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Validation of the Thermal-Hydraulic Model in the SACAP Code with the ISP Tests

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1. Introduction

In the event of severe accident of the nuclear power plant, the containment undergoes continuous changes of the thermal-hydraulic conditions due to increasing steam generated by the fuel decay heat and the non-condensable gases such as hydrogen produced by oxidation of the metallic materials. The pressure, the temperature, the gas composition of the local regions of the containment would have different conditions and tendencies compared with those of other regions. In safety viewpoint, the pressure of the containment is the important parameter, of course, the local hydrogen concentration is also the parameter of the major concern because of its flammability and the risk of the detonation. It is important to predict the thermal-hydraulic behaviors of the containment during a severe accident by a reasonable accuracy for preparation of mitigation strategies and safety features required.

In Korea, there have been an extensive efforts to develop the computer code which can analyze the severe accident behavior of the pressurized water reactor. The development has been done in a modularized manner and SACAP(Severe Accident Containment Analysis Package) code is now under final stage of development. SACAP code adopts LP(Lumped Parameter) model and is applicable to analyze the synthetic behavior of the containment during severe accident occurred by thermal-hydraulic transient, combustible gas burn, direct containment heating by high pressure melt ejection, steam explosion and molten core-concrete interaction.

The analyses of a number of ISP(International Standard Problem) experiments were done as a part of the SACAP code V&V(verification and validation). In this paper, the SACAP analysis results for ISP-35 NUPEC[1] and ISP-47 TOSQAN[2] are presented including comparison with other existing NPP simulation codes.

2. Description of the ISP Tests

2.1 ISP-35 NUPEC

ISP-35 NUPEC M-7-1 hydrogen mix and distribution test was conducted in a ¼ scale experiment facility of PWR large dry containment, the purpose of which is mainly for investigation of the change in hydrogen concentration and thermal-hydraulic condition during severe accident. Fig.1 shows the outline of the NUPEC experiment equipment which is covered with a dome whose diameter is 10.8m, height 17.4m and volume 1310m^3. The vessel has 3 floors inside. Vessel is made by carbon steel that is covered with insulator. Drain tank, located under 1st floor, is to store condensed water and spray water and is separated from other space by insulator.

Test simulates a situation where a break occurs on steam generator, which lead hydrogen and steam release to containment, and comparatively cold water is injected into containment from its top under initial condition of high temperature, high pressure, and high humidity. Fig.2 shows the flow rate of helium, steam, and spray water.

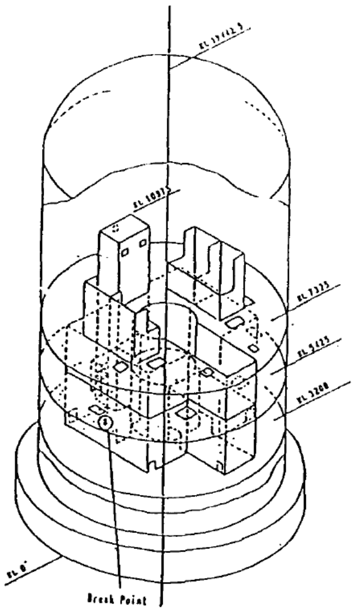

Fig. 1. Containment Vessel of NUPEC[1]

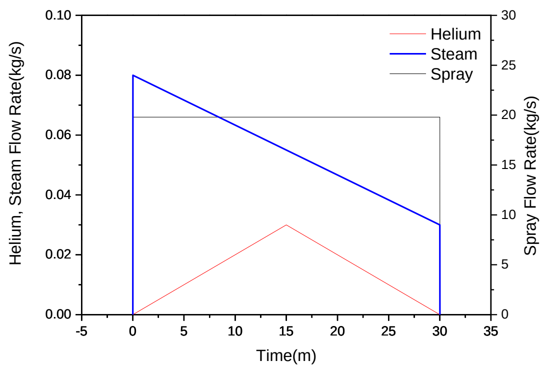

Fig. 2. Gas Flow Rate

2.2 ISP-47 TOSQAN

The main purpose of TOSQAN test is to observe the steady-state when various gases are injected in a series of different gas composition. First, it conducts test for gas mixture of steam and air(Phase A) before testing another gas mixture of air, steam, and helium(Phase B).

Fig. 3 displays TOSQAN experiment equipment that consists of stainless steel cylindrical vessel and sump on its bottom. Total volume including sump is $7m^3$, and temperature of vessel wall is controlled by oil circulating inside. For non-condensation area at top and bottom of vessel, the temperature must be always higher than saturation temperature to avoid condensation. And temperature of condensation area retains lower than that of non-condensation area. Gas is injected into the vessel vertically from the bottom via a tube that is bent 90 degree. All gases such as steam, air, and helium flow through the tube and steam condensate flows into sump.

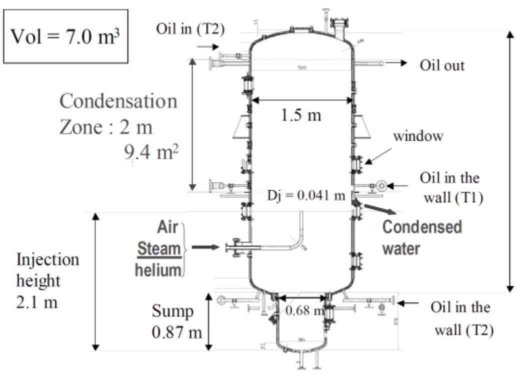

Fig. 3. TOSQAN Geometry[2]

3. SACAP Modeling

3.1 ISP-35 NUPEC

As shown in Fig.4, NUPEC experimental equipment was modeled by using 25 nodes and 66 junctions required for ISP-35 simulation. Initial and boundary conditions are as same as the test. Spray model inside SACAP code was utilized.

3.2 ISP-47 TOSQAN

Fig.5 shows SACAP modeling for ISP-47 TOSQAN experimental equipment. It sets boundary at the end of injection tube of gas mixture of vapor, air and helium. It simulates both cold wall and hot wall conditions by dividing heat conductor into the regions of condensation and non-condensation. To simulate TOSQAN test, 2 nodes are defined as the TOSQAN vessel and the boundary.

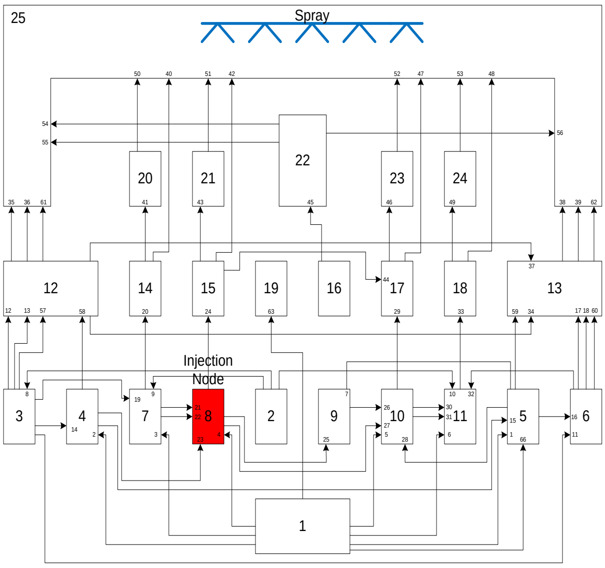

Fig. 4. Modeling of NUPEC facility

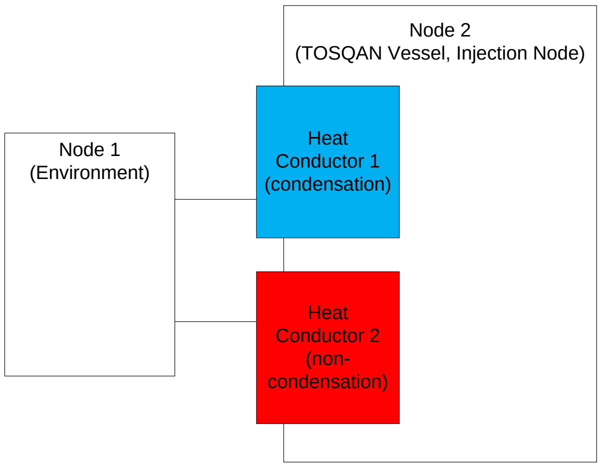

Fig. 5. Modeling of TOSQAN facility

4. Code-Experiment Comparison

4.1 ISP-35 NUPEC

As a part of ISP-35 project, 12 organizations from 10 countries have analyzed NUPEC M-7-1 test using 8 different codes. It observes how the code appropriately simulates a situation that helium injected to node.8 spreads to other nodes. Table I lists up participating organizations and code used for ISP-35 project[1].

Fig. 6 ~ 11 describes the helium concentration in node 8 and node 25 as well as SACAP code calculation result comparison of experiment result and other codes' results of a blind problem[1].

4.2 ISP-47 TOSQAN

In consistency with the experiment result, SACAP calculation result reaches no.4 steady-status under the condition of uniform gas injection. Fig.12 shows pressure change of TOSQAN vessel and comparison of

SACAP result with the experiment result and the other codes' calculation results[3].

Table I: List of Organization and Code

Group	Legend	Code	Organization	Country
1	AEAUK	CONTAIN 1.12	AEA	UK
	JEARI	CONTAIN 1.12	JAERI, MRI	Japan
	JRCEC	CONTAIN 1.12	JRC, Ispra	CEC
	SNLUS	CONTAIN 1.12	USNRC, SNL	USA
2	GRSGE	RAROC	GRS	Germany
	IVOFA	RAROC	IVO	Finland
	PISAI	FUCO	University Pisa	Italy
	PSISW	WAVCO	PSI	Switzerland
3	KEMAN	MAAP 4.0	KEMA	Netherlands
	NNUCK	COMPACT	NNC Ltd.	UK
	TRACT	MELCOR 1.8.2	TRACTEBLE	Belgium
	WESUS	WGOTHIC 1.0	DOE/ Westinghouse	USA

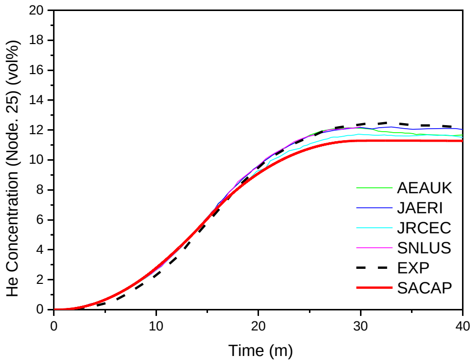

Fig. 6. He Concentration of Node 25(Group 1)

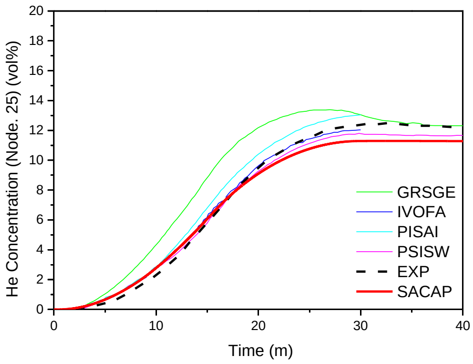

Fig. 7. He Concentration of Node 25(Group 2)

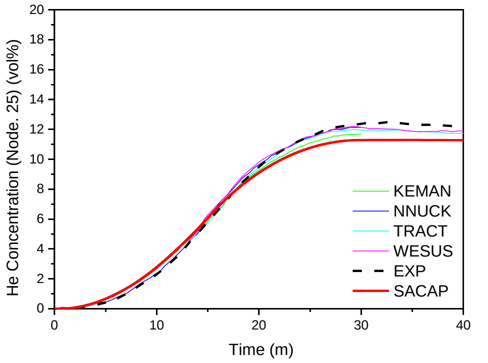

Fig. 8. He Concentration of Node 25(Group 3)

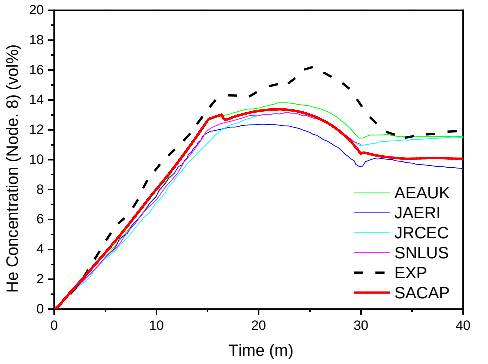

Fig. 9. He Concentration of Node 8(Group 1)

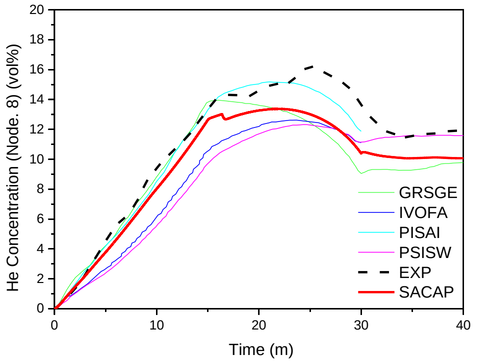

Fig. 10. He Concentration of Node 8(Group 2)

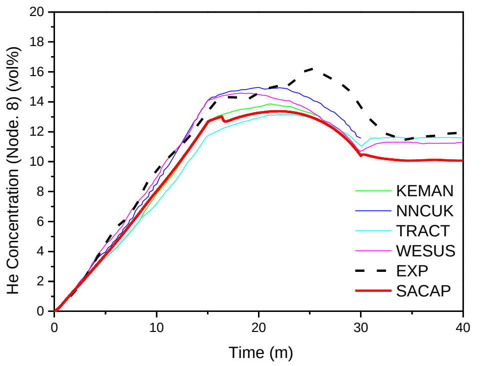

Fig. 11. He Concentration of Node 8(Group 3)

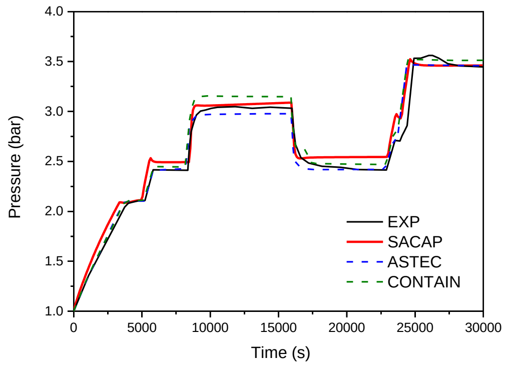

Fig. 12. Experimental and simulated pressure variations

5. Conclusions

In this paper, we selected and analyzed ISP-35 NUPEC, ISP-47 TOSQAN in order to confirm the computational performance of SACAP code currently under development. Now the multi-node analysis for the ISP-47 is under process.

As a result of simulation, SACAP predicts well the thermal-hydraulic variables such as temperature, pressure, etc. Also, we verify that SACAP code is properly equipped to analyze the gas distribution and condensation.

In the future, it is planned to test the prediction capability of SACAP code by analyzing the experiments of hydrogen combustion and other severe accident phenomena.

ACKNOWLEDGEMENT

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