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Analysis of SBLOCA in SMART-P Using RELAP5/SMR Code

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1. Introduction

SMART-P (System integrated Modular Advanced ReacTor) is an integral reactor being developed with indigenous technology and has many key design features that are highly unconventional in comparison to the commercially operating reactors. Such design features include self-pressurizing pressurizer, helically coiled once-through steam generators, PRHRS (Passive Residual Heat Removal System), power operation under natural circulation, and twisted fuel rods of roughly square cross-section.

Because the safety analysis codes used for the commercially operating domestic nuclear reactors are not capable of describing such design features, these codes can not be applied in simulating SMART-P. Hence, it is essential to develop a regulatory technology specific to SMART-P designs with high degree of reliability in order to be able to verify the safety through audit calculations [1].

The main objectives of this study are to verify the validity of simulation results and to evaluate the adequacy of the system design by developing the SMART-P model and performing thermal-hydraulic analysis of small break LOCA (Loss Of Coolant Accident).

In this study, the new RELAP5/SMR model of SMART-P was developed by considering the changes of the recent design information and SMART-P SAR (Safety Analysis Report) [2]. And the analysis of SBLOCA transients was calculated to support the licensing review in KINS.

2. Methods and Results

2.1 Improvement of Previous SMART-P Model for RELAP5/SMR Code

RELAP5/SMR is a thermal-hydraulic system code for SMART-P developed on the basis of RELAP5/MOD3.3 in such a way to modify inside model for simulating the heat transfer of helical tube steam generators, multi-component two phase critical flow, etc [1, 3]. It was developed to establish the regulatory technology for SMART-P. The previous RELAP5/SMR model of SMART-P was based on the design information in 2002 [3, 4]. But the design of SMART-P had being changed until the publication of SMART-P SAR (2005). So the new RELAP5/SMR model of SMART-P was developed by considering the changes of the recent design information and SMART-P SAR.

The modified or added features are as follows;
- Total volume of primary system
- Number of gas cylinders
- Location of safety injection (SI) pipe and break pipe
- Primary steam generator model
- Refueling water tank (RWT) model
- Characteristics of MCP
- Pressurizer operating temperature
- Long term cooling by sump recirculation

2.2 Thermal-hydraulic Modeling

Fig. 1 shows RELAP5/SMR nodalization of SMART-P. The primary system includes core region, two main coolant pumps (MCPs), three pressurizer cavities (upper annular cavity, intermediate cavity, and end cavity), two gas cylinders, and twelve steam generator cassettes.

The primary steam generator region consists of a bypass region and four heat exchange regions having three steam generator cassettes.

The secondary system and PRHRS are modeled with four independent flow paths. Two RWTs function as water source of SI and heat sink of PRHRS. When the level of RWT decreases to RAS (Recirculation Activation Signal) point, the water source of SI changes from RWT to recirculation sump.

2.3 SBLOCA Transient Analysis

The initial steady-state conditions are well agreed with the design values for 103% power operation condition specified in the SMART-P SAR as shown in Table 1.

The break at SI line was chosen as an event due to the potential for more serious decrease of collapsed water level in reactor vessel than any other events.

It is assumed that the break is initiated at the SI pipe whose inner diameter is 25.4mm. After the break is initiated, the primary system depressurized rapidly due to blow-down of the coolant through break pipe. And the reactor is tripped by the low pressurizer pressure signal. Turbine is tripped with loss of off-site power at 3 sec after reactor trip. Then MCPs begin to coastdown, main feedwater/steam isolation valves begin to be closed, and PRHRS begins to be connected to the secondary system.

MCPs stop causes the rapid decrease of core coolant flow. The feedwater from PRHRS exit region comes into the bottom of steam generator, ascends through the helical tubes, and becomes superheated steam by absorbing the heat of primary system. This superheated steam goes into PRHRS inlet region, loses its energy by heat exchange with RWT, condenses into single phase liquid, and comes into the steam generator heat exchange region. These procedures are repeated and natural circulation flow is established.

When the pressurizer pressure decreases below 9.02MPa, SI is activated with delay time of 30 seconds. In the case of SI pipe break, the single failure is assumed, so only one SI line is activated.

Fig. 2 shows the break discharge flow and SI flow calculated by RELAP5/SMR code and those calculated by licensee's code, TASS/SMR code [2] respectively. In the simulation of RELAP5/SMR, SI from recirculation sump is activated by RAS at about 58366 sec. There are some differences in break discharge flows between RELAP5/SMR and TASS/SMR calculation results. These differences seem to be caused by the differences in governing equations, two-phase model, etc. in both codes.

Fig. 3 shows that TASS/SMR code is more conservative than RELAP5/SMR code from the viewpoint of the minimum collapsed water level. But the recovery time of collapsed water level by RELAP5/SMR (46126 sec) is delayed compared with that by TASS/SMR (4605 sec). And it can be concluded that activation conditions of the shutdown cooling system should consider whether the water level is higher than the suction duct of MCP in addition to the conditions of pressure (2.3MPa) and coolant temperature (200℃).

In conclusion, there were no core uncovery and fuel temperature increase harming the fuel integrity after SI from recirculation sump is activated.

3. Conclusion

The safety analysis of SI pipe break accident was performed using RELAP5/SMR code and compared with the results from TASS/SMR code to support the licensing review in KINS.

The calculation results of RELAP5/SMR code shows that the core is not uncovered even if SBLOCA happens. Also it was verified that there was a nonconservative feature in the prediction of reactor water level by TASS/SMR code.

REFERENCES

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Table 1. Initial steady-state conditions

Main Parameters	100% FP		
	Previous RELAP5/SMR	SMART−P SAR	Modified RELAP5/SMR
Reactor Power [MWt]	65.5	65.5	65.5
Pressurizer Pressure [Mpa]	14.7	14.7	14.9
Steam Common Header Pressure [Mpa]	3.2	-	3.21
RCS Total Flow [kg/sec]	350.0	326.0	326.0
Core Flow [kg/sec]	339.5	316.0	316.0
Core Bypass Flow [kg/sec]	10.5	10.0	10.0
Feedwater Flow [kg/sec]	24.024	24.024	24.024
Core Inlet Temperature [°C]	274.5	272.2	275.155
Core Outlet Temperature [°C]	310.0	310.0	312.576
Secondary SG Inlet Temperature [°C]	50	50.0	50.0
Secondary SG Outlet Temperature [°C]	283.0	281.8	285.242
Pressurizer Temperature [°C]	75.1	50	49.941
Secondary steam superheated temperature [°C]	larger than 40.	larger than 40.	47.547
RCP Speed [rad/sec]	376.99	376.99	376.99
RCP Head [kPa]	-	60.0	61.2

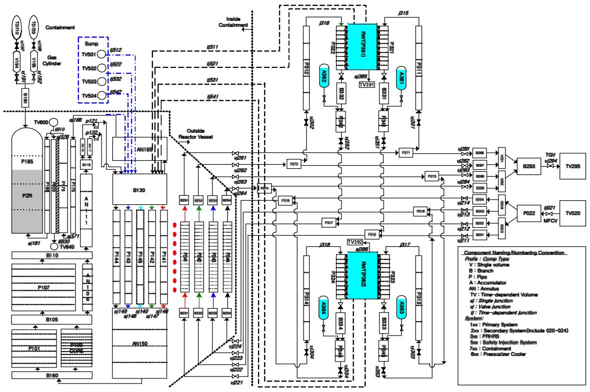

Fig. 1 RELAP5/SMR nodalization of SMART-P

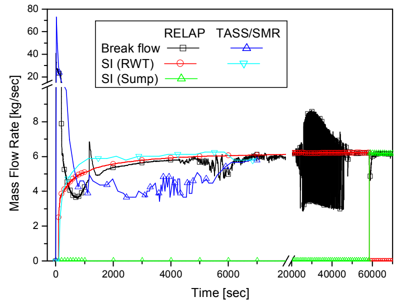

Fig. 2 Break discharge and SI flows transients

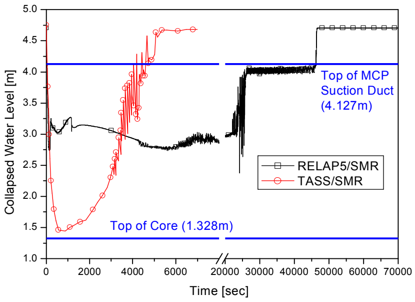

Fig. 3 Collapsed water level transients