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Behavior and Response Capability of CANDU 6 NPP at Shutdown Condition during Extended Loss of All AC Power

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1. Introduction

After the Fukushima accident, there has been a growing interest in countermeasures against station black out (SBO) in nuclear power plants. In particular, there have been needs to prepare a strategy for responding to power plants considering the loss of all the AC power, so called the Extended Loss of All AC Power (ELAP). The accident showed that could lead to serious consequences even under the initial conditions of low power/shutdown operation. It would be seemed that the current Emergency Operating Procedures (EOP) of domestic nuclear industry is not enough to deal with the ELAP accident. So the additional procedures or strategies for coping with ELAP situation have been required.

The purpose of this study is to identify the behavior and response capacity of the CANDU 6 plant (Wolsong Unit 1,2,3,4) during shutdown operation for ELAP. In case of analysis for the full power condition, the fuel cladding and pressure tubes are damaged within 2 hours without the operator actions during ELAP. However if the operator acts appropriately within the time, the plant cooling could be maintained without core damage [1].

The analysis was performed with CATHENA, which is an industry standard toolset to simulate thermal-hydraulic phenomena in pressurized heavy water reactor [2].

2. Scenario and Assumption

The ELAP of heavy water reactor nuclear power plant assumes loss of off-site power, standby diesel generator, and emergency diesel generator. It means loss of all AC power except Class 1&2 power.

The ELAP accident was assumed to be occurred in operation mode 4 with Emergency Core Cooling System (ECCS) blocked. The initial conditions of primary and secondary side for the accident are following Table 1.

Shutdown Cooling System (SDCS) is not available due to SBO after the accident. So it assumed that the available systems are following;

- main steam safety valve (MSSV)
- liquid relief valve (LRV)
- gravity feeding to SG from Dousing Tank (DT)
- external injection to SG secondary

Table 1. Initial conditions for ELAP analysis

	Parameter	Conditions
Primary side	Outlet Header pressure	7 MPa
	Outlet Header temperature	100℃
	PHTS pump	tripped
	PZR	solid mode
	SDCS	operating
Secondary side	SG pressure	0.1 MPa
	SG level	normal
	Main and Aux. feed	isolated
	ASDV	isolated

The analysis was performed on case A and B during the accident. Each case is assumed as following;

<u>Case-A</u>
- No operator action

<u>Case-B</u>
- MSSV open at 4,000sec
- SG gravity feeding from DT at 5,800sec

3. Results

3.1 Case A

In this scenario, there is no operator action after the accident. But reactor is tripped automatically by reactor trip system in a few seconds.

As shown in Figure 1, the inlet and the outlet header pressure of case A increases to LRV opening pressure and maintained constantly. MSSV open at 3.7hr makes the pressure decreasing below the LRV set-point. The pressure increases again to the point due to the steam generator (SG) depletion at 6.5hr. It means the loss of SG cooling capability from that time.

The inlet and the outlet header temperature increases continually in the early stage. And the temperature remains constant during opening MSSV. But at the point of SG depletion, the temperature increase again up to the corresponding of the PHTS saturation pressure as shown in Figure 2.

The cladding temperature increases and exceeds the integrity reference value of 800℃ at about 7.2hr as shown in Figure 3. Also the pressure tube temperature exceeds 600℃ at which the tube is damaged.

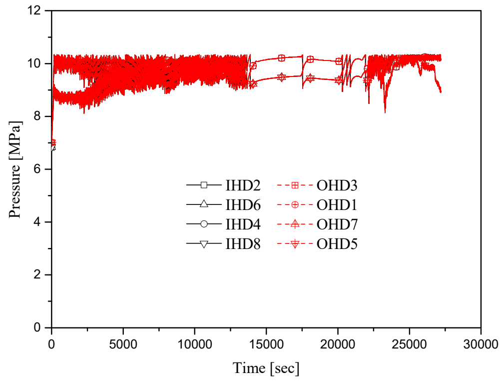

Fig.1. In/Outlet Header Pressure (case A)

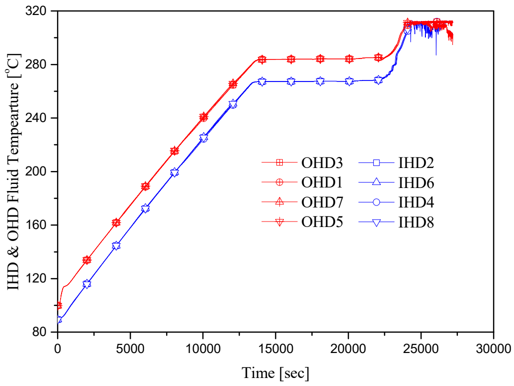

Fig.2. In/Outlet Header Temperature (case A)

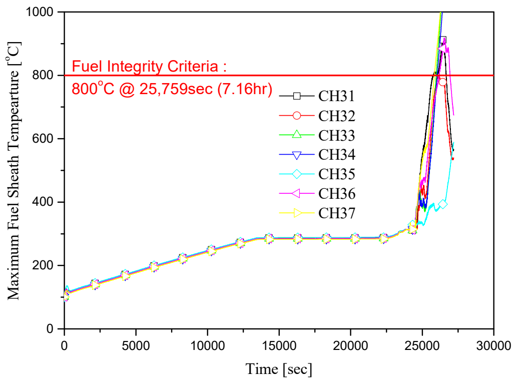

Fig.3. Fuel Cladding Temperature (case A)

3.2 Case B

Scenario case B assumes operator intervention during ELAP. Accident progression up to 4,000sec is the same with case A.

As shown in Figure 4, the inlet and outlet header pressure is steadily decreased after MSSV open. Therefore, the dousing tank water is fed to SG at 1.6 hours. The pressure is decreased to 0.2MPa. The inlet and outlet header temperatures are also decreased as shown in Figure 5. And the temperatures are maintained between 90 and 120℃ by SG cooling.

The maximum temperatures of fuel cladding increase to 175℃ as shown in Figure 6. It locates well below the point of the fuel cladding damage. It shows that the damage of the integrity of cladding and pressure tube can be prevented through the operator actions during ELAP condition.

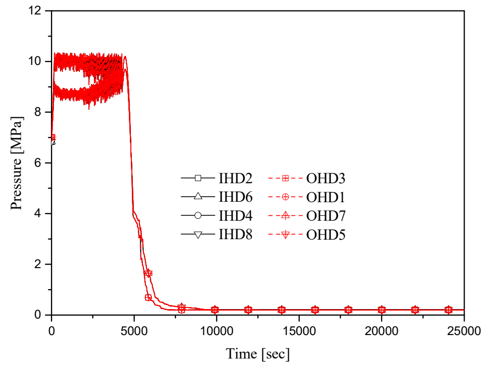

Fig.4. In/Outlet Header Pressure (case B)

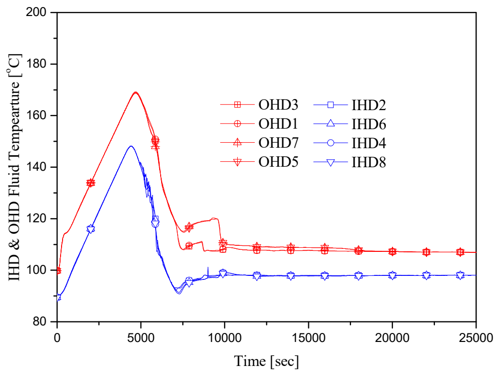

Fig.5. In/Outlet Header Temperature (case B)

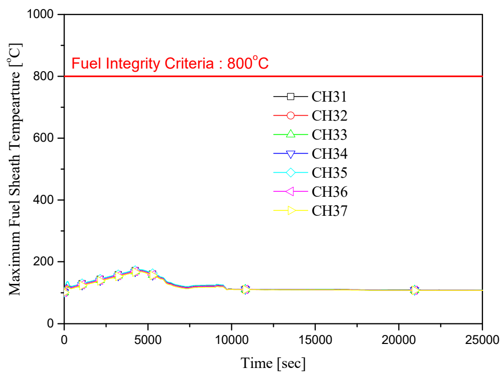

Fig.6. Fuel Cladding Temperature (case B)

4. Conclusions

The analysis was performed to estimate the behavior and the response of CANDU 6 plant at shutdown operation mode 4 with ECCS blocked during ELAP accident. If there is no operator action in the accident, the damage of the pressure tube occurs within about 7 hours. However, if the operator acts appropriately with available measures, the plant cooling could be maintained without the core damage.

These results can be used as basic data for developing a strategy or a procedure to cope with ELAP situation during the shutdown operations.

REFERENCES

[1] Kyung Jin Lee, Behavior and Response Capability of CANDU 6 NPP during Extended Loss of All AC Power, KNS Autumn Meeting, 2016

[2] B.N. Hanna, CATHENA: A thermal-hydraulic code for CANDU analysis, Nuclear Engineering and Design 180, 1998