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Preliminary Analysis of Two Phase Natural Circulation in the Cooling Channel of the Core Catcher

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1. Introduction

The ex-vessel core catcher of the PECS (Passive Ex-vessel corium retaining and Cooling System) is installed to retain the corium in the reactor cavity of the EU-APR1400 [1]. When the reactor vessel fails, the reactor cavity is flooded by the gravity driven flow from the IRWST (In-containment Refueling Water Storage Tank) after the molten corium spreads onto the core catcher body during a severe accident. The decay heat and sensible heat of the relocated and spread corium are removed by the natural circulation flow at the bottom and side wall of the core catcher and the top water cooling of the corium combined with the dedicated containment spray system.

The coolant in the inclined channel absorbs the decay heat and sensible heat transferred from the corium through the structure of the core catcher body and flows up to the pool as a two phase mixture. On the other hand, some of the pool water will flow into the inlet of the downcomer piping, and will flow into the inclined cooling channel of the core catcher by gravity. The engineered cooling channel is designed to provide effective long-term cooling and stabilization of the corium mixture in the core catcher body while facilitating steam venting. To maintain the integrity of the ex-vessel core catcher, however, it is necessary that the coolant be circulated at a rate along the inclined cooling channel sufficient to avoid CHF (Critical Heat Flux) on the heating surface of the cooling channel. For this reason, a verification experiment on the cooling capability of the EU-APR1400 core catcher has been performed in the CE (Cooling Experiment)-PECS facility, which is shown in Fig. 1. In this study, preliminary simulations of two phase natural circulation in the CE-PECS have been performed to predict two phase flow characteristics and to determine the natural circulation mass flow rate in the flow channel using the RELAP5/MOD3 computer code [2].

2. RELAP5 Input Model

Fig. 2 shows a RELAP5/MOD3 input model for the two phase natural circulation analysis in the flow channel of the CE-PECS. The coolant supplied by the outer tank (Time Dependent Volume No. 400) circulates from the cooling channel of the CE-PECS (Pipe No. 45, 50, 60, 70, 80, 90, 100, and 110) through the downcomer (Pipe 140, 160). The electrical heater body is simulated by the RELAP5 heat structure. The heater source [1] is simulated as a boundary condition of the heat flux at the left side of heat structure number 100. The generated steam is vented into the atmosphere (Time Dependent Volume No. 310). In all simulations, the initial conditions are assumed to be ambient pressure with no coolant mass flow rate.

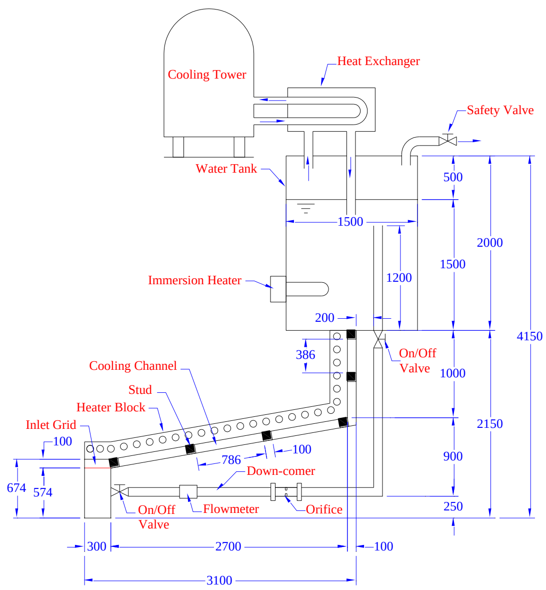

Fig. 1 Schematic of the CE-PECS test facility.

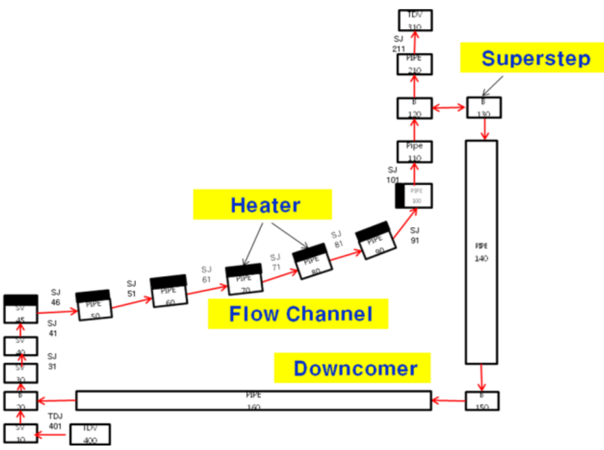

Fig. 2. RELAP5/MOD3 input model for the CE-PECS.

The coolant level of the reactor cavity maintains a constant value by the outer water. The modified design super-step of the coolant inlet in the down comer is simulated by RELAP5 branches with cross-flow junctions, which is shown in Fig.3. From the preliminary test, much steam injected into the downcomer. For this reason, the super-step was designed at the inlet for a prevention of the steam injection into the downcomer in the PECS, because the steam injection leads to flow instability for a reduction of the two phase natural circulation mass flow rate.

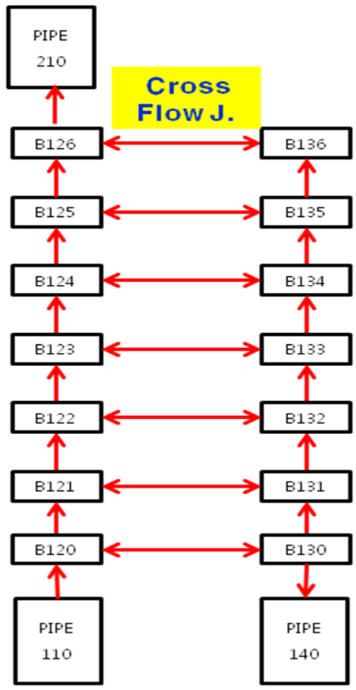

Fig. 3. RELAP5/MOD3 input model for the super-step.

3. Results and Discussion

Fig. 4 shows the RELAP5 results on the water circulation mass flow rate. An oscillatory coolant flow was generated. The RELAP5/MOD3 results have shown that the water circulation mass flow rate is approximately 6.8 kg/s.

Fig. 5 shows the local pressure distribution. A small oscillatory was generated. Fig. 6 shows the local void fraction distribution in the flow channel. An oscillatory coolant flow was generated and the exit void fraction was approximately 0.57.

Figs. 7 and 8 show the local void fraction without and with the super-step in the dowmcomer. In the case without a super-step, the void fraction of the downcomer is 0.3, which means a lot steam is injected into the downcomer. However, there is no void in the case with the super-step.

For this reason, the super-step design is suitable for a downcomer inlet design to prevent steam injection into the downcomer.

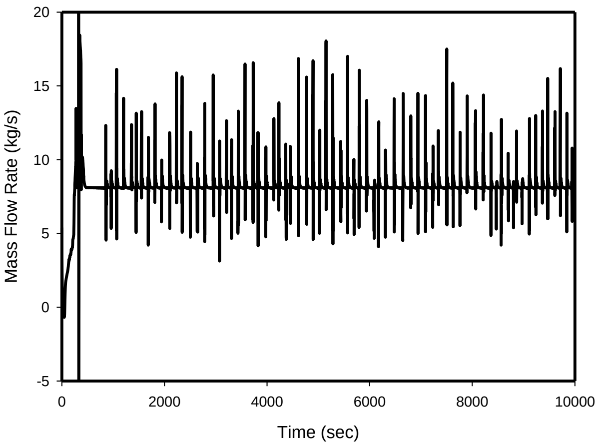

Fig. 4. RELAP5 result of the natural circulation mass flow rate.

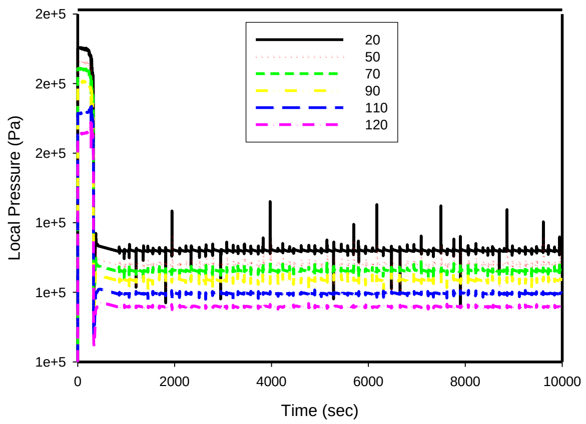

Fig. 5. RELAP5 results on the local pressure in the flow channel.

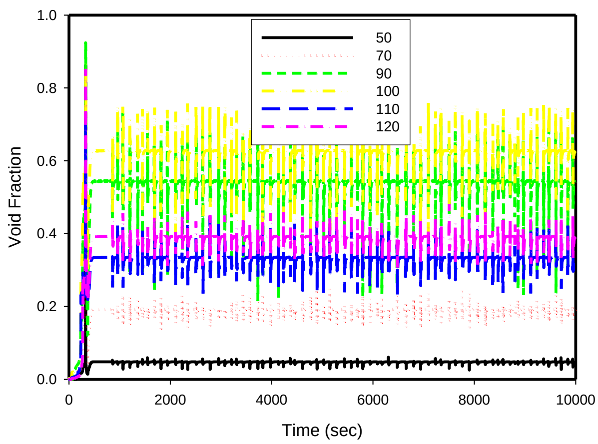

Fig. 6. RELAP5 results on the local void fraction in the flow channel.

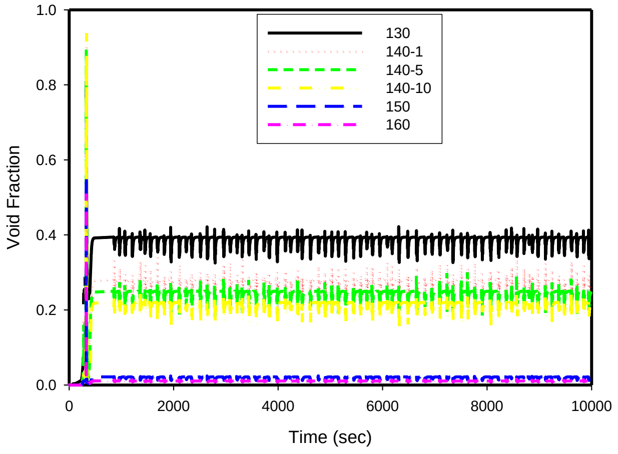

Fig. 7. RELAP5 results on the local void fraction without the super-step in the downcomer.

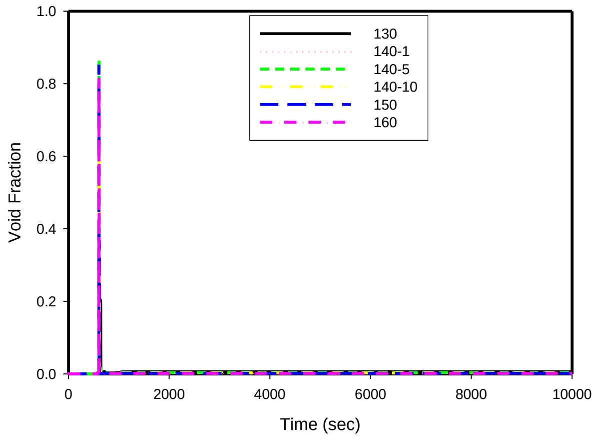

Fig. 8. RELAP5 results on the local void fraction with the super-step in the downcomer.

Table 1 shows the RELAP5 results on the void fraction, liquid velocity, and vapor velocity in the coolant channel. In the cooling channel exit, the liquid and vapor velocities are 0.58 and 4.06, respectively.

Table I: RELAP5 results on the void fraction and coolant velocity in the CE-PECS.

Number	Void Fraction	Liquid Velocity (m/s)	Vapor Velocity (m/s)
50	0.02	0.18	0.72
60	0.06	0.19	1.48
70	0.11	0.2	2.32
80	0.14	0.29	2.95
90	0.42	0.35	2.7
100	0.57	0.58	4.06

4. Conclusion

Preliminary simulations of two phase natural circulation in the CE-PECS were conducted to predict two phase flow characteristics and to determine the natural circulation mass flow rate in the flow channel using the RELAP5/MOD3 computer code. The RELAP5/MOD3 results have shown that the water circulation mass flow rate is approximately 6.8 kg/s. The super-step design is suitable for the downcomer inlet to prevent steam injection into the downcomer. After the CE-PECS, a more detailed analysis is necessary to evaluate the experimental data.

ACKNOWLEDGMENTS

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[2] The RELAP5 Development Team, RELAP5/MOD3 Code Manual, NUREG/CR-5535, INEL95/0174, 1995.