# Preliminary Study on a Steam Generator Tube Rupture of SMART-ITL using MARS-KS

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## 1. Introduction

A steam generator tube rupture (SGTR) of SMART Reactor [1] is defined as a rupture of a single helical tube that is in contact with the reactor coolant system filled in the shell side of the steam generator and is classified as a virtual accident. Spiral tubes located in the steam generator are the barrier to isolate the secondary system from the reactor coolant system and prevent the leakage of the radioactive material to the secondary system. The rupture of the pressure boundary between the reactor coolant system and the secondary system is an important issue in terms of radioactive material leakage as well as thermal hydrodynamic aspects. The reactor coolant system coolant containing the radioactive material is discharged through the damaged portion of the heat transfer tube and mixed with the secondary system fluid.

A preliminary study using the MARS-KS code [2] was performed before the SGTR test using SMART-ITL facility [3]. The analysis using the MARS-KS was carried out according to the SGTR accident scenario of the SMART reactor, and the test will be conducted in the same sequence in the near future. When the SGTR occurs, a passive residual heat removal system (PRHRS) removes the residual heat of the core, and a passive safety injection system [4] which consists of the core makeup tank (CMT) and safety injection tank recovers the inventory of the reactor coolant system (RCS). The analysis results were sufficient to show that the SMART reactor was safe in the SGTR.

## 2. Scaling and Nodalization of the SMART-ITL

### *2.1 Scaling of the SMART-ITL*

SMART-ITL was designed following a three-level scaling methodology consisting of integral scaling, boundary flow scaling, and local phenomena scaling. Its height is preserved to the full scale, and its area and volume are scaled down to 1/49 compared with the prototype plant, SMART. The maximum core power is 2.0 MW, which is about 30% of the scaled full power. The design pressure and temperature of SMART-ITL can simulate the maximum operating conditions, that is, 18.0 MPa and 350°C. The scaling ratios adopted in SMART-ITL with respect to SMART are summarized in Table I.

Table I: Major scaling parameters of the SMART-ITL facility

| Parameters | Scale Ratio | Value |
|---|---|---|
| Length | $l_{0R}$ | 1/1 |
| Diameter | $d_{0R}$ | 1/7 |
| Area | $d_{0R}^{\ 2}$ | 1/49 |
| Volume | $l_{0R}\ d_{0R}^{\ 2}$ | 1/49 |
| Time scale, Velocity | $l_{0R}^{\ 1/2}$ | 1/1 |
| Power, Volume, Heat flux | $l_{0R}^{\ -1/2}$ | 1/1 |
| Core power, Flow rate | $d_{0R}^{\ 2}\ l_{0R}^{\ 1/2}$ | 1/49 |
| Pump head, Pressure drop | $l_{0R}$ | 1/1 |

### *2.2 Nodalization of the SMART-ITL*

A preliminary calculation using a best-estimate safety analysis code, MARS-KS was performed for the experimental SGTR scenario which is based on the SMART SGTR. During the simulation of the SGTR, it is assumed that the tube rupture occurs at the bottom of the steam generator. In addition, the set-point and sequence of events in the SGTR scenario were the same as those used in the test, as shown in Table II.

The nodalization of the SMART-ITL was based on an isometric drawing and design reports provided by KAERI. In addition, some assumptions and modifications were made. A MARS-KS nodalization diagram for SMART-ITL is represented in Fig. 1. The nodalization for a MARS-KS analysis includes all reactor coolant systems, a passive safety injection system, and a secondary system including the PRHRS.

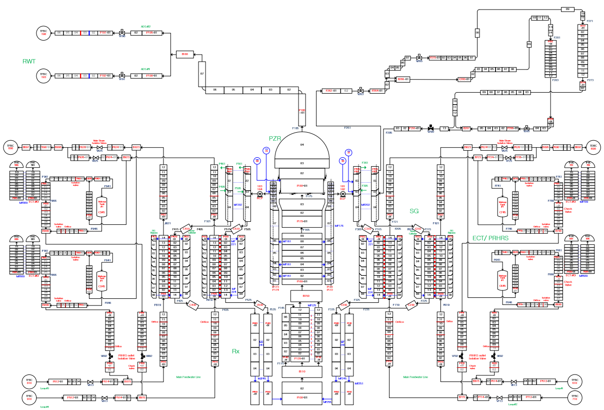

Fig. 1. Nodalization diagram of SMART-ITL for MARS-KS model

## 3. Results

The SMART-ITL has been used to investigate the thermal-hydraulic behavior for SMART during the operational transients and the design base accident. The preliminary analysis using the MARS-KS code before the SGTR test using the SMART-ITL facility. To simulate the SGTR, a nozzle at the bottom of the steam generator of the SMART-ITL is connected to the main steam line by piping. The SGTR occurs as an isolation valve on the simulation pipe is opened. The thermal-hydraulic behavior happens at the same time in the SMART-ITL and SMART design according to the time scale ratio. Table II shows the major sequence of events for the SGTR simulation.

As a single helical tube of the steam generator is ruptured in the SMART design, the coolant of the RCS is released through the ruptured tube and mixed to the coolant of the secondary system. The pressure and level of the RCS decrease. When the RCS level reaches the low pressurizer level (LPL) set-point, the reactor trip signal is generated with a 1.1 s delay. With an additional 0.5 s delay, the control rod is inserted. When the PRHR actuation signal is generated by the LPL, the SG secondary side is isolated from the turbine by closing the main steam and feedwater isolation valves, and is connected to the PRHRS. The CMT actuation signal (CMTAS) is generated by the PRHRAS and the CMT water is passively injected by gravity head. The SIT actuation signal (SITAS) is generated when the pressurizer pressure reaches the SIT set-point and the SIT water begins the passive injection by gravity head as well.

Fig. 2 shows the pressure behavior of the RCS, which decreased rapidly during the early stage and slowly after middle stage of the code simulation.

Fig. 3 shows the temperature of the core inlet and outlet. Immediately after the SGTR occurs the core inlet and outlet temperature decrease with a constant difference. These two temperatures are almost the same when core residual heat is simulated after the reactor trip with the residual heat. The decreasing slope of the temperature is constant and almost similar to the RCS pressure behavior. Inlet temperature is expected to decrease along with the saturation temperature. Outlet temperature is distributed under the saturation temperature.

Fig. 4 shows the RCS level, which decreases and increases repeatedly. The decreasing level is recovered by the CMT and SIT injection.

Fig. 5 shows the secondary system flow rate. As the PRHRS system operates, the flow rate shows a dramatic decrease at the beginning, and natural circulation is achieved within a few seconds. After that, the natural circulation flow rate decreases gradually at a constant rate. The natural circulation flow rate is dependent on the heat balance between the heat exchanger and the SG, and the hydraulic resistance in the loop. With the operation of the PRHRS, a two-phase natural circulation flow formed inside the PRHRS loop.

Table II: Major sequence of SGTR simulation

| Event | Trip signal and Set-point SMART-ITL |
|---|---|
| Break | CVCS max. charging |
| LPL set-point | Low PZR Level = $L_{LPL}$ |
| LPL reactor trip signal | LPL+1.1 s |
| Control rod insert | LPL+1.6 s |
| PRHR Actuation Signal<br>CVCS Isolation Actuation Signal | LPL+1.45 s |
| CMT Actuation Signal | PRHRAS+1.45 s |
| CMT injection | CMTAS+1.45 s |
| PRHRS IV open<br>MSIV/FIV close | PRHRAS+5.0 s |
| SIT Actuation Signal | PZR Press = $P_{SIT}$ |
| SIT injection | SITAS+1.45 s |

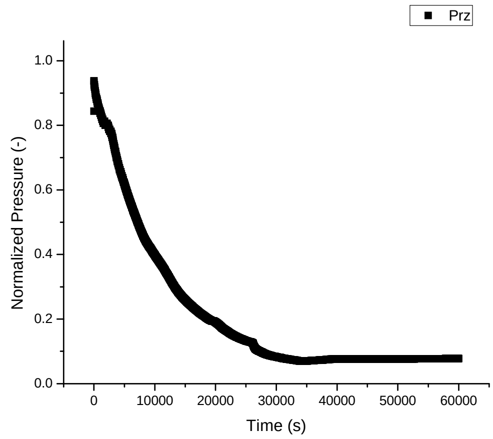


Fig. 2. Pressurizer pressure distribution

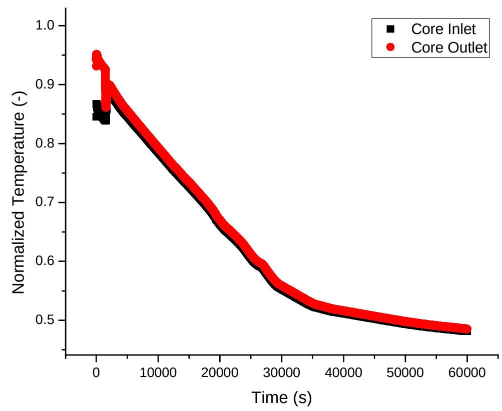


Fig. 3. Core temperature distribution

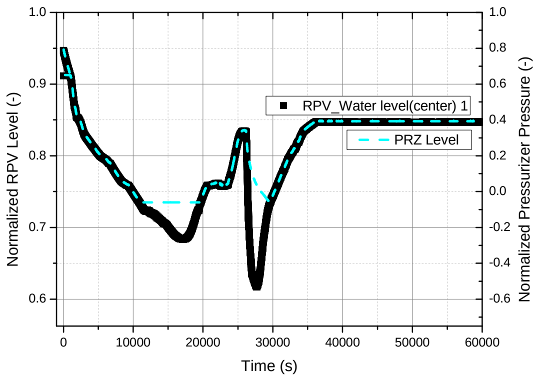


Fig. 4. Pressurizer level distribution

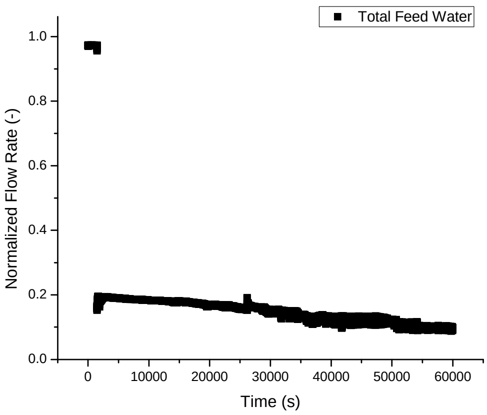


Fig. 5. Natural circulation flow rate of PRHRS

## 3. Conclusions

The MARS-KS code analysis on the SGTR was performed to prepare the SGTR test using the SMART-ITL. The transient sequence proceeded with the SMART SGTR scenario. All of the actuation signals were generated on time and the corresponding components and systems were appropriately operated. The PRHRS operation removed the core residual heat, the passive injection of the CMTs and SITs recovered the RCS inventory. The simulation results by the MARS-KS reveal that the SMART reactor is safe in the SGTR accident.

## REFERENCES

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