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# A Study on the Secondary-Primary Coolant Temperature Deviation to Prevent Overpressure During RCP Startup

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## 1. Introduction

Hanbit Units 1 and 2 are pressurized water reactors, and when the reactor coolant pump (RCP) is initially started, low-temperature overpressure that can occur due to heat inflow can cause brittle failure of the reactor pressure vessel. It can also cause partial loss of reactor coolant. The types that can cause low temperature overpressure are mass injection and heat inflow. In particular, the pressure rises above the low-temperature overpressure protection system operation set point value when RCP is started in the secondary-primary coolant temperature difference of 50°F, which is limited by the technical specification. [1] Therefore, the secondary-primary coolant temperature difference at which the pressure in the reactor coolant system can be stabilized below the low-temperature overpressure protection system operation set point value during heat inflow was calculated through transient analysis.

The pressure change of the RCS was confirmed by setting the secondary-primary coolant temperature difference to 1°F, 2°F, 5°F, 10°F, 25°F, and 50°F, respectively. In addition, it was confirmed that the pressure of the reactor coolant system is stable below the pressure-temperature limit value of the reactor pressure vessel when heat is introduced into the reactor coolant system. Considering the safety-related operator action time, the temperature difference between the secondary and primary coolant, which does not cause a pressure transient, was analyzed to be less than 5°F.

This paper analyzed the low-temperature overpressure transient state during heat inflow with relatively high frequency in nuclear power plants.

## 2. Methods and Results

### *2.1 RETRAN-3D*

RETRAN-3D [2], a code developed by EPRI, was used to evaluate the safety of heat input transients. The characteristics of RETRAN-3D are as follows.

One-dimensional and two-dimensional calculations are possible, the number of nodes is less than 1,000, and the analysis results are relatively accurate.

The scope of use is applied to various fields such as simulator development and verification of new concept facilities, and is used for optimal analysis codes, but recently, attempts are being made to replace design codes.

As for the advantages, it is excellent in simulating the behavior of the entire system and can be applied to all types of power plants.

### *2.2 Governing equations*

The secondary side of the steam generator was modeled with Time Dependent Volume, and in the initial steady-state calculation, the temperature of the secondary side of the steam generator was given the same as that of the primary side, so that there was no heat transfer between the primary and secondary sides of the steam generator. The heat input transient is initiated by increasing the temperature on the secondary side of the steam generator by 1°F. The rotational speed of the reactor coolant pump was assumed to be the same as the rotational speed of the pump at full power operation. As a result, this has the effect of increasing the heat transfer rate between the primary and secondary steam generators, leading to conservative calculations. The heat generated from the reactor coolant pump coincided with the time to increase the temperature of the secondary side of the steam generator, maximizing the energy flowing into the primary system during the transient start time.

This assumption is valid because the heat input transient occurs over a very short period of time. Therefore, changes in the flow rate and pressure of the energy flowing into the reactor cooling system and the discharged coolant can be predicted using the first law of thermodynamics for the system and the equation for conservation of mass and momentum.

First, 1st law of thermodynamics for systems [3]

Energy increase rate of system = Energy increase rate by heat transfer + Energy increase rate by work transfer

$$\frac{\partial}{\partial t}\int_{RCS} e\,\rho dV = (Q_{net\,in} + W_{net\,in})_{RCS} = \sum_{i}^{n}(\rho_i\, C_{P_i}\Delta T_i)\Delta V_i\,(Btu) \quad (1)$$

where

e : Total energy per unit mass
ρ : Density of water
ΔT : Temperature difference
$C_{P_i}$ : Specific heat
RCS : Reactor Coolant System,
V : Volume of water
$Q_{net\,in}$: Amount of heat transferred to RCS
$W_{net\,in}$: Amount of work transferred to RCS

Water, a fluid, decreases in volume when pressure is applied from the outside and returns to its original state when the pressure is removed. This property is called compressibility of water. Water is also compressed, albeit slightly, and the degree of compression differs depending on the amount of air contained in the water.

$$P_{max} = [P + \frac{\partial P}{\partial M}\Delta M + \frac{\partial P}{\partial U}\Delta U + \frac{\partial P}{\partial M_v}\Delta M_v + \frac{\partial P}{\partial M_{nc}}] \quad (2)$$

Where

P: Volume pressure

$\frac{\partial P}{\partial M}$ : Ppressure change with respect to volume total mass

$\Delta M$ : Change in volume mass

$\frac{\partial P}{\partial U}$ : Pressure change with respect to volume internal energy

$\Delta U$ : Change in volume internal energy

$\frac{\partial P}{\partial M_v}$ : Pressure change with respect to volume vaporphase mass

$\Delta M_v$ : Change in volume vaporphase mass

$\frac{\partial P}{\partial M_{nc}}$ : Pressure change with respect to volume noncondensable mass

$\Delta M_{nc}$ : Change in volume noncondensable mass

Second, Conservation equation of mass and momentum [4]

When energy is transferred to the RCS, the volume of the RCS water increases as the temperature of the reactor coolant increases and the density of the water decreases. At this time, the pressurizer of the reactor coolant system is at full water level (Solid Water), and since it is a closed system, the pressure increases, and when the pressure rises to the extent that the LTOP facility operates, outflow mass flow is generated.

Mass conservation equation for water

$$\frac{dM}{dt} = W_{in} - W_{out} \quad (3)$$

$$\frac{1}{A}\frac{\partial W}{\partial t} + \frac{\partial}{\partial z}\left(\frac{W^2}{\rho A^2}\right) = -\frac{\partial P}{\partial z} - K\frac{W|W|}{2\rho A^2} + \frac{\Delta P_{PRZ}}{\Delta z} \quad (4)$$

### *2.3 Nodalization*

Hanbit Units 1 and 2 are Westinghouse-type nuclear power plants with a reactor heat output of 2,900 MWt and a rated flow at the core inlet of 40,248 lbm/sec. The reactor coolant system consists of a reactor pressure vessel, three steam generators, three reactor coolant pumps, a pressurizer, and a flow path connecting them. Fig. 1. shows the nodalization used for RETRAN-3D[2] analysis of Hanbit Units 1 and 2, which are Westinghouse-type three-loop nuclear power plants. The reactor coolant loop of the primary system is modeled as loops A, B, and loop C, and each loop consists of a Hot-Leg, a steam generator heat transfer tube, a pump suction pipe, a reactor coolant pump, and a Cold-leg. And the pressurizer and surge line are connected to Loop B. The secondary side of the steam generator was modeled with Time Dependent Volume to maintain constant thermal hydraulic conditions. This is to ensure that the temperature of the secondary side does not decrease as heat is transferred from the secondary side of the steam generator to the primary side. The reactor pressure vessel was composed of 14 control volumes. The reactor coolant system was modeled with 16 control volumes. The pressurizer and surge line were composed of one control volume each. PRT was modeled with Time Dependent Volume, and the design pressure of 100 psig was used for the pressure boundary to show conservative results. For the low-temperature overpressure transient analysis, the safety valve located at the inlet of the residual heat removal system and the pressurizer PORV were modeled respectively. It was assumed that the PORV at the top of the pressurizer starts to open when the pressurizer pressure reaches the opening set pressure and takes 2 seconds to fully open. It was assumed that the low-temperature overpressure protection valve at the inlet of the residual heat removal system started to open at the valve opening pressure setpoint and fully opened after 10% accumulation.

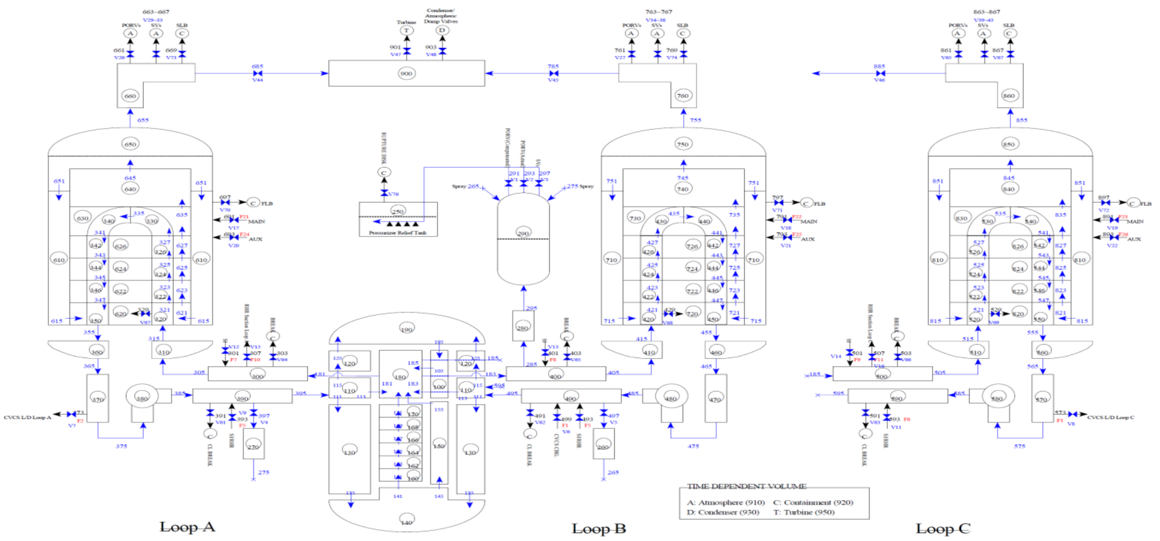


Fig. 1. shows the nodalization used for RETRAN-3D

*2.4 System input data*

As initial conditions, the water level of the pressurizer was full, the temperature of the RCS cold pipe was 140 °F, the RCS pressure was the RCP minimum operating pressure of 327 psia, and the opening setting of the low temperature overpressure protection valve was set to 451 psia, the minimum opening setpoint in the technical specification. When operating one RCP, the heat output generated by the reactor coolant pump was 6.44 MWt. Assuming a single active device failure, the low-temperature overpressure protection system was analyzed using one series. That is, when performing the analysis of the pressurizer PORV, it was assumed that only one pressurizer PORV with a high set value was useful among the two available pressurizer PORVs. The safety valve at the inlet of the residual heat removal system was analyzed assuming that only the safety valve of loop A among the safety valves of loops A and C was useful. The purpose is to find a temperature deviation that will not cause a low temperature overpressure transient state after inputting operating variables according to the conservative assumptions applied during the low temperature overpressure safety evaluation and the operating conditions of the field operation procedure.

*2.4 Determining the Time of RCS Pressure Relief Actions*

Response results for safety-related operator action times are determined based on plant conditions in ANSI 58.8. [5] Response times implemented based on each plant condition are used in the analysis to cope with pressurized water reactor (PWR) transients and are based on empirical simulator measurements from EPRI and Westinghouse Electric Corporation. RCS pressure transients are classified as Moderate Frequent Incidents. Symptom-based operating procedures and guidelines provide a structure for operator diagnosis and action during transient scenarios. An operator response structure is proposed for the purpose of subdividing a sequence of events at various time intervals. If a single device operation is assumed, it is assumed that operator action can be mitigated after at least 7 minutes [5+(1+N) minutes = 5 minutes diagnosis time + 2 minutes action time] from the time of event occurrence. Guidelines for reducing operator response time in the event of an alarm require a clear alarm response procedure.

*2.5 Results*

With the initial conditions set, the difference between the temperature of the secondary side of the steam generator and the temperature of the cold leg is 1°F, 2°F, 5°F, 10°F, 25°F, and 50°F, respectively, and the reactor coolant pump ( RCP) was started to check the pressure change of RCS. As a result of the analysis, under the condition that the reactor coolant pump (RCP) is started, the RCS pressure increases up to the low-temperature overpressure protection valve opening setpoint value (451 psia) regardless of the temperature difference between the secondary side temperature of the steam generator and the temperature of the RCS cold-leg. The time to reach the low-temperature overpressure protection valve operating set point (451 psia) for each temperature deviation when the RCP is started under the pressurizer full water level condition is as follows Fig. 2. and [Table 1].

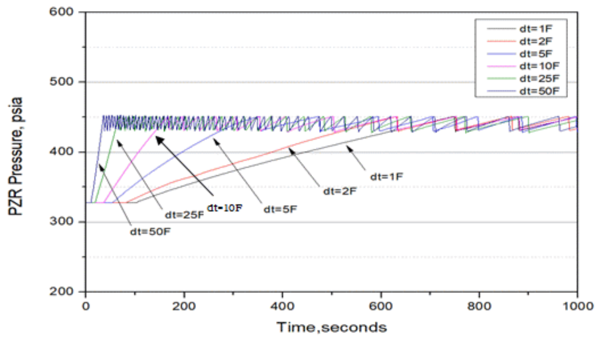


Fig. 2. Pressure changes in case of heat inflow (Initial temperature 140°F)

[Table 1] LTOP set point reach time follow to temperature deviation

| Temperature Deviation °F | LTOP set point Reach time (sec) |
|---|---|
| 1 | 745.0 |
| 2 | 620.0 |
| 5 | 353.0 |
| 10 | 167.2 |
| 25 | 67.4 |
| 50 | 35.7 |

Diagnosis within 5 minutes from the occurrence of the low-temperature overpressure condition, entering the relevant procedure, taking action to prevent the pressure from increasing any more, and restoring the RCS pressure to normal pressure within 2 minutes, the action is terminated. As a result of the RETRAN-3D analysis, when the temperature difference between the secondary and primary coolants is less than 5 °F, the RCS pressure can be stabilized within 120 seconds by increasing the letdown flow rate after 300 seconds with the intervention of an operator. RCS pressure transient can be prevented when the RCP is started when the secondary-primary coolant temperature difference is less than 5°F. That is, RCS pressure stabilization actions can be taken before reaching the low-temperature overpressure protection system operating set point (451 psia).

## 3. Conclusions

The temperature difference in which the pressure of the reactor coolant system can be stabilized was analyzed below the set operating value of the low-temperature overpressure protection system when heat is introduced into the RCS. Through RETRAN-3D analysis, it was confirmed that the temperature difference between the secondary side coolant of the steam generator and the coolant of the primary system was less than 5°F. It is possible to secure the integrity of the reactor pressure vessel and prevent the operation of the low temperature overpressure protection system by preventing the occurrence of low temperature overpressure when the reactor coolant pump is started in a temperature deviation of 5°F or less. Prevention of low-temperature overpressure transients will not affect the power plant start-up process and will be of great help in improving the utilization rate and safety of nuclear power plants.

## REFERENCES

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