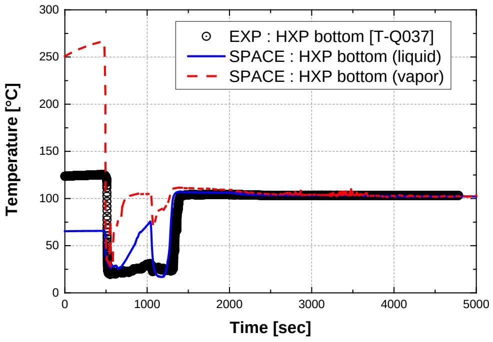

Fig. 7. HXP Bottom Temperature (T-Q037)

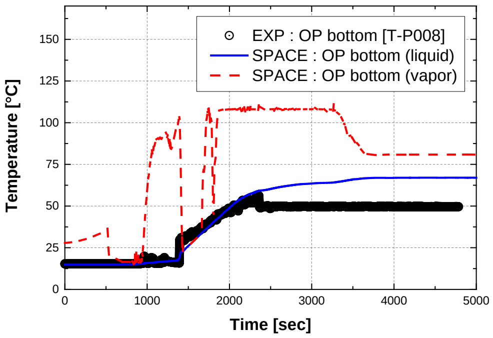

Fig. 8. OP Bottom Temperature (T-P008)

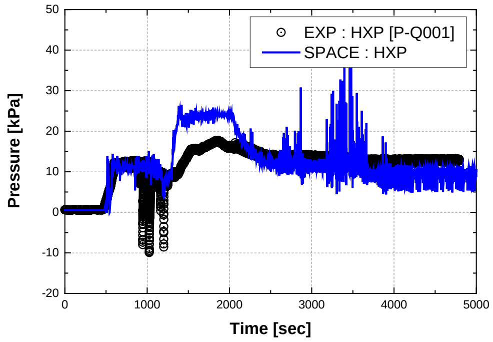

Fig. 9. HXP Top Pressure (P-Q001)

Fig. 9 indicates that the overall pressure in the HXP is also well predicted, except the 3rd triggering valve opening region. In this region, the pressure in the HXP is over-predicted. The overall predictions of the SPACE code are well followed to the experimental results. The major heat transfer phenomena in the PERSEO benchmark test are condensation and natural circulation. When the steam is directly condensed at the interface between the injector and the OP, the calculation process can be unstable. Thus, there are large fluctuations.

4. Summary

In the part of OECD/NEA/CSNI/WGAMA activity, the benchmark problem of the PERSEO test No. 7 Part-1 is calculated by SPACE. The SPACE code shows reasonable results comparing to the experimental results. However, the heat transfer rate in the pool heat exchanger is well predictable with multiplication factor of 3. Therefore, additional work for the heat transfer model for pool type heat exchanger is necessary. In addition, some results show that the SPACE prediction is not well matched or has large fluctuations.

This validation analyses using SPACE are on-going project. The PERSEO No. 7 Part-2 has been preliminarily calculated. Sensitivity analyses with some parameters, such as the heat transfer model, the number of nodes in the pool, the ratio of pool area, have carried out to obtain better prediction.

ACKNOWLEDGMENT

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