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Reactor Coolant Heatup Procedure for an Integral Reactor with a Gas Pressurizer

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1. Introduction

The design features of an integral reactor SMART-P are significantly different from the commercial loop-type PWR from several aspects such as the component design, component arrangement, water chemistry condition, core design, auxiliary system, and so on. Therefore the development of operation procedures complying to the unique design features of the reactor of interest is important in view of the design and operation. In the case of development of operation procedures for a reactor heatup, the following design features of the reactor should be considered:

While reactor coolant pumps are used for the heat source of the heatup operation for the commercial PWR, such an operation is not possible for an integral reactor because of the small dissipation energy of the pumps. For this reason, the nuclear energy for a heatup operation is needed. Core power should follow the steam generator (SG) power which is determined by the thermal hydraulic conditions of the operational parameters.

According to the pressure-temperature limit for the reactor pressure vessel of an integral reactor, the maximum allowable rate of a heatup operation is 100 ℃/h, which is larger than that of the commercial PWR. Because nuclear energy is used for a reactor heatup, the core criticality limit, which is more restrictive, should be a limiting allowable curve for a heatup operation.

A Multi-cavity Cold Gas PressuriZeR (MCGPZR) is used for the SMART-P, while an external steam-gas pressurizer is used for the commercial PWR. The MCGPZR is intended to be designed to meet a pressure transient during a normal power operation by its gas volume capacity and during a plant heatup/cooldown operation by a manual operation of an active gas control (filling/venting) system.

The suction of the Main Circulation Pump (MCP) is located near the bottom of the upper annular cavity of the MCGPZR. There is the concern of a critical submergence for the MCP operation.

The vacuum operation for the condenser is initiated at the condition of a reactor coolant temperature of 180 ℃, a steam pressure of 0.8 MPa. Steam pressure control is initiated at the condition of a reactor coolant temperature of 210 ℃, a steam pressure of 1.6 MPa.

Considering the above design features of an integral reactor with a gas pressurizer, the following operational procedures for a reactor coolant heatup are proposed:

- Critical submergence for the MCP operation is a minimum water level during a heatup operation.
- At a reactor coolant temperature of 180 ℃, a pressurizing operation is initiated. The pressurizer is pressurized upto the pre-determined level. During a pressurization, the heatup operation is assumed to hold.
- The letdown of the reactor coolant during a heatup operation is allowed upto a reactor coolant temperature of 180 ℃.
- Feedwater is increased twice at the temperature of 210 ℃ where a steam pressure control is required.

2. Methods and Results

In this study, operation procedures for a reactor coolant heatup from a cold state to a hot state of zero power were developed considering the above-mentioned design features of the SMART-P.

During a heatup operation, nuclear power should follow the SG power, which is determined by the primary and secondary-side thermal hydraulic conditions at the inlet and outlet of the SG. In this study, the SG power during a heatup operation was calculated using the PZRTR [1] code. Required core power during a heatup operation is obtained from the summation of the SG power, the sensible heat of reactor coolant and the metal structure.

From the analysis using the PZRTR code, the optimal operation temperature for a pressurization for the RCS is revealed to be near 180 ℃, at which superheated steam at the outlet of the SG is produced. It is preferable that the required mass of nitrogen gas is filled all at once.

Level control logic to minimize the letdown inventory was developed and the conceptual feasibility of the proposed level control logic is confirmed by an analysis by using the PZRTR code.

There are two operational steam pressures required to be passed during a heatup operation. In this study, feedwater flow is controlled at the condition of a reactor coolant temperature of 210 ℃. The control concept of the steam pressure by changing the feedwater flowrate is confirmed by the analysis (not shown in this study).

In order to verify the proposed procedures for a reactor coolant heatup, heatup operations were simulated by using the PZRTR code. The code results are confirmed by the experiment conducted by using the high temperature/high pressure test facility - VISTA (Experimental Verification by Integral Simulation of Transients and Accidents).

A 100 ℃/h heatup rate is assumed in this study. Figure 1 shows an analysis model for the simulation. Secondary system is modeled with a startup cooling device, which is a special component with a constant resistance dedicated to cool the hot water or steam from a steam generator during a heatup operation.

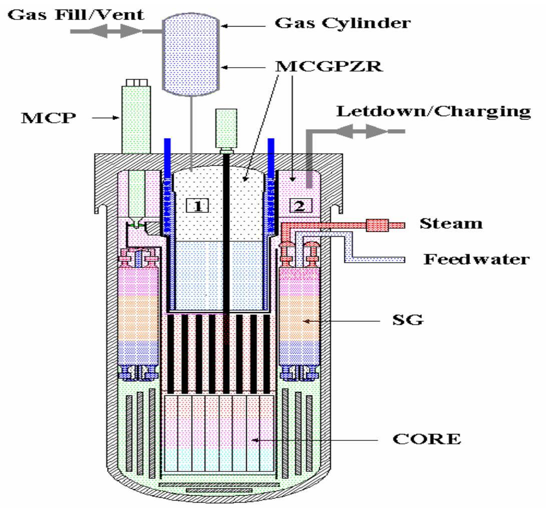

Figure 1 An analysis model for reactor coolant heatup operation simulation by the PZRTR code

As shown in Figure 1, the pressurizer is composed of three cavities called EC, IC, and UAC respectively. Initial water level at a cold condition is about 60 % of the UAC. Figure 2 shows the predicted pressure and level in the pressurizer during a heatup operation. The overall trends of the pressurizer levels are in good agreement with experimental results from the VISTA. The pressure near the end of the heatup operation from the VISTA is a lot lower than the predicted values. This is due to the fact that the VISTA's pressurizer is located outside the reactor vessel and maintained relatively cooler than the SMART-P pressurizer. In addition, there may be a control problem of the gas solubility during a heatup operation, which is not modeled in the PZRTR code. The discrepancy in the pressure between the predicted and measured is apparent in the pressure-temperature domain as shown in Figure 4.

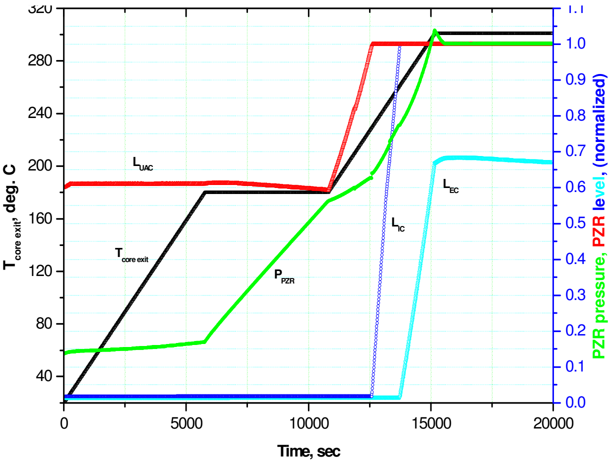

Figure 2 Predictions of pressurizer pressure and level during heatup operation by the PZRTR code

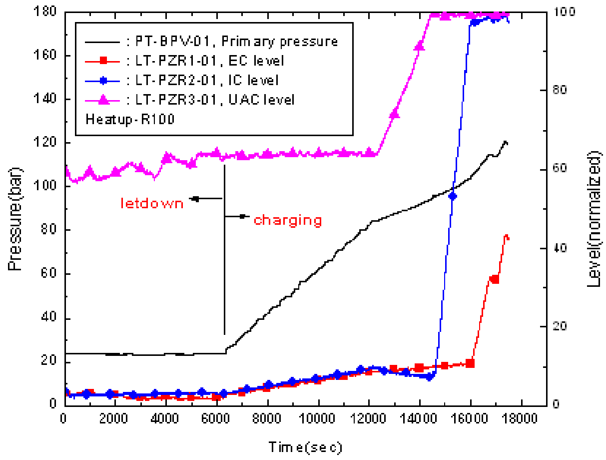

Figure 3 PZR pressure and level during heatup operation by using the VISTA

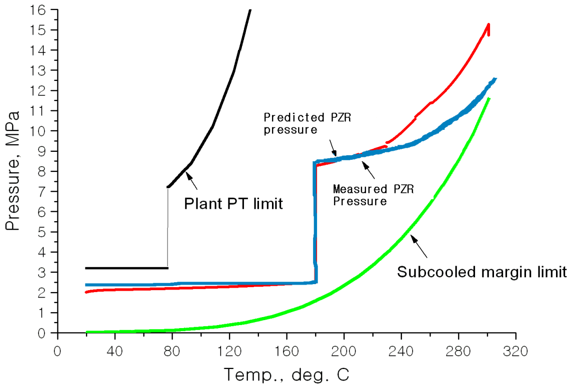

Figure 4 PZR pressures v.s. temperature during heatup operation

3. Conclusion

Reactor coolant heatup procedures for an integral reactor with a gas pressurizer were proposed and simulated by using the PZRTR code. The overall trends of the proposed procedures for a heatup operation are in good agreement with the experimental simulation results conducted by using the VISTA facility. Possible explanation for a discrepancy in the pressure trend at the end of a heatup operation was given. It will not be a problem in reality because of an operator's action. In general, the procedures proposed in this study are sufficiently feasible and applicable to a real plant.

REFERENCES

[1] J. K. Seo, and J. Yoon, Development of a computer code, PZRTR, for the thermal hydraulic analysis of a multi-cavity cold gas pressurizer for an integral reactor, SMART-P, KAER/TR-2632/2003.

[2] K. Y. Choi et al., Experimental report for thermal hydraulic behavior during startup, power change and MCP transient operation by using the high temperature/high pressure test facility (VISTA), KAERI/TR-3020/2005.