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ASSESSMENT OF SYSTEM BEHAVIOR AND ACTIONS UNDER LOSS OF ELECTRIC POWER FOR CANDU

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1. **Introduction**

Following Fukushima accident, the safety of nuclear power plant under severe accidents from external events is internationally reassessed. As one of unexpected accidents which happen very infrequently, this analysis assumes station black out (SBO) and even the emergency power is not available due to earthquake. For the analysis, the CANDU-6 plant in Korea is considered and only the passive components are operable. The other systems are assumed to be at failed condition due to the loss of electric power.

At this accident, only the inventories remained in the primary heat transport system (PHTS) and steam generator can be used for the decay heat removal. Due to the transfer of decay heat, the inventory of steam generator secondary side is discharged to the air through passive operation of main steam safety valves (MSSVs). After the steam generators are dried, the PHTS is over-pressurized and the coolant is discharged to fuelling machine vault through passive operation of degasser condenser tank relief valves (DCRVs). Under this situation, the maintenance of the integrity of PHTS is important for the protection of radionuclides release to the environment. Thus, deterministic analysis using CATHENA code is carried out for the simulation of the accident and the appropriate operator action is considered.

2. Methods and Results

2.1 Assumptions and conditions of Analysis

CANDU-6 reactor has 380 horizontal fuel channels surrounded by a cool low-pressure heavy water moderator. The PHTS has two loops and each loop has two core passes with 95 fuel channels per core pass. For the thermal-hydraulic analysis of upset condition, the circuit models including PHTS, secondary system and emergency core cooling systems are established and the core is modeled as multiple average channel group. One core pass is represented by 7 average channel groups and each channel group represents average channel behavior of constituent 11~19 channels in multiple average channel group. The conditions of inlet and outlet headers of fuel channels are approximately 11 MPa(a)/ 265 ℃ and 10 MPa(a)/310 ℃, respectively.

The loss of electric means that the operations of the systems and components to mitigate the accident are not considered. Only the components operated by passive actuation are assumed to be available in this analysis. In this accident, the degasser condenser relief valves in primary system and main steam safety valves in secondary system operate as the upstream pressure increases. These two kinds of valves prevent the over-pressurization of primary and secondary systems.

2.2 Analysis Model

Best-estimate analysis is performed using CATHENA thermal hydraulic computer code [1] to assess the system behavior. The plant is assumed to be initially operated at 100% FP. At the start of the simulation all primary heat transport pumps and feedwater pumps stop and the reactor and turbine also trip. The PHTS pressure and inventory control system, such as feed and bleed system, pressurizer heater and pressurizer steam bleed valves are assumed to be unavailable. The liquid relief valves (LRVs) connected in two outlet headers are assumed as failed to open from the start of simulation due to the loss of electric power and remains open until the end of the simulation.

As the feedwater pumps stop, the coolant to the steam generator secondary side is not supplied. As long as the coolant remains in the steam generator secondary side, the decay heat is well transferred through steam generator U-tubes and the generated steam is discharged to air through MSSV. Four MSSVs are installed at each steam generator and sequentially open according to their set-points at 5.11, 5.17, 5.20 and 5.24 MPa(a).

As the inventory of steam generator secondary side is depleted, the decay heat cannot be removed and the pressure and temperature of the primary system start to increase. As the LRVs open at the start of accident, the coolant in the primary system discharges to the degasser condenser tank (DCT) that has spring-loaded safety valves, which are open when the up-stream pressure exceeds 10.16 MPa(a). DCRVs have a size of 2”x3” of the proportional opening type and liquid valve capacity is assumed as 25 kg/s. The pressure of DCT increases as the LRVs discharge the coolant into the DCT. The pressure of DCT is increased to almost the same pressure with the Reactor Outlet Header (ROH). As the pressure of DCT is increased the discharge flow stops until the pressure of the primary side starts to increase.

2.3 System behavior

The sequence of events is listed in Table I. The pressure behaviors of PHTS and secondary system are shown in Fig. 1. Four core passes and four steam generators have the symmetrical layout and show almost the same behavior under SBO accident. The PHTS pressure decreases as reactor trips and the coolant discharges to DCT through LRVs and the pressure approaches to equilibrium condition according to decay heat production and heat transfer to secondary system. The PHTS pressure starts to rise after the inventory of steam generator secondary side is depleted about 6,000s. About 6,500s, DCRVs (3332-RV11 and 3332-RV21) are open. The steam is discharged at first and then the liquid is discharged when the DCT level increases over the DCRV location. The DCRVs liquid discharge flow increases to maximum of 25 kg/s at each valve. At about 7,500s, DCRV discharges mostly steam and the PHTS pressure increases to maximum of 14 MPa(a). When DCRV discharge flow is almost steam, the PHTS pressure starts to decrease. Fig. 2 shows the liquid and steam discharge flow rate of RV11. RV21 shows almost the same trend with RV11.

The decay heat is transferred to the steam generator secondary side and the generated steam is discharged to the air through MSSV. As shown in Fig. 1, the operation of MSSV makes the pressure of secondary system maintain at MSSV open set-point. As the feedwater is not supplied to steam generator, the inventory of steam generator secondary side is depleted and the inventory of four steam generators is depicted in Fig. 3. When the PHTS inventory is depleted, the PT is dried out and ruptured eventually. The wall temperature of PT estimated using circuit simulation with multiple average channel group is depicted in Fig. 4. The detailed channel failure characteristic can be estimated from a single channel analysis [2].

A manual operator action to supply the feedwater to steam generators is considered. The operator opens MSSVs at 4,800s after start of SBO accident to depressurize the steam generator before the steam generator secondary side is dried out. As the valves between dousing tank and steam generator are at the condition of failed open, the 2,059 tons water in dousing tank can be supplied to steam generators if the pressure of steam generator is decreased. Maximum feedwater flow of 8 kg/s to each steam generator is assumed considering valve capacity. As a result, the PT failure can be prevented if the operator action is done and feedwater is supplied to steam generator under SBO accident.

Table I: Sequence of Events

Events	Time (sec)
Reactor and turbine trip, Loss of all electrical power, LRV open	0
MSSV open	3
SG empty	6,000
DCRV open	6,500
DCRV steam discharge	7,500
ROH peak pressure reached (~ 14 MPa(a))	7,600

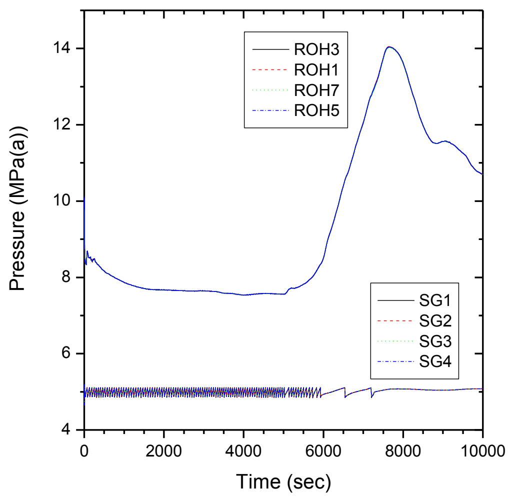

Fig. 1. reactor outlet header and steam generator pressure

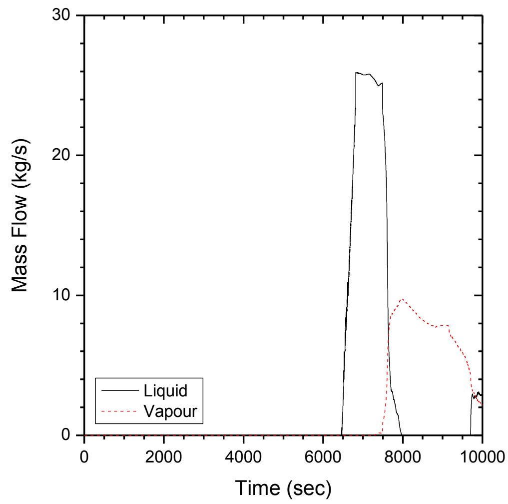

Fig. 2. degasser condenser relief valve flow

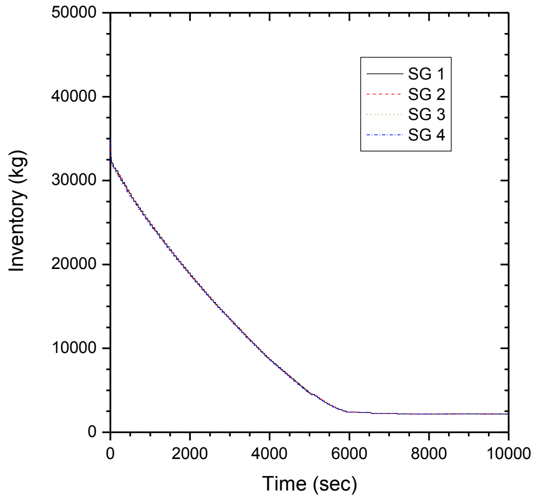

Fig. 3. the inventory of steam generator secondary side

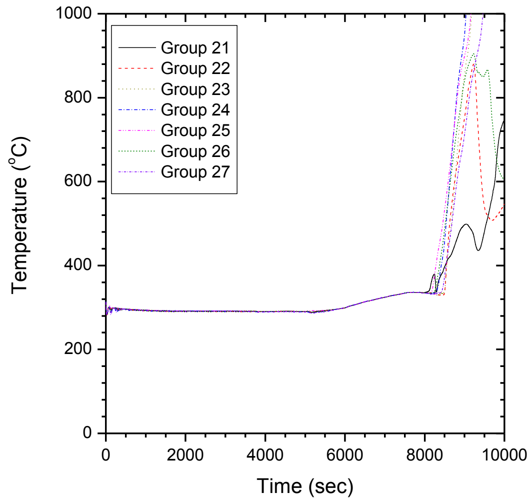

Fig. 4. the temperature of pressure tube

4. Conclusion

The loss of electric power results in the depletion of steam generator inventory which is necessary for the decay heat removal. If only the passive system is credited, the PT can be failed after the steam generator is depleted. For the prevention of the PT failure, the feedwater should be supplied to the steam generator before 4,800s after the accident. The feedwater can be supplied using water in dousing tank if the steam generators are depressurized. The decay heat from the core is removed through natural circulation if the feedwater can be supplied continuously.

5. Acknowledgements

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REFERENCES

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