A Study on the NSSS Thermal-Hydraulic Modeling for Kori #1 Nuclear Power Plant

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1. Introduction

The nuclear steam supply system thermal-hydraulic module (named "ARTS" code) is adopted to simulate the nuclear plant simulator for KORI unit 1[1,2]. The best-estimate code RETRAN developed by EPRI is selected as a reference code for the ARTS and is the possibility of training personnel to act in terms of not only the design-basis but rather beyond the design-basis accidents. To develop the RETRAN code as a nuclear steam supply system thermal-hydraulic module for the simulator, a number of code modifications, such as simplifications and removing of discontinuities of the physical correlations, were made to satisfy the simulator requirements of robustness and real time calculation capability. Some simplified models and a backup system were also developed to simulate some transients that cannot be efficiently calculated by the RETRAN. And its scope for the simulation has been extended by supplementation of new calculation modules such as a dedicated pressurizer relief tank model and a backup model. The supplement is developed so that users cannot recognize the model change from the main ARTS module. For the transient behavior, the ARTS module is well adapted for the Kori unit 1 NPP simulator. The simulated results show good agreement with the plant data and the ANSI/ANS-3.5-1998 simulator software performance criteria under steady state or transient conditions.

2. ARTS-Kori Code Development

RETRAN is a best-estimate transient thermal-hydraulic code designed to analyze operational transients, small break loss-of-coolant accidents, anticipated transients without scram, natural circulation, long-term transients, and events involving limited non-equilibrium conditions in light water reactors. RETRAN, however, has some limitations in real-time calculation capability and its robustness to be used in the simulator for some transient conditions. To overcome these limitations, its robustness and real-time calculation capability have been improved with simplifications and removing of discontinuities of the physical correlations of the RETRAN code. And some supplements are also developed to extend its simulation scope of the ARTS code.

2.1. Nuclear Power Plant Modeling

The target plant for simulator is Kori nuclear unit 1. Kori 1 is a typical Westinghouse, two-loop pressurizer water reactor (PWR) with a rated core power of 1723.5 MW (thermal) and rated core flow of 8557.6 kg/sec. The reactor coolant system (RCS) consists of a reactor vessel, two inverted U-tube steam generators (SGs), two reactor coolant pumps (RCPs), a pressurizer, and various inter-connecting piping. Two loops of the RCS are designated loops A and B, and pressurizer is connected to loop A. Two pressurizer spray line is connected from cold legs of loop A and loop B.

The RETRAN-3D input model of Kori 1 has been developed for wide-range plant transient and accident analyses under considerations for real-time calculation, robustness and fidelity. The non -homogeneous, non-equilibrium option of RETRAN with algebraic slip was selected for realistic simulation of two-phase flow system. The schematic diagram for plant model is shown in Fig. 1.

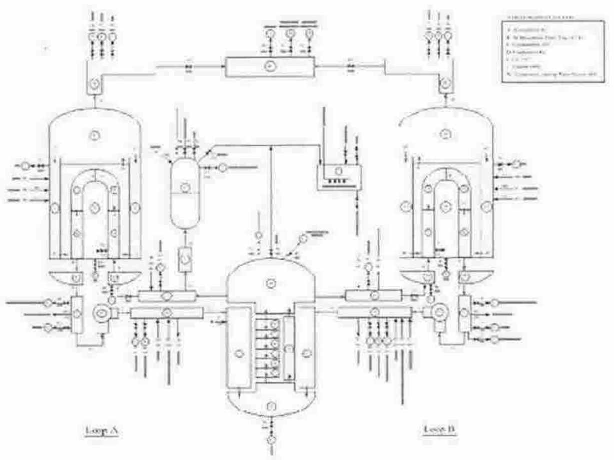

Fig. 1. Nodalization of ARTS for W/H type Kori unit 1

Each primary loop consists of 10 computational volumes. The secondary side of each SG is modeled by 3 control volumes which represent the evaporator, steam dome and downcomer. The domes and downcomers of the steam generators are modeled with non-equilibrium bubble-rise model to simulate the phase separation. The heat structure for the active core region is divided into 3 core zones. The reactor power is obtained for a separated 3-D kinetics model as a boundary condition and 6 heat structures in each fuel channel are modeled to simulate the heat transfer from fuel rods to coolant. Each of the steam generator U-tube bundles is modeled by 4 heat structures. The feedwaters, steam flows, safety injections, CVCSs (Chemical and Volume Control System) and others are modeled with 91 of fills and 7 of time dependant volumes and treated as boundary conditions. These boundary conditions are provided from other simulator modules.

2.2. Pressurizer Relief Tank (PRT)

A pressurizer discharges its steam to PRT when a RCS is pressurized. The discharged steam is condensed in PRT. It is consist of subcooled water in bottom and non-condensable gas in top. The sparger merged under subcooled water enhances condensation. The complicated thermal-hydraulic phenomena such as condensation, phase separation with existence of non-condensable gas makes difficult to simulate. Therefore, the PRT volume can limit the time-step size if we model it with a general control volume. To prevent the time-step size reduction due to convergence failure for simulating this component, we developed a dedicated model for PRT.

2.3. Backup Calculation Module

ARTS can simulate the most transients in real-time and its robustness is ensured. However, real-time calculation and robustness can be failed for large-break LOCA and long-term two-phase transients which includes low-pressure, low-flow condition. The NIST(Non-Integrated Standalone Test) results show that it is not occurs except for LB LOCA[4]. In order to improve its robustness, the backup calculation module is developed to replace the main ARTS module whenever a regular ARTS module fails to calculate (see Fig. 3).

3. Results and discussion

3.1 Transient Test

Transient test has been performed to evaluate the robustness and fidelity of the ARTS module (see Fig. 2).

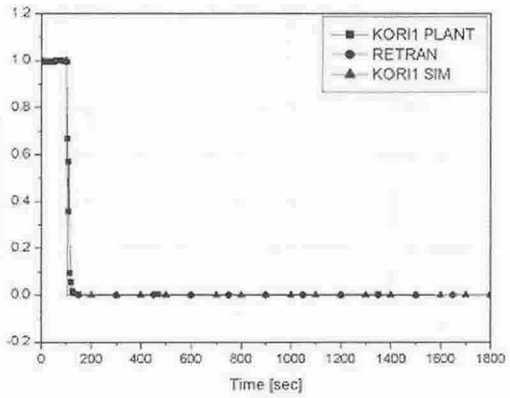

Fig. 2. Turbine Power (Turbine Trip)

3.2 Site Acceptance Test

The SAT was performed with a complete set of the full-scope simulator, which includes all hardware and software. The SAT consists of over several hundred test items and it was done according to the ATP. The test was completed with a few minor discrepancies.

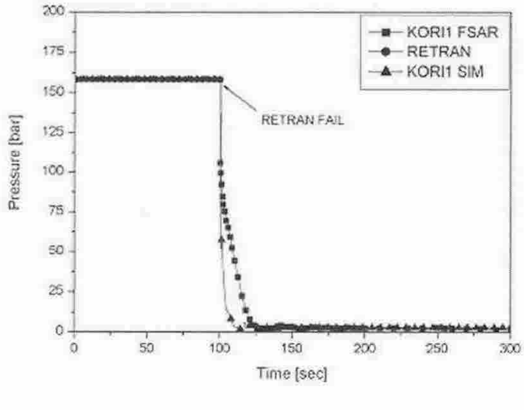

Fig. 3. Pressurizer Pressure (Large Break LOCA)

4. Conclusions

We developed an advanced NSSS T/H simulation code, ARTS-Kori, based on a best-estimate code, RETRAN[3]. To make the RETRAN code fit to the simulator, its robustness and real-time calculation capability have been improved with simplifications and removing of discontinuities of the physical correlations of the RETRAN code. Some supplements are also developed to extend its simulation scope of the ARTS code. Since ARTS is a part of simulator modules, ARTS was integrated with 3-D reactor kinetics model and other system models.

The ARTS code guarantees the real-time calculations of almost all transients and ensures the robustness of simulations. However, there are some possibilities of calculation failure in the cases of large break loss of coolant accident (LBLOCA) and low-pressure low-flow transient. The backup calculation system has been developed to substitute automatically the ARTS in this case. The results were reasonable in terms of accuracy, real-time simulation, robustness and education of operators, complying with the ANSI/ANS-3.5-1998 simulator software performance criteria[5].

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