EFFECTS OF ECCS ON THE COLD-LEG FLUID TEMPERATURE DURING SGTR ACCIDENTS

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ABSTRACT

The LSTF experiment simulating the SGTR accident at the Mihama Unit-2 reactor is analyzed using the RELAP5/MOD3.3 code. In the accident, and thus in the experiment, the ECC water was injected not only into the cold legs but into the upper plenum. Overall transients during the experiment such as pressures and fluid temperatures are simulated well by the code. The cold-leg fluid temperatures are shown to decrease if the upper plenum injection system is connected to the cold leg. It is found that the cold-leg fluid temperatures also decrease if the upper-plenum injection is not used and the cold-leg injection alone is actuated.

KEYWORDS
SGTR, LSTF, RELAP5, ECCS, PTS

1. INTRODUCTION

A steam generator tube rupture (SGTR) accident occurred at the Mihama Unit-2 reactor of Kansai Electric Power Co. Ltd. in 1991. The rupture was a double-ended break of a U tube above the highest support plate. The events those occurred shortly after rupture included the reactor scram, reactor coolant pump trip, injection of auxiliary feed water and actuation of emergency core cooling system (ECCS). The operator initiated corrective actions: the secondary side of intact loop was depressurized by manually opening the SG relief valve, and the primary side was depressurized using the pressurizer auxiliary spray. The reactor coolant pump was finally restarted after the termination of ECCS actuation.

The integral effect experiment was conducted using the Large Scale Test Facility (LSTF) at Japan Atomic Energy Research Institute (JAERI) in order to investigate the thermal-hydraulic phenomena during the accident. The LSTF is 1/21 scale in volume as compared to the Mihama Unit-2 reactor. The conditions and the procedures of LSTF experiment were almost the same as those in the accident: the initial steady state, trip conditions and operating procedures, and so on. The double-ended U-tube break in the accident was simulated by the break nozzle placed in the line connected from the inlet plenum to the bottom of the secondary side of SG. The experimental results of LSTF were compared with the Mihama Unit-2 plant

records, and the experimental analyses were performed using the RELAP5/MOD2 code. The thermal-hydraulic phenomena during the experiment were in good agreement with those during the accident, and predicted well by the code [1]. Both the accident analysis and experimental analysis were performed using the TRAC-PF1 code, and it was concluded that the experimental results could be extrapolated to nuclear power plants [2]. Some sensitivity calculations were also performed using the RELAP5/MOD2 code, and effects of operator actions were discussed [3].

In this study, the LSTF experiment is analyzed using the RELAP5/MOD3.3 code. The initial and operating conditions in the analysis are almost the same as those in the experiment. Overall transients during the experiment are shown to be simulated well by the code. In the experiment and the accident, and thus, in the analysis, the ECC water was injected into the cold legs and the upper plenum. The effect of upper plenum injection is evaluated by sensitivity analyses, and the decrease in fluid temperature in the cold leg, which is important for the integrity of pressure vessel in terms of pressurized thermal shock, is discussed.

2.   ANALYSIS OF LSTF EXPERIMENT SIMULATING MIHAMA SGTR ACCIDENT

The LSTF experiment simulating the Mihama SGTR accident and the experimental analysis using the RELAP5/MOD3.3 code are described in the following.

2.1. LSTF Experiment

The LSTF is originally designed to model a Westinghouse-type 3423 MWt 4-loop PWR with a volumetric scale of 1/48 [4], and is 1/21 scale as compared to the Mihama Unit-2 reactor, which is a 1456 MWt 2-loop PWR. The major components elevations of LSTF are the same as those of the reference PWR to simulate the natural circulation phenomena, which are important during small break loss of coolant accidents, and are almost the same as those of the Mihama Unit-2 reactor.

The LSTF is operated at the same high pressures and temperatures as the reference PWR. The maximum core power is, however, 10 MW, and it corresponds to 14 % of the full power of the reference PWR and the Mihama Unit-2. The primary flow rate is, thus, 14 % of the scaled value, and the SG secondary side pressure is adjusted so as to obtain the desired heat transfer rate from the primary to the secondary sides. The general facility arrangement is shown in Fig. 1. The four primary loops of the reference PWR are represented by the two equal-volume loops of the LSTF, and the two primary loops of the Mihama Unit-2 reactor can be well simulated ty these two loops. The double-ended U-tube break at above the highest support plate in the accident was simulated by the break line connecting the SG inlet plenum and the bottom of the SG secondary side. The scaled break area and the single-phase water pressure drop in the U tube up to the break point were simulated in the experiment using the break nozzle. The pressurizer is located in the broken loop in the Mihama Unit-2 reactor, while in the intact loop in the LSTF. The effect of pressurizer location on the SGTR transient was, however, shown to be small by sensitivity calculations [1].
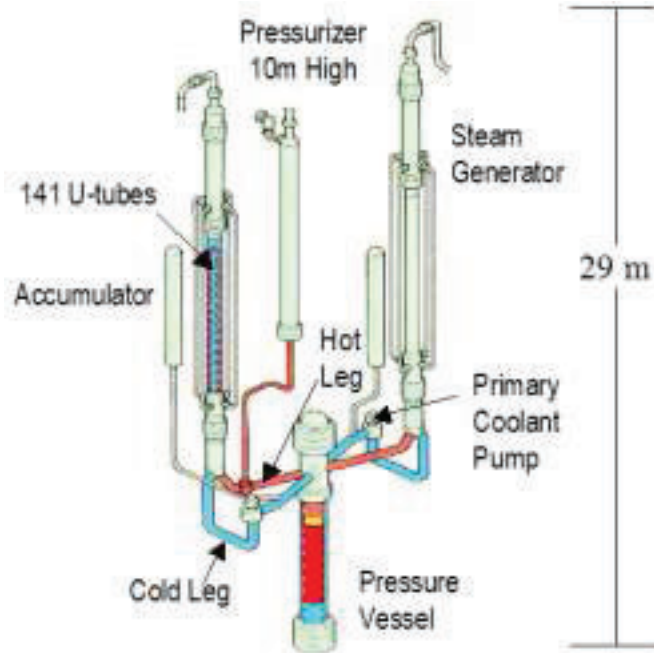
Figure 1. Schematic View of Large Scale Test Facility (LSTF).

The initial steady state conditions such as the primary pressure and the fluid temperatures were the same as those in the Mihama Unit-2 reactor just before the accident. The core power and the primary loop flow rate were 10 MW and 34 kg/s, respectively, which were both 14 % of the scaled values of the Mihama Unit-2 reactor. The flow rates of the ECC water and the pressurizer auxiliary spray were also scaled. The experiment was conducted up to 5000 s after break and the results are compared with the plant records, and the thermal-hydraulic phenomena during the experiment were in good agreement with those during the accident [1,2].

2.2. RELAP5/MOD3.3 Analysis

The above SGTR experiment is analyzed using the RELAP5/MOD3.3 code with the standard input model shown in Fig.2 for analyses of LSTF experiments [5]. The input model in Fig. 2 is slightly modified to simulate the line connected from the SG inlet plenum to the bottom of the SG secondary side in the broken loop. The number of volumes, junctions and heat structures are 192, 203 and 180, respectively. The Ransom-Trapp choked-flow model is used [6] with a discharge coefficient of unity for both subcooled and saturated discharge flows. The initial steady state for the transient calculation is obtained so that the experimentally observed initial condition is established. The ECCS conditions and the operator actions are the same as those in the experiment for the base case calculation. The ECCS conditions are changed in the sensitivity calculations: the case with no upper-plenum injection, the case with no upper-plenum and cold-leg injections, and the case in which the upper-plenum injection is changed to the cold-leg injection.

2.3. Base Case Analysis

The primary and secondary pressures are shown in Fig. 3 along with the experimental results. The calculated primary pressure is shown to be in good agreement with the experimental result. The primary pressure decreases after break, and the reactor trip occurs at the pressure of 13.42 MPa. The safety

injection signal is issued at the pressure of 12.87 MPa. The main feed water is terminated 31 s after reactor trip, and the auxiliary feedwater pump is actuated. The primary coolant pump coast down starts 80 s after reactor trip. The timings of major events are calculated well since the primary pressure is predicted well as shown in Fig. 3. The outflow due to the break flow and the inflow due to the injection are, thus, found to be simulated well. The outflow from the primary to the secondary sides through the break nozzle is always a single-phase liquid in this transient.

The relief valve in the intact SG is opened manually at 988 s to depressurize the secondary side, and the secondary side pressure in the broken SG starts to increase. Three spikes in the secondary side pressure in the broken SG in Fig. 3 correspond to the opening of the SG relief valve. The SG relief valve opened three times automatically since the SG pressure reaches the opening set point. The relief valve opened, however, once in the experiment, and one spike is seen in the SG pressure in Fig. 3. The difference in the pressure increase in the broken SG might be due to the modeling of secondary side or the condensation model in the code. The pressure in the intact SG is simulated well in Fig. 3.

The ECC water is injected into the cold legs and upper plenum at about 500 s and 560 s, respectively, in the analysis, while 403 s and 605 s, respectively in the experiment. The ratio of flow rate is roughly 1.0:1.2:1.5 for the broken-loop cold leg, the intact-loop cold leg and the upper plenum. The upper plenum injection is stopped manually at about 2870 s both in the analysis and the experiment. The pressurizer auxiliary spray is actuated manually at about 2930 s to depressurize the primary side, and stopped at about 3650 s in the analysis and 3620 s in the experiment after the primary pressure decreases to the secondary pressure. The decrease in primary pressure during this period is simulated well as shown in Fig. 3. The cold leg injection is stopped at about 3290 in the analysis and 3390 s in the experiment after the pressurizer liquid level recovered. The overall pressure transient is found to be simulated reasonably well.

The cold-leg fluid temperatures in the intact loop and the broken loop are shown in Fig. 4. Fluid temperatures are measured at five vertical locations in the cross section of cold leg in the experiment, and the highest and lowest values are shown along with the calculated results. It is shown by the experiment that the temperature stratification occurs in the cold legs, and the temperature difference in the cross section is large in the broken loop. This is because the natural circulation flow rate is much smaller in the broken loop than that in the intact loop. The RELAP5 calculated results with one-dimensional modeling are almost in between the experimental values as shown in Fig. 4. This temperature stratification would be of importance for the pressurized thermal shock to the pressure vessel, since the low temperature fluid, not the average temperature fluid, flows into the downcomer.

In the base case experimental analysis shown in Figs. 3 and 4, the SGTR transient is simulated reasonably well by the input model shown in Fig. 2. It is thus confirmed that the input model is reliable for analysis of SGTR transient in the LSTF. Since the LSTF experiment simulates the Mihama accident well [1,2], the sensitivity calculations performed in the following using the same input model would simulate the real plant behavior.
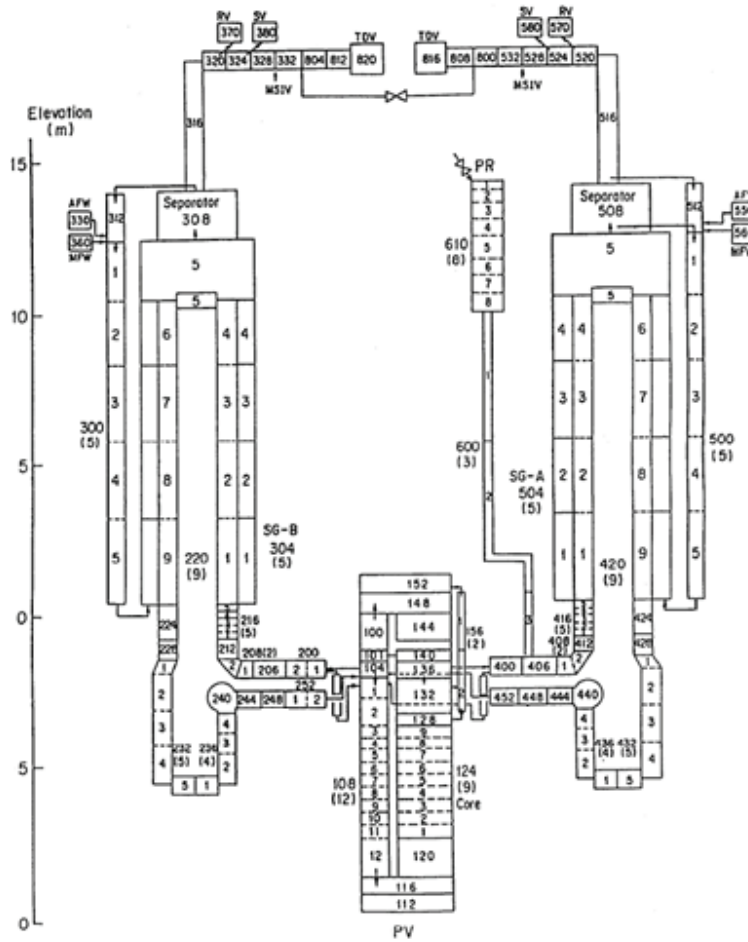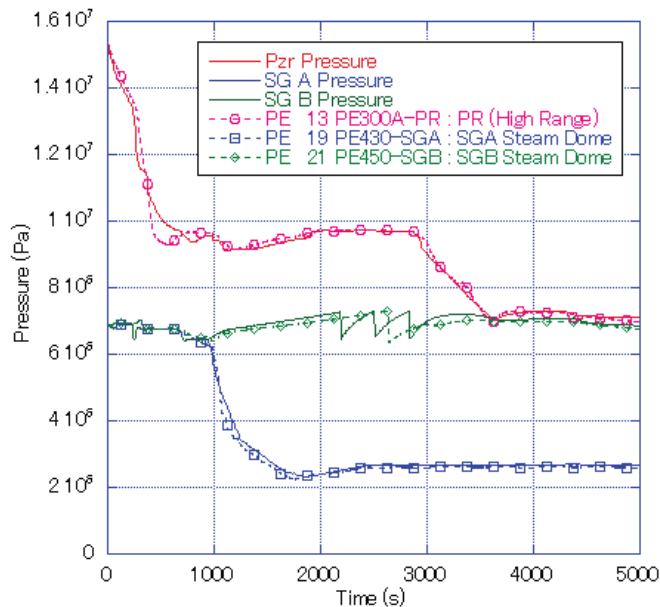
Figure 2. LSTF Input Model.

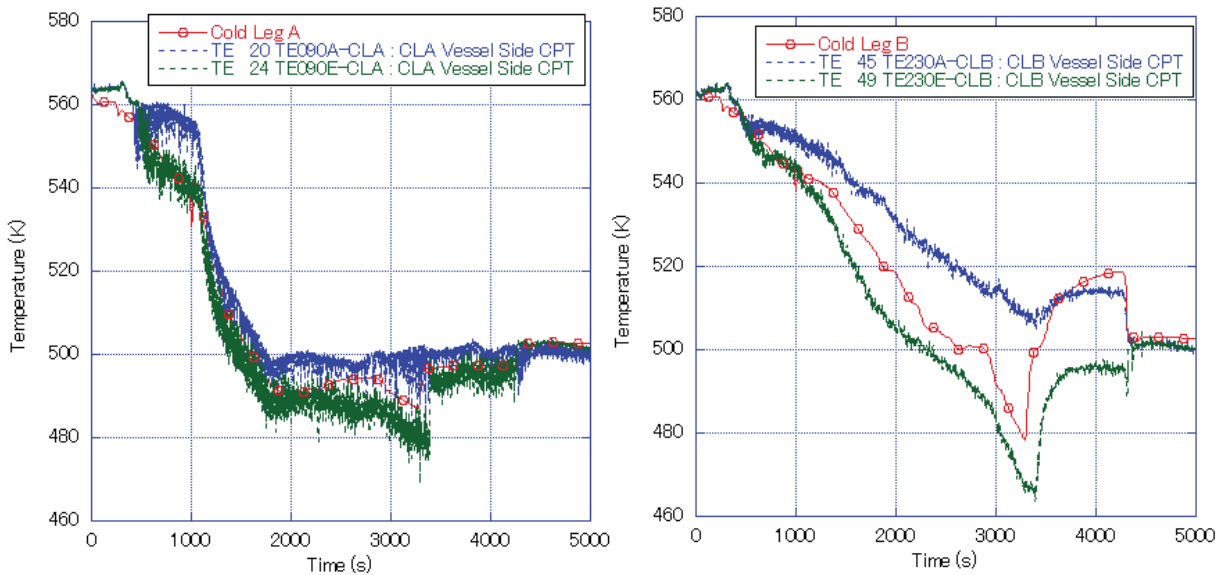**Figure 3. Primary and Secondary Pressures.**

Figure 4. Cold-Leg Fluid Temperature in Intact Loop (left) and Broken Loop (right).

3. SENSITIVITY ANALYSES FOR STUDYING EFFECT OF UPPER-PLENUM INJECTION

In the Mihama accident, and thus in the LSTF experiment, the ECC water was injected not only into the cold legs but into the upper plenum. Sensitivity analyses are performed for studying the effect of upper-plenum injection on the cold-leg fluid temperature, which is of importance for the integrity of pressure vessel in terms of pressurized thermal shock. Three cases with different ECCS conditions are calculated: the case with no upper-plenum injection (Case-I), the case with no upper-plenum and cold-leg injections (Case-II), and the case in which the upper-plenum injection is changed to the cold-leg injection (Case-III).

The primary pressure is shown in Fig.5, where the base case and three sensitivity cases are shown. The result of Case-III is shown to be almost the same as the base case result. This is because the amount of injection is almost the same between the base case and Case-III. In contrast to Case-III, the primary pressure decreases much in Case-II. The difference between the base case and Case-II is seen after the ECCS actuation at about 500 s in the base case. The primary side is depressurized using the pressurizer auxiliary spray at about 2930 s, and the primary pressure is equalized with the secondary pressure at about 3650 s in the base case. These timings are almost the same in Case-III, while in Case-II, the primary pressure continues to decrease, and reaches the secondary pressure level at about 1300 s. Case-I is in between Case-II and Case-III, since the amount of injection for Case-I is in between Case-II and Case-III. The amount of outflow from the primary side to the secondary side through the break nozzle is reduced in Case-I since the pressure difference between the primary and secondary sides is smaller than that in the base case.

The cold-leg fluid temperatures are shown in Fig. 6 for the intact loop (left) and the broken loop (right). It is clearly seen that the fluid temperature in Case-II does not decrease to the base case temperature. Especially in the broken loop, the natural circulation is stopped at about 1200 s, and the fluid temperature is much higher than that in the base case. It is of interest that the cold-leg fluid temperature is almost the same for Case-I and Case-III in the intact loop and not much different in the broken loop. In Case-III, the upper-plenum injection is changed to the cold-leg injection, and thus, the amount of injection to the primary side is almost the same as that in the base case. The primary pressure in Case-III is, thus, almost the same as the base case pressure, while the cold-leg fluid temperature becomes much lower. The upper-

plenum injection is simply set to zero in Case-I, and the amount of injection to the primary side is smaller than that in the base case. The primary pressure in Case-I is, thus, lower than the base case pressure as shown in Fig. 5. The amount of cold-leg injection, however, increases in Case-I due to the relation between the pump head and injection flow rate. The primary pressure becomes lower and the cold-leg injection increases, and the cold-leg fluid temperature decreases much in Case-I. It is found in Fig. 6 that the upper-plenum injection is not effective for cooling in the SGTR transient. In other words, the cold-leg fluid temperature does not decrease much due to the upper-plenum injection since the primary pressure is kept high. Furthermore, the amount of outflow from the primary side to the secondary side is smaller for Case-I, since the pressure difference between the primary and secondary sides is smaller. The increase in secondary pressure in Case-I is, thus, smaller than that in the base case and Case-III, and the relief valve opens twice in Case-I, while three times in the base case and Case-III. This point is also of interest from the viewpoint of radioactive release to the environment.
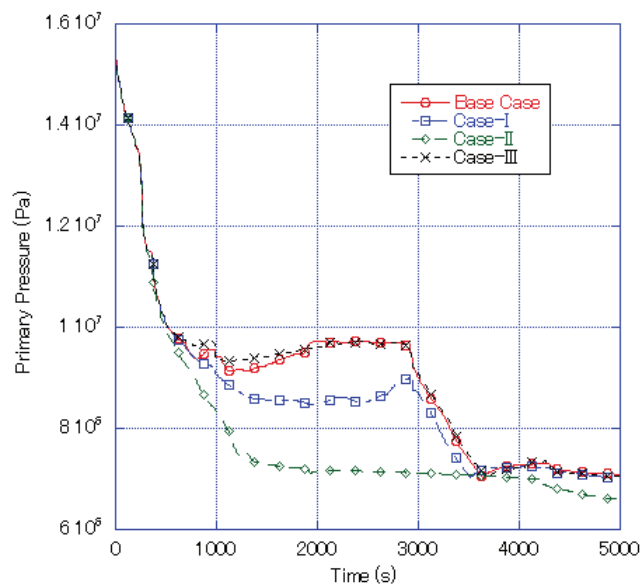

Figure 5. Primary pressure in sensitivity calculations.

4.   CONCLUSIONS

In this study, the LSTF experiment simulating the SGTR accident in the Mihama Unit-2 reactor has been analyzed using the RELAP5/MOD3.3 code. The initial and operating conditions in the analysis were almost the same as those in the experiment. Overall transients during the experiment were simulated well by the code. In the experiment, and thus in the accident, the ECC water was injected not only into the cold legs but into the upper plenum. The effect of upper-plenum injection on the cold-leg fluid temperature, which is of importance for the integrity of pressure vessel in terms of pressurized thermal shock, was evaluated by sensitivity analyses.

The cold-leg fluid temperature was shown to decrease much if the upper-plenum injection was changed to the cold-leg injection. The amount of outflow from the primary to the secondary sides was almost the same, since the primary pressure was almost the same as that in the base case. It was found that the cold-leg fluid temperature also decreased if the upper-plenum injection was not actuated, since the primary pressure became lower and the amount of cold-leg injection increased. The amount of outflow became

smaller, since the pressure difference between the primary and secondary sides became smaller. It was shown that the upper plenum injection was not effective for cooling in the SGTR transient.
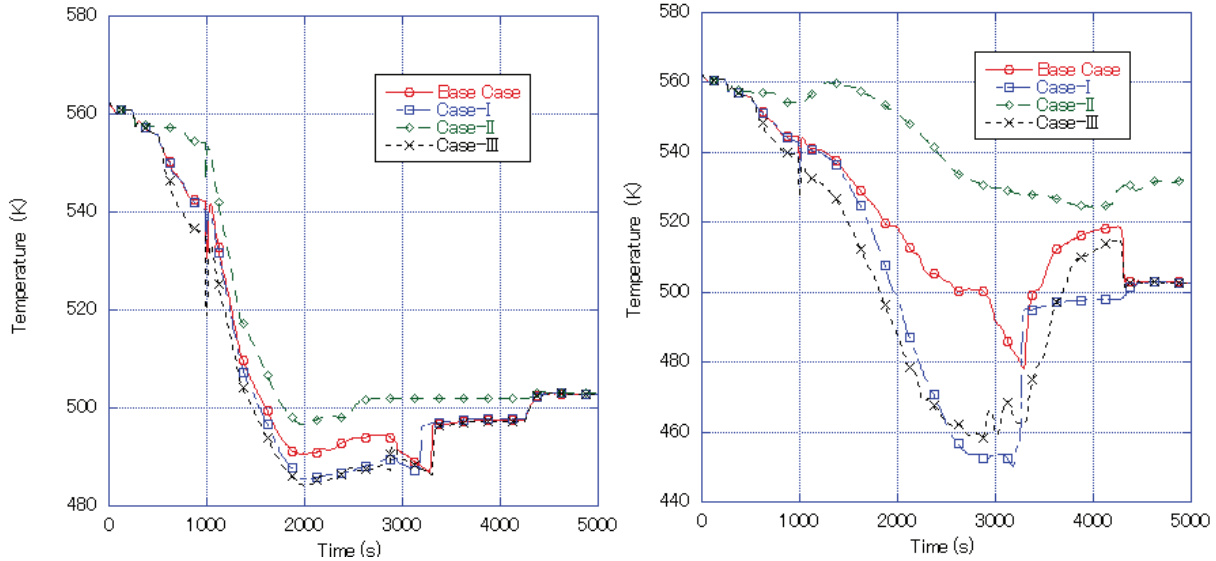

Figure 6. Cold-Leg Fluid Temperature in Intact Loop (left) and Broken Loop (right).

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