Natural Circulation Cooldown Analysis for APR 1400 using the SPACE code

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1. Introduction

The result of a computer simulation of natural circulation cooldown (NCC) for APR1400 is presented in this paper. The simulation has been performed for the NCC process comprised of 4 hour hot standby, cooldown within the administrative maximum cooldown rate and depressurization phases, using the SPACE code [1].

2. NCC process

The nuclear power plant must demonstrate that it can be brought from the normal operation to shutdown cooling entry conditions by NCC using only safety-grade systems under the assumption of a single failure. Natural circulation is dominated by decay heat, component elevations, primary to secondary heat transfer, loop flow resistance and void formation. The natural circulation flow to remove decay heat can be achieved by a difference of fluid density between the core region and the Steam Generator (SG) tube region. Atomspheric Dump Valves (ADVs) are used as a safety-grade means of the Reactor Coolant System (RCS) cooldown. ADVs are also used to restore and stabilize the RCS by controlling the SG secondary steam release rate.

A nuclear power plant should be maintained at hot standby for 4 hours following the loss of offsite power and reactor trip. After the 4 hour hot standby, the RCS is depressurized by opening PZR Gas Vent Valve (PGV) to the point where the RCS subcooling margin decreases to the minimum control limit. This initial depressurization enables an early inventory make up through the Safety Injection System (SIS) as soon as the RCS contraction occurs due to the RCS cooldown.

A cooldown is initiated with a normal cooldown rate by increasing steam release rate through the ADVs. Once the RCS subcooling margin increases to a maximum control limit, a depressurization is initiated by reopening the PZR gas vent valve. During this depressurization period, the RVUH steam void starts to form and is allowed to grow until it reaches a volume of maximum control limit. From this time on, RVUH Gas Vent Valve (UGV) opens to collapse steam void. This not only collapses the RVUH steam void, but also depressurizes the RCS.

During the whole transient, the depressurization or cooldown process is to be ceased whenever the RCS subcooling margin decreases below minimum control limit or exceeds maximum control limit in order to prevent void formation or overcooling in the RCS, and the process is to be resumed whenever the subcooling margin is restored within the appropriate operating range. Steam void formation is allowed in the RVUH during the whole cooldown and/or depressurization period as long as core heat removal is maintained.

3. Application Results

Figure 1 shows the APR1400 nodalization for this simulation, and Figures 2 through 5 show the simulation results. The pressure of PZR given in Figure 2 shows slow depressurization in the initial 4 hours of hot standby period and two deep depressurizations by opening a PZR vent valve. The pressure of PZR at the end of depressurization is about 4 MPa.

The level of PZR is shown in Figure 3. For 4 hours of hot standby the level is kept on an almost constant value and starts to decrease after the hot standby due to RCS cooldown. It is rapidly increased at the 5.3 hour since void is formed at the RVUH and then decreased because of removing the void from the RVUH.

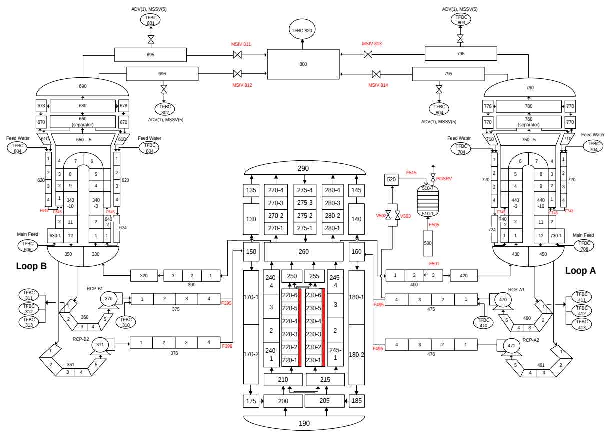

Figure 1. APR 1400 Nodalization

The pressure of steam generator is shown in Figure 4. The pressure appeares as constant for 4 hours of hot standby and then deeply is depressurized at the 4 hour and the 5.3 hour at which the cooldown process is initiated by opening ADVs.

Figure 5 shows the temperatures of reactor coolant. The temperatures of inlet and outlet are about 565 K and 580 K at the hot standby and then decrease into 440 K and 480 K, respectively. About 100 K is decreased by 2 times of cooldown. The first and second cooldowns are performed by opening ADV valves to decrease the

SG pressure with the rate of 5 M Pa/hr. The temperature of hot leg at the end of cooldown in this simulation is found to be about 480 K.

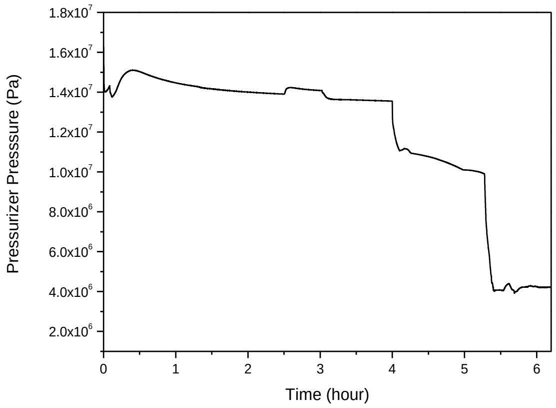

Figure 2. Pressure of pressurizer in the NCC process

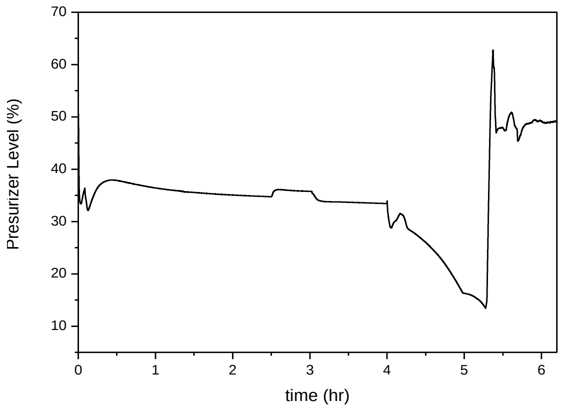

Figure 3. Level of pressurizer in the NCC process

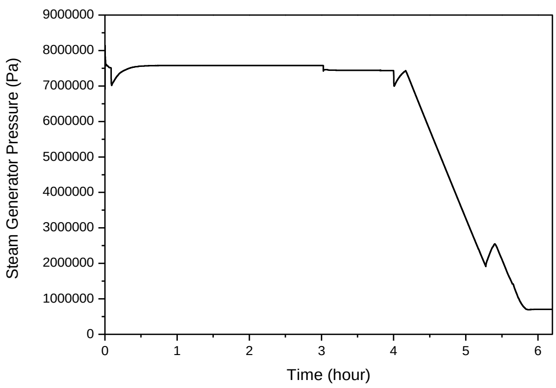

Figure 4. Pressure of steam generator in the NCC process

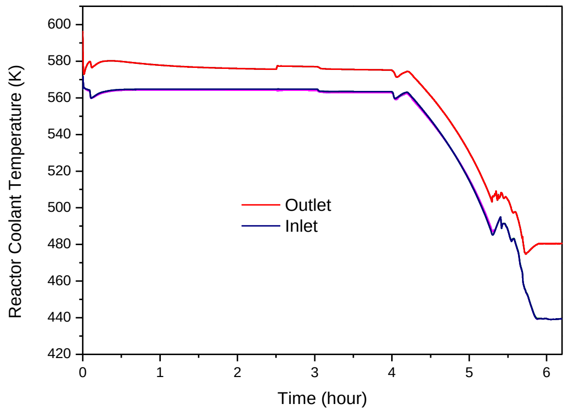

Figure 5. Temperatures of reactor coolant in the NCC process

4. Conclusions

The NCC process for APR1400 was simulated using the SPACE code. That process was divided into hot standby, cooldown and depressurization phases. The hot standby state was maintained for 4 hours after reactor trip. During the cooldown period, the temperature of hot leg was decreased to 480 K. The depressurization of pressurizer was reached at 4 M Pa in the end of NCC process. As a result, it is found that the SPACE code can simulate properly the NCC process for APR1400.

Acknowledgment

This study was performed under the project, “Development of safety analysis codes for nuclear power plants” sponsored by the Ministry of Knowledge Economy.

REFERENCES

[1] S. J. Ha, C. E. Park, K. D. Kim, and C. H. Ban, “Development of the SPACE Code for Nuclear Power Plants”, Nuclear Technology, Vol. 43, No. 1, 2011