A CINEMA Code Analysis of the Simplified ERVC Loop in the SMART

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1. Introduction

SMART (System-integrated Modular Advanced ReacTor) [1] is a small-sized integral type PWR containing major components within a single reactor vessel, which adopts a sensible mixture of new innovative design features and proven technologies aimed at achieving highly enhanced safety and improved economics.

To terminate the progression of severe accidents of SMART, IVR-ERVC (In-Vessel corium Retention through External Reactor Vessel Cooling) [2] is adapted to prevent the reactor vessel failure by cooling the external reactor vessel wall using the method to fill the reactor cavity with cooling water from the IRWST (In-containment Refueling Water Storage Tank).

In this study the CINEMA (Code for INtegrated severe accidEnt Management and Analysis) [3] code is used to simulate the cavity flooding, the natural circulation of ERVC loop, steam boiling and venting.

2. Methods and Results

In this section CINEMA code modeling of the simplified ERVC loop, and initial and boundary conditions are described. The simplified ERVC loop includes the IRWST tank, cavity, inner channel, outer channel, and the inter connecting loops between each component.

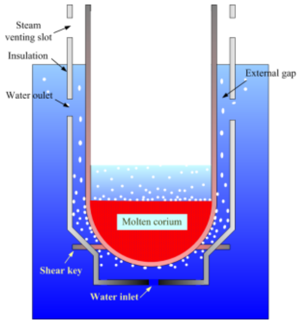
2.1 Analysis Code

The CINEMA code version 3.0 (SVN 193) is used for ERVC simulation.

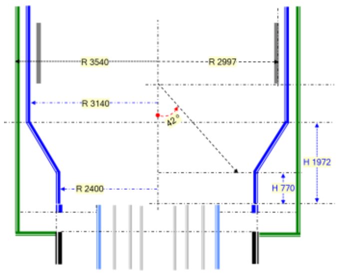
2.2 Input Model

The geometric configuration and size of ERVC loop are reviewed and shown in Figure 1. Since the final design of ERVC loop is not confirmed, some assumptions and boundary conditions are decided for this simulation. The simulation part in the reactor region only includes the inner and outer channels outside the vessel wall. The IRWST tank and injection lines to cavity are also considered.

The flow area of the inner channel is dependent on the space volume between the outside wall of reactor vessel and outer channel. Outer radius of inner channel and inner radius of the outer channel are assumed to be 3340 mm and 3540 mm, respectively. The cylindrical part of outer vessel wall has a radius of 3140 mm. The curvature of half-hemisphere in the part of lower head of reactor vessel has some complicated flow region, so some assumptions to decide the flow volume of ERVC channel are needed as shown in Figure 1 (b).



(a) Conceptual design of ERVC



(b) Geometry of ERVC

Fig. 1. Reference configuration of External Reactor Vessel Cooling System (ERVC) of SMART.

Figure 2 shows the CINEMA nodalization of ERVC loop. This loop includes IRWST, injection pipe, cavity, inner channel, and outer channel. This flow region is divided by pipe components to model each part. The elevation for each part is based on the SMART design data.

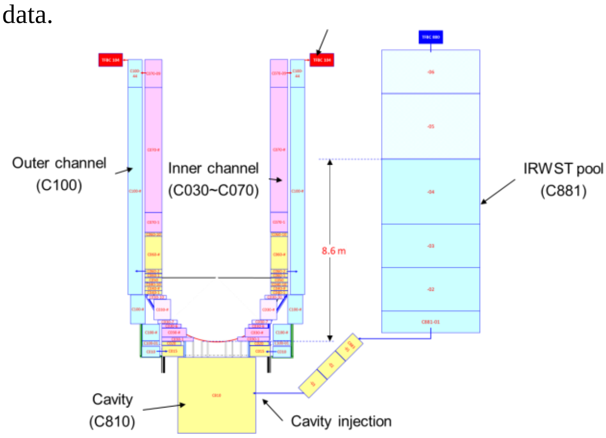


Fig. 2. Nodalization of the ERVC.

Table I shows the initial and boundary conditions used for the hydrodynamic components in Figure 2. The heated wall with heat flux boundary condition is to model the core decay heat. The initial water level of IRWST is assumed to be 8.0 m. The injection pipe from IRWST to cavity inlet is open at 2,000 seconds of simulation time.

Table I: Initial and Boundary Conditions

Location	Parameter	Value
Heated wall	Thermal power	2.82 MW
ERVC channel	Initial inventory	0 (empty)
Outlet	Pressure	1.0 bar
IRWST	Initial level	8.0 m
	Initial head*	8.6 m
	Temperature	50°C
	Pressure	1.55 bar
Cavity	Opening time of injection valve	2,000 sec.

* *From bottom of RPV to top of IRWST water*

2.3 Calculation Results

This section describes the simulation results.

Figure 3 shows injection flow rate to cavity inlet. As injection valve is open at 2,000 seconds, the injection flow starts from 150 kg/sec and it is linearly decreased up to 10,000 seconds when the hydraulic head between IRWST and cavity inlet is balanced. Injection flow becomes nearly stagnant after 10,000 seconds.

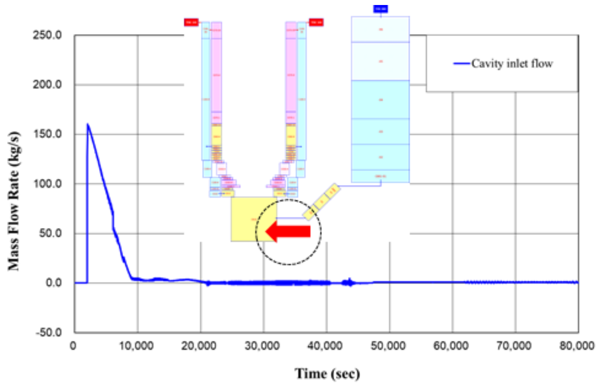


Fig. 3. Cavity injection from IRWST.

IRWST water level is investigated in Figure 4.

Level is rapidly decreased from 2,000 seconds (valve opening time) to 10,000 seconds. Small decrease rate from 50,000 seconds is observed because of flow balance between inlet and outlet flows in the ERVC channel.

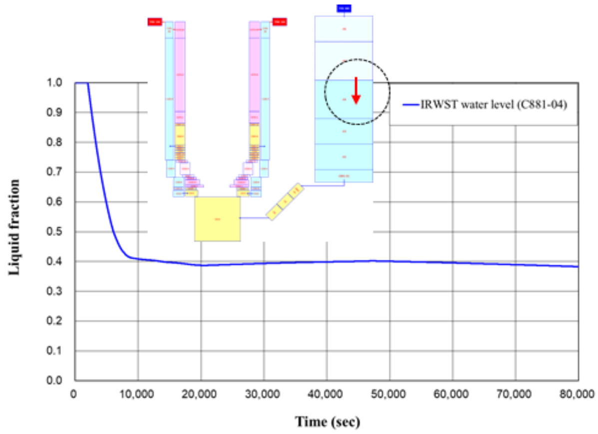


Fig. 4. Time variation of IRWST water level.

Flow circulation between inner and outer channels are shown in Figure 5. As cavity injection flow starts, channel inlet flow and return flow (water outlet flow) are rapidly increased and become stable (~t 600 kg/sec).

Natural circulation is stabilized after saturation condition (~50,000 seconds).

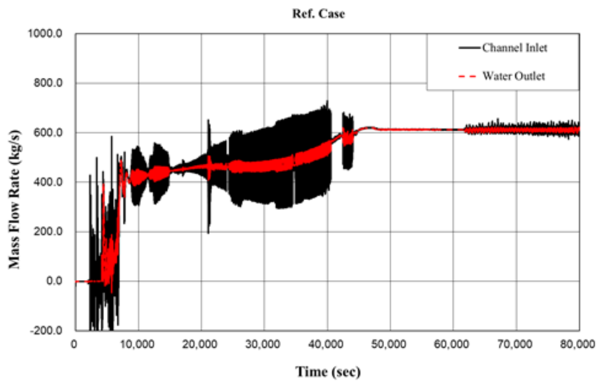


Fig. 5. Time variation of ERVC channel flows.

Steam venting to the containment is compared with cavity inlet flow in Figure 6.

Boiling of ERVC channel produces 1 kg/sec of steam flow rate. Cavity inlet flow rate is little smaller than steam outlet flow rate.

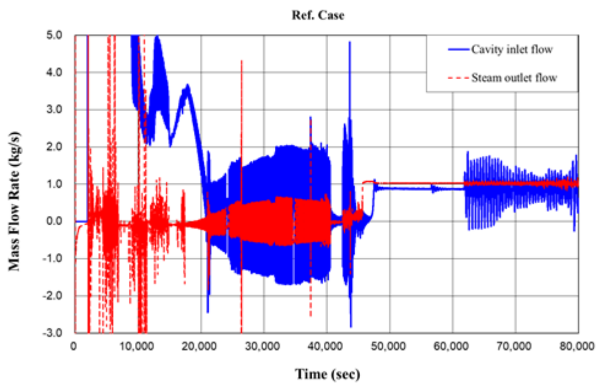


Fig. 6. Comparison of inlet and outlet flows in the ERVC channel.

The difference of flow is nearly constant, so channel level is continuously and linearly decreasing after 50,000 seconds.

Water level in the ERVC channel is shown in Figure 7.

The water level is rapidly increase up to 10,000 sec. (maximum of ~5.8 m)

The level is linearly decreasing after 50,000 sec.

The inventory is continuously lost during the boiling period.

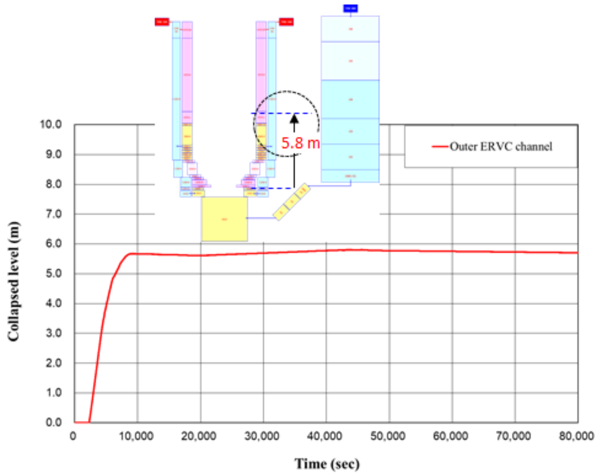


Fig. 7. Comparison of water level in the ERVC channel.

Pressure behaviors in the channel are shown in Figure 8. Pressure rapidly increased and fluctuating during subcooled boiling, and stabilized after saturation boiling.

Pressure difference is mostly by hydraulic head for each elevation.

Steam pressure in the upper part of the channel approaches 1.0 bar (outlet pressure BC).

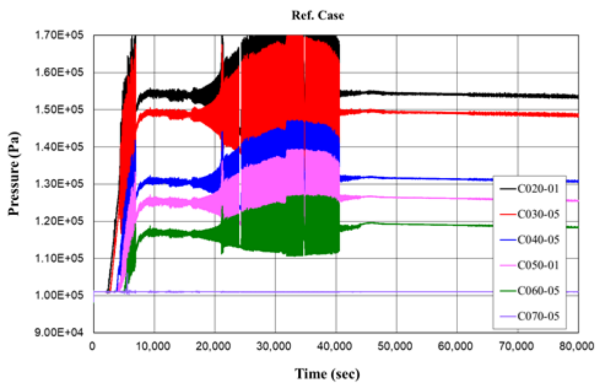


Fig. 8. Time variation of pressure at different elevations of the ERVC channel.

Temperature behaviors in the channel are shown in Figure 9.

Initially subcooled water (323 K) is fulfilled and its temperature is increasing up to saturation temperature.

Saturation conditions reaches at about 50,000 sec where temperature become constant value of saturation temperature.

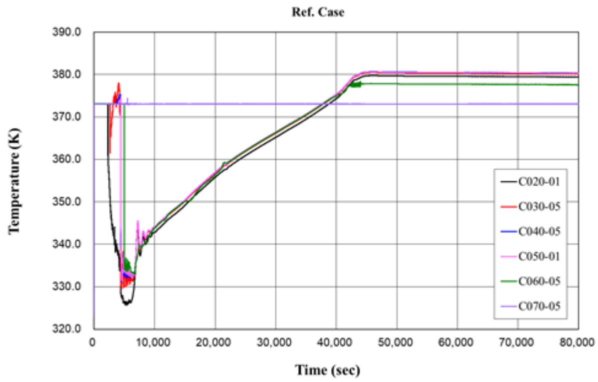


Fig. 9. Time variation of temperature at different elevations of the ERVC channel.

3. Conclusions

Simplified ERVC loop is modeled with assumptions of geometry conditions, IC, and BC from SMART design and severe accident management strategy. The SPACE code (ver. 3.0, SVN 193) is used to simulate the performance of ERVC in the SMART.

The simulation results show the following phenomena:

- Cavity flooding by gravity driven flow from IRWST
- Heat removal by natural circulation in the ERVC channel
- Channel voiding and continuous steam venting to containment

From the present study it is found that

- Thermal-hydraulic flow conditions are stabilized after saturation boiling in the ERVC channel
- Steam release to containment is about 1 kg/sec
- Long term cavity flow is small but sustains the cavity flooding

For future works, the ERVC loop model should be extended to overall plant calculations for inner vessel and containment analysis. SMART-CINEMA version should be established for ERVC modeling. Furthermore, CINEMA-SACAP analysis can be performed for severe accident scenarios of SMART.

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