Analysis of Two Phase Natural Circulation Flow in the Cooling Channel of the PECS

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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 on the core catcher body during a severe accident. 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.

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. As shown in Fig. 1, 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 in the PECS. To maintain the integrity of the ex-vessel core catcher, however, it is necessary that the coolant be sufficiently circulated along the inclined cooling channel 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 at KAERI. Preliminary simulations of two-phase natural circulation in the CE-PECS were performed to predict two-phase flow characteristics and to determine the natural circulation mass flow rate in the flow channel [2]. In this study, simulations of two-phase natural circulation in a real core catcher of the PECS have been performed to determine the natural circulation mass flow rate in the flow channel using the RELAP5/MOD3 computer code [3].

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 PECS. One sector (1.3 m x 0.1 m) of the half PECS is simulated in this study. The coolant supplied by the IRWST (Time Dependent Volume No. 400) circulates from the cooling channel of the PECS (Pipe No. 45, 50, 60, 70, 80, 90, 100, and 110) through the downcomer (Pipe 140, 160). The heat flux from the corium to the channel water is simulated using the RELAP5 heat structure. 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.

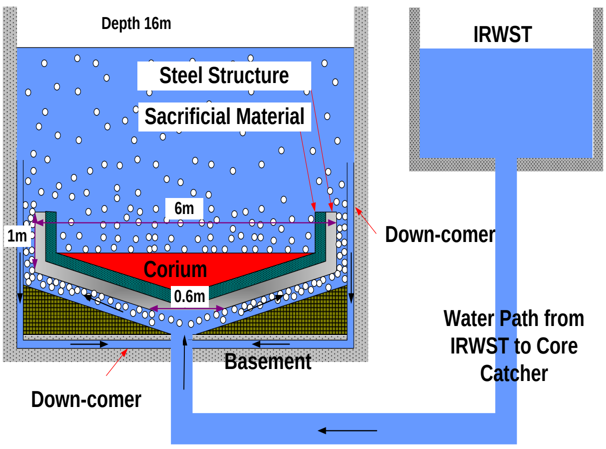

Fig. 1 Schematic diagram of the PECS in the reactor cavity.

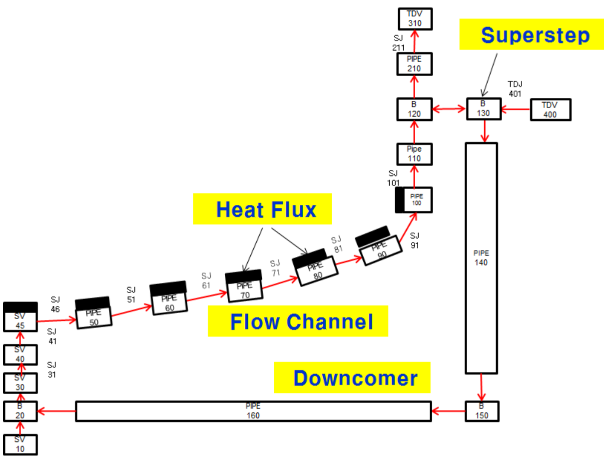

Fig. 2. RELAP5/MOD3 input model for PECS.

The coolant level of the reactor cavity maintains a constant value by the IRWST. The 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. The super-step design is for a prevention of the steam injection into the downcomer in the PECS, because the steam injection leads to the flow instability for a reduction of the two phase natural circulation mass flow rate.

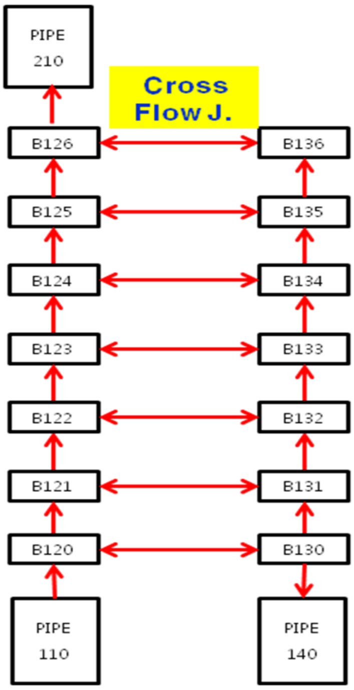

Fig. 3. RELAP5/MOD3 input model for the super-step.

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 40 kg/s (307.7 kg/m^2.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 0.62.

Fig. 7 shows the local void fraction with the super-step in the dowmcomer. As shown in the Fig., there is no void in the case with the super-step. For this reason, the super-step design is suitable design for downcomer inlet to prevent steam injection into the downcomer.

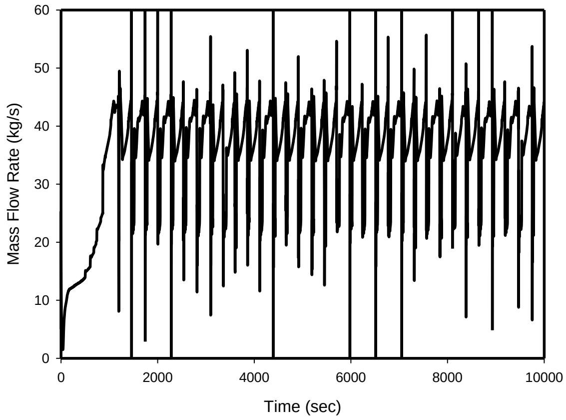

Fig. 4. RELAP5 result of the water circulation mass flow rate.

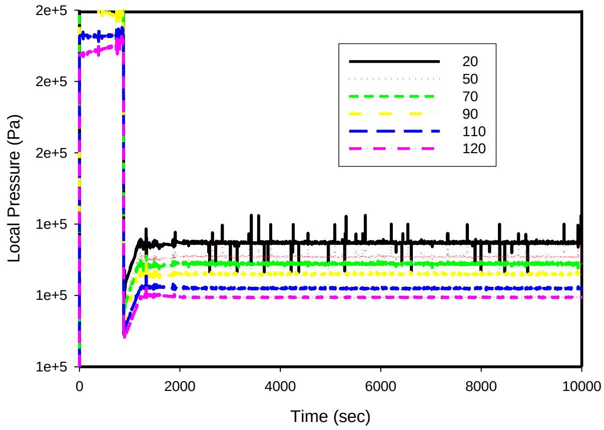

Fig. 5. RELAP5 results on the local pressure in the flow channel.

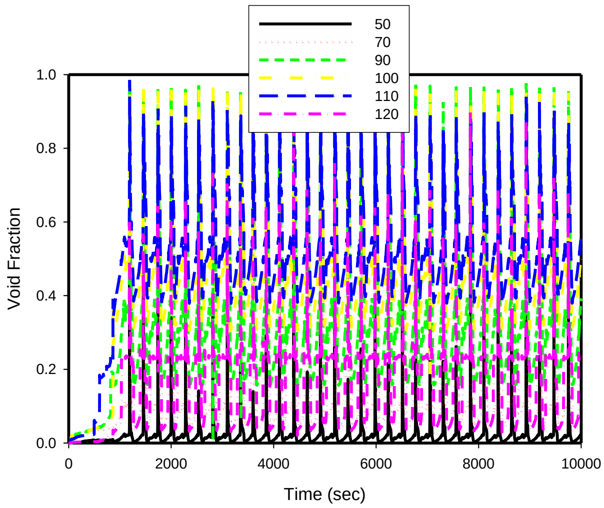

Fig. 6. RELAP5 results on the local void fraction in the flow channel.

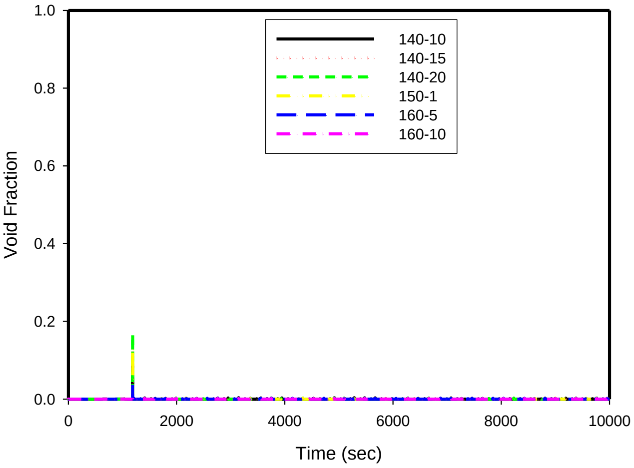

Fig. 7. RELAP5 results on the local void fraction with the super-step in the downcomer.

Fig. 8 shows the RELAP5 results on the water circulation mass flow rate. 100% means the normal heat flux from the corium to the core catcher body. 125% and 75 % mean the increase and decrease of 25 % in the normal condition, respectively. An increase in the heat flux leads to an increase in the water circulation mass flow rate.

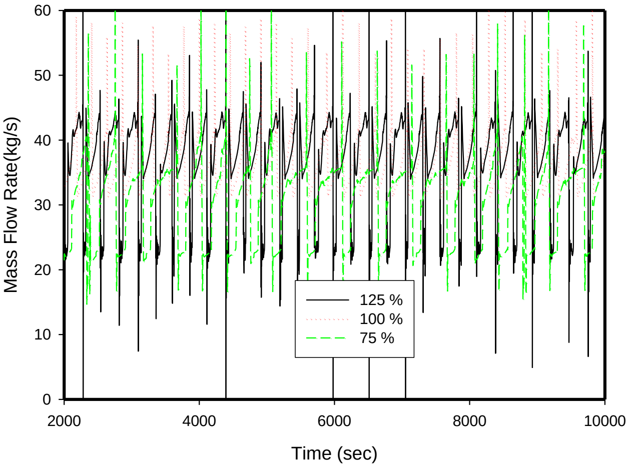

Fig. 8. RELAP5 result of water circulation mass flow rate as a function of power .

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 0.67 and 5.65, respectively.

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

Number	Void Fraction	Liquid Velocity (m/s)	Vapor Velocity (m/s)
50	0.04	0.19	1.34
60	0.1	0.21	2.81
70	0.14	0.22	4.19
80	0.19	0.31	4.98
90	0.53	0.45	3.59
100	0.62	0.67	5.65

4. Conclusion

Simulations of two phase natural circulation in the PECS have been performed to determine the two phase natural circulation mass flow rate in the flow channel using the RELAP5/MOD3 computer code. The water circulation mass flow rate is approximately 307.7 $kg/m^2.s$. The super-step design is suitable for downcomer inlet to prevent steam injection into the downcomer.

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