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Evaluation of Passive RHRS Design for OPR1000

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1. Introduction

In the current design of OPR1000, the auxiliary feedwater system (AFWS) is used to cool down the reactor coolant system (RCS) after reactor trip by using the steam generators (SGs). The new conceptual design of the passive residual heat removal system (PRHRS) is considered to enhance the plant safety without using the AFWS. The PRHRS cools the RCS by forced or natural circulation using PRHRS heat exchanger in the in-containment refueling water storage tank (IRWST).

The feasibility study for YGN 5&6 nuclear power plant is performed to evaluate the acceptability of the new design and to verify decay heat removal and the cooling capability of the RCS, instead of the AFWS.

2. System Description and Analysis Methods

Figure 1 shows a simple design for the PRHR system. The PRHRS is a kind of passive core cooling system similar to the system designed for AP600 and AP1000. Inlet and outlet side of the PRHR HX is connected to the hot leg of RCS and the outlet plenum of the SG, respectively. The hot water of the hot leg passed through the PRHR HX in the IRWST is cooled due to the heat transfer from PRHR HX to IRWST. The natural convection occurs in PRHRS due to the temperature difference between the inlet and outlet of the PRHR HX. IRWST needs to remove residual heat in the RCS without boiling during two hours. The IRWST can be cooled by the shutdown cooling system.

Figure 2 shows RELAP5/MOD3 nodalization for PRHRS. This nodalization is added to the RELAP5 nodes for YGN 5&6. The inlet and the outlet of PRHRS are divided into several nodes to consider its elevation and pipe routing. It is assumed that both valves actuate when the level of SG reaches to the low SG level. The PRHR HX is modeled as pipe component and is divided into several nodes to model heat transfer.

The analysis is performed using the RELAP5/MOD3 code [1]. To evaluate the decay heat and RCS sensible heat removal, a loss of condenser vacuum (LOCV) event is selected because the temperature and the pressure of RCS during this event are the highest among AOOs (anticipated operational occurrences).

Table 1 shows the principal initial conditions and assumptions with setpoints and PRHRS design value. The initial conditions and assumptions for analysis are assumed as normal operating condition.

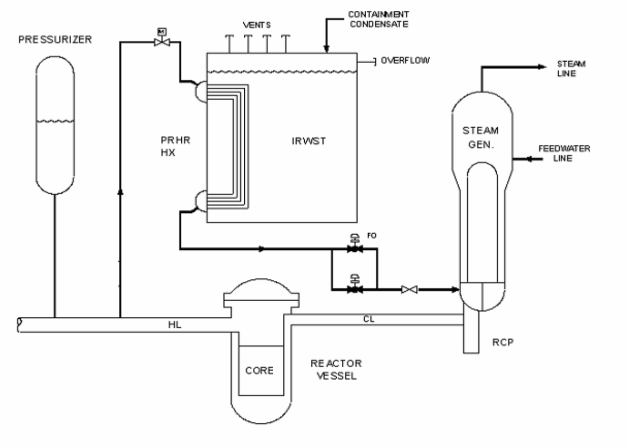

Figure. 1. Simple Configuration of PRHR System

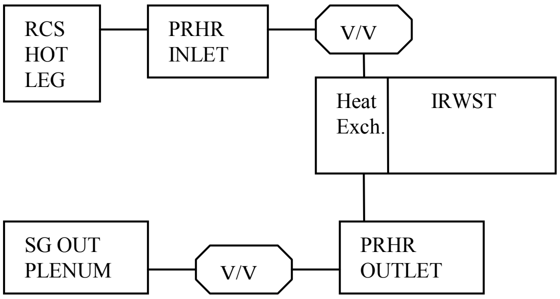

Figure. 2. RELAP5 Nodalization for PRHR System

Table 1. Principal Initial Conditions and Assumptions

Parameters	Value
Main Steam and Feedwater Flow	Stop at 0 sec.
Initial Core Power	102 % (2871.3 MWt)
Decay Heat	ANS 73+ uncertainty
Loss of Offsite Power	Assumed
High PZR Pressure Trip Setpoint	Maximum (2421psia)
Low PZR Pressure Setpoint for Safety Injection	Minimum (1705psia)
Low SG Level Setpoint for AFW	Nominal (23.5%WR)
PSV and MSSV Setpoint	Nominal (2500/1250 psia)
AFW Pump Flow Rate	Nominal (625gpm)
Core Inlet Temperature	Nominal (564.5°F)
RCS Pressure	Nominal (2250 psia)
RCS Flow Rate	Nominal (100%)
PZR Level	Nominal (52.6%)
SG Level	Nominal (79%WR)
IRWST Capacity	AP1000 (78900ft^3 and 28.58ft)
PRHR HX Tube	
Size	0.62"(ID)/0.75"(OD)
Number	689 ea
Material	Inconel600
HTC	134 Btu/hr-ft2-°F

The initial core power is assumed as 102% of the nominal full power and the decay heat of ANS 73 with uncertainty (20% up to 1,000 sec and 10% after 1,000 sec.).

All control systems were assumed to operate in the manual mode. The minimum water volume and height of the IRWST are assumed as in Table 1. The size of the PRHR HX tube is assumed as 0.62 in for inside diameter and 0.75 in for the outside diameter and the 689 tubes are assumed. However, the heat transfer coefficient of HX is assumed as the minimum value under the worst conditions.

3. Results and Discussion

Four cases are used to evaluate the feasibility of PRHRS during a LOCV event. For the Case 1, the residual heat removal of RCS is performed by AFWS like OPR1000. For the Case 2, 3 and 4, the residual heat removal of RCS is performed by PRHRS without AFWS. For the Case 1, 2 and 3, the heat transfer from PRHR HX is performed under the natural convection caused by a LOOP (loss of offsite power). For the Case 4, the heat transfer from PRHR HX is performed under the forced convection caused by the reactor coolant pumps (RCPs). For the Case 2 and 3, the RCS-to-IRWST heat transfer is calculated using constant HTC (heat transfer coefficient) and the convective heat transfer model in RELAP5, respectively.

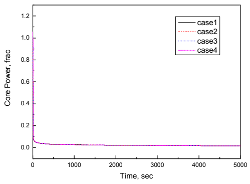

Figure 3. Core Power

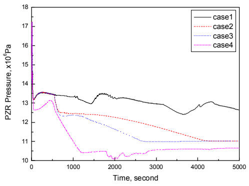

Figure 4. PZR Pressure

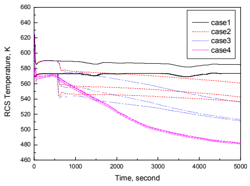

Figure 5. RCS Temperature

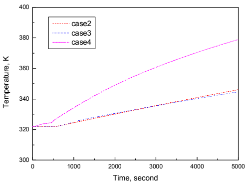

Figure 6. IRWST Temperature

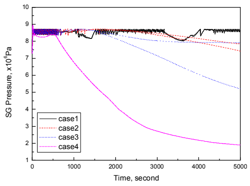

Figure 7. SG Pressure

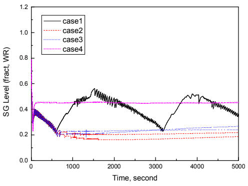

Figure 8. SG Level

Figures 3 through 8 provide the NSSS thermal-hydraulic behavior during the LOCV event. Figure 3 shows the comparison of core power for each case. The pressurizer pressure of the PRHRS design is lower than that of the AFWS design. As expected, the HTC of RELAP5 (Case 3) provided a little lower pressure than the constant HTC (Case 2). This trend is similar to the RCS cooldown provided in Figure 4. The forced convection case (case 4) predicted a higher cooling than the natural convection case. This phenomenon is also shown in the temperature increase of IRWST (Figure 5). Figure 7 and 8 provide the SG secondary pressure and level behavior.

Table 2 shows the cooling rate of the RCS and the expected time when the RCS temperature reaches the shutdown cooling entry condition (350˚F). For Case 1, the cooling rate is the smallest among all cases because the cooldown is performed through the SG inventory. The decrease of the SG inventory causes the decrease of heat transfer from the primary to the secondary system. However, the temperature of RCS will reach shutdown cooling entry condition within 4 hours, which meets the URD requirement, if the operator controls the SG level using atmosphere dump valve and manual operation of AFW pump. For Case 4, the IRWST will start to boil within two hours because of the forced convection by the RCPs. However, the water in IRWST will be prevented from boiling if the shutdown cooling system is operated to cool the IRWST.

The results of all cases showed that the PRHRS used for this study has enough cooling capability for residual heat removal after reactor trip.

Table 2. Cooling Rate and Expected Time to 350 ^{o}F

Case	Cooling Rate, ˚F/hr	Expected time to be reach 350˚F, hr
1	-8.2	30.9
2	-39.8	6.3
3	-78.3	3.2
4	-134.9	1.7

4. Conclusion

The feasibility study on the passive residual heat removal system for a LOCV event showed that the system is enough to remove decay heat and has enough cooling capability for the RCS without AFWS. It is verified that the temperature of RCS is able to reach the shutdown cooling entry conditions within the limited hour for natural circulation if the HTC of PRHR HX is properly controlled. Therefore, the new design of the passive RHRS is acceptable to remove the decay heat of OPR1000.

REFERENCES

[1] The RELAP5 Development Team, "RELAP5/MOD3 Code Manual," NUREG/CR-5355, August 1995.