A Sensitivity Study of a Steam Generator Cassette Module Pipe Break Accident for the SMART-P

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1. Introduction

SMART-P, a small sized integral type pressurized water reactor with the rated power of 65.5 MWt is one of the advanced types of small reactors.

The Steam Generator (SG) is one of the major reactor components in the SMART-P. The heat that is generated in the core is transferred to the secondary system in the steam generator. The definition of the Steam Generator Cassette Module Pipe Break (SGCMPB) accident in SMART-P is meant to be one module pipe break of a SG in the reactor vessel. From an analysis of this accident we can obtain a confidence in the safety of the SMART-P plant.

2. Description for the SMART-P

The design concept of the SMART-P is the adoption of an integral arrangement. All the primary components, which consist of a core, SGs, main coolant pumps, and a pressurizer (PZR) are integrated into a single pressurized vessel without any pipe connections between those primary components. The core is located in the lower part of the reactor vessel. While the overall arrangement of the Reactor Coolant System (RCS) is simplified by the elimination of the primary piping systems, the layout in the reactor vessel becomes more complex. The reactor coolant is forced to flow upward through the core to then flow down into the shell side of the SG from the top of the SG and then back to the core.

The core decay heat can be removed through the passive residual heat removal system (PRHRS) by a natural circulation in emergency situations. The SMART-P has four independent PRHRS trains with a 50% capacity for each train, and an operation of two trains is sufficient enough to remove the decay heat. The system is capable of a decay heat removal for a minimum 36 hours without any action by operators for the design basis accidents.

The definition of the SGCMPB in SMART-P is meant to be one module pipe break of a SG in the reactor vessel. The penetration parts of the reactor vessel are the subsection pipes of the Feedwater pipes and the main steam pipes. They consist of 12 pipes, respectively and one pipe has 6 module pipes with a 13 mm diameter. These 6 module pipes have 96 helical tubes in a SG [1]. The module pipes in a reactor vessel act as a protective barrier for any radioactivity propagation from the primary to the secondary system. If a SGCMPB occurs, there is a complex thermal hydraulic phenomena as well as a leakage of the break flow to the secondary system.

3. Analysis Methods

A thermal hydraulic analysis of the SGCMPB accident has been performed by the TASS/SMR code [2]. The basic code structure adopts a one-dimensional geometry, and a node and flow-path network models the system responses. The node encloses control volumes, which represent the fluid mass and energy. The flow-path connecting the nodes represents the fluid momentum and it has no volume. The conservation variables are the mixture mass with liquid and steam, liquid mass, non-condensable gas mass, mixture energy, steam energy, and the mixture momentum. The critical heat flux ratio (CHFR) analysis is performed using a SSF-1 (Self-sustained square finned-1) correlation [3], which is a one dimensional correlation for the core averaged thermal hydraulic condition and is calculated based on the local coolant conditions calculated at every time step.

The initiating event is one module pipe break in a SG. The fluid in the secondary system is mixed with that of the primary system which including radioactivity. The mixed fluid is sent to the turbine continuously until closing of the main steam isolation valve. The radioactivity can be released to the environment by the air ejector at a condenser after sending it to the condenser. The air ejector is used for the release of the non-condensable gas to the atmosphere. Actually the reactor trip signal will be actuated soon by the radioactivity detectors on the steam lines. This signal indicates a high level leakage of radioactivity from the secondary system. For a conservation of the result, a reactor trip signal by a low PZR pressure is used after skipping the signal of a high level radioactivity in the secondary system. The pressure of the RCS is decreased according to the leakage of the coolant to the secondary system continuously. The system is tripped by a low PZR pressure signal. After signaling a reactor trip, the SGs are isolated by the feedwater and main steam isolation valves. And the SGs are connected to the PRHRS. Then the PRHRS removes the decay heat by a natural circulation. The concerned parameters of this study are the fuel integrity and system pressure. In view of the break flow a smaller break area creates a larger integrated steam amount through the main steam lines. Because the small break area brings about a delay of the reactor trip time. From this view the maximum leakage of SGCMPB is similar or less conservative to the result of a SGTR [4].

4. Analysis Results

To determine the most conservative set of initial operating conditions and transient parameters for the SGCMPB accident, a sensitivity analysis for a fuel integrity viewpoint is performed. These parameters include the initial power/flow/pressure/coolant temperature, reactivity parameters, Loss Of Offsite Power (LOOP) condition and the break location. The sensitivity study for the various initial conditions with the double-ended break is performed. The diameter of the SG feedwater module pipe and steam module pipe is 13 mm and 27 mm respectively.

Limiting condition for the operation: The initial condition is one of the important parameters affecting the most adverse CHFR. It is determined that the most adverse CHFR occurs when the operating condition is a high power, high coolant temperature, high PZR pressure and a low coolant flow rate.

Power level: Spectra of the initial power levels are analyzed for a power level of 100%, 75%, 36% and 20% and a main coolant pump speed of 3600 rpm and 1300 rpm. The power level's effects are different. There is a tendency as the higher initial power level makes the lower minimum CHFR as shown in Fig. 1.

Break location: The parametric analysis includes the three break locations and the SG heat transfer characteristics with nominal full power plant conditions. The break locations are selected at the different parts of the SG cassette module pipes as described in Fig. 2. The selected break locations are feedwater module header, feedwater nozzle outlet and steam nozzle inlet. In the case of break at feedwater module header, the minimum CHFR is found. It is caused by high feedwater flow rate which create a larger break amount.

5. Conclusion

The sensitivity study for a conservative calculation of the SGCMPB accident in SMART-P is performed using the TASS/SMR code. The minimum CHFR is 1.73 at 24 seconds. It is maintained at over 1.3, which is the one of acceptance criteria, during the transient.

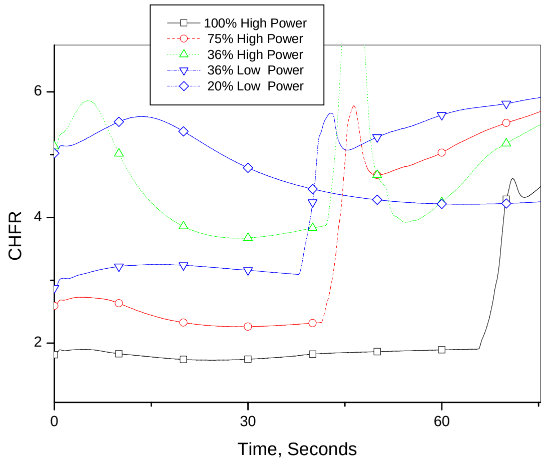

Fig. 1 The effect of the power levels

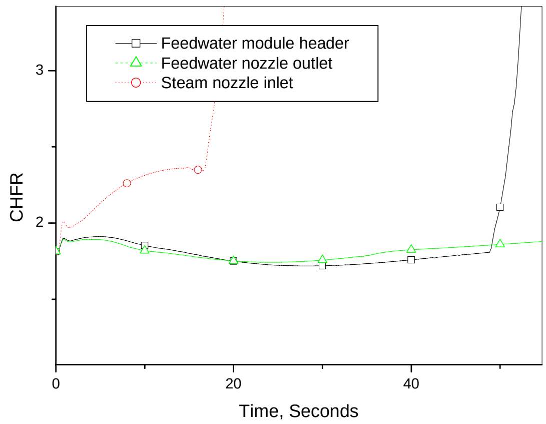

Fig. 2 The effect of the break positions

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