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

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1. Introduction

The Fukushima Daiichi nuclear disaster can be summarized as an accident caused by extreme natural disasters that resulted in the reactor core melt-down and a massive release of radioactive. The disasters brought the long-term Station Black-out (SBO). For these lessons of the Fukushima nuclear accident, the US and, European governments, IAEA and other regulatory agencies around the world have recommended follow-up measures to build and develop a strategy to cope with the Extended Loss of All AC Power (ELAP)

The purpose of this study is to identify the behavior and response capacity of the CANDU 6 plant during ELAP such as the one occurred in the Fukushima accident. The analysis was performed with CATHENA, which is an Industry Standard Toolset (IST) to simulate thermal-hydraulic phenomena in pressurized heavy water reactor.

2. Modeling for Analysis

CATHENA code has been developed for best-estimate transient simulation of CANDU plants. It is a one-dimensional, two-fluid thermal-hydraulic simulation code designed to analyze two-phase flow and heat transfer in the plant. It has been used for the analysis and simulation of the consequences of transient and accident scenarios in CANDU reactors. CATHENA provides high flexibility in modeling thermal-hydraulic systems [1].

Initial reactor power, taking into account the uncertainty, is assumed to be 103%. A system model is set up with two circuits, and includes coolant system, steam and feed water system, and an emergency core cooling system (ECCS). The four core paths in the system model consist of each of the seven multi-round channel groups. The nodalization model is shown in Fig. 1. The core model used in the analysis is an aged core model. This core model reflects the pressure tube creep in each channel group.

3. Analysis Assumption and Results

3.1 No Operator Action (case 1)

3.1.1 Scenario and Assumption

Scenario case 1 assumed no operator intervention during ELAP. ELAP in CANDU 6 plant means loss of offsite power, standby diesel generators and emergency diesel generators. Only Class 1 & 2 Power is available.

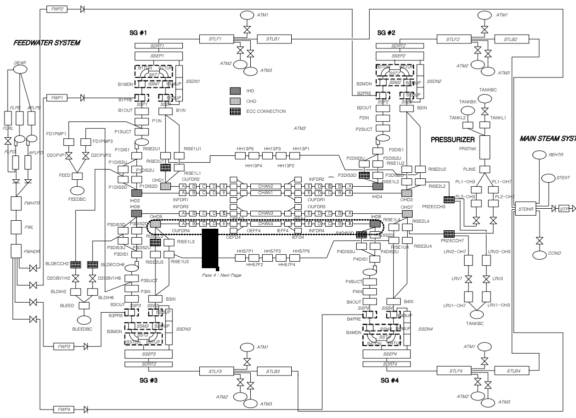

Fig.1. Nodalization Model of CANDU 6 NPP

In this situation, most of the safety systems are unavailable, and the only available system is shutdown system (SDS), main steam safety valve (MSSV), and liquid relief valve (LRV).

The heat transport pump seal leak is not assumed. The integrity test result for CE type RCP Seals shows that there is no leak up to 50 hours [2]. Wolsong unit 1 heat transport pump seals are the same type. If there is no operator intervention, the pressure tube will be damaged before the coolant pump seal leaks.

3.1.2 Results

Reactor is tripped by a later trip signal of the first and second trip system. As shown in Fig. 2, the inlet and outlet header pressure is slightly raised and reduced, and then maintained constantly. The pressure is raised again after approximately 4,000 seconds, which is 1,000 seconds faster than the steam generator (SG) depletion. And the pressure is maintained near the set point of the LRV opening pressure.

In the early stage of the accident, inlet header temperature increases and outlet header temperature decreases as shown in Figure 2. The temperature of headers also rises as the pressure trend at the time. And it maintains the saturation temperature. It means the loss of SG cooling capability from that time.

The cladding temperature after the loss of the cooling capacity increases and exceeds the integrity reference value of 800℃ at about 6,700 seconds as shown in Fig. 3. Also the pressure tube temperature exceeds 600℃ and the tube is likely damaged.

3.2 Operator Action (case 2)

3.2.1 Scenario and Assumption

Scenario case 2 assumes operator intervention during ELAP. Accident progression up to 30 minutes is the same with case 1. The actions and response measures in case of operator action are the following:

- MSSV opening within 30 minutes after the accident
- Water supplying from dousing tank to SG by gravity
- Power supplying by mobile generator
- Emergency water supplying to SG with EWS pump

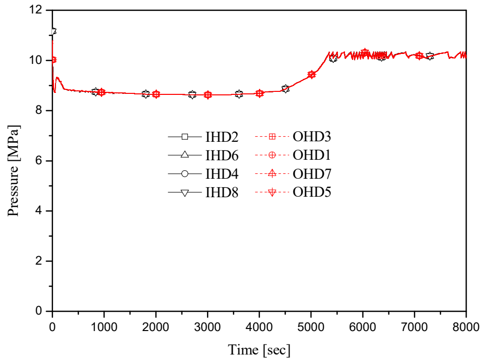

Fig.2. In/Outlet Header Pressure (case 1)

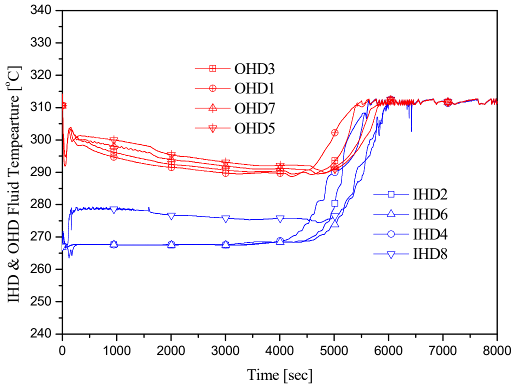

Fig.3. In/Outlet Header Temperature (case 1)

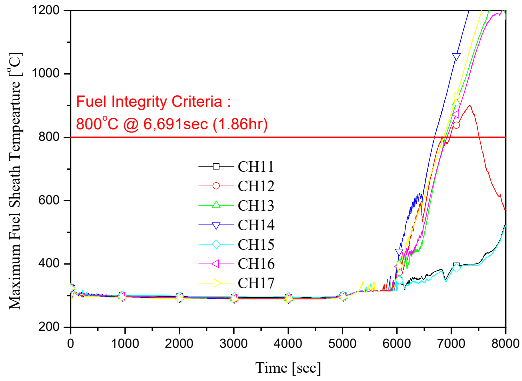

Fig.4. Fuel cladding temperature (case 1)

3.2.2 Results

As shown in Fig. 5, the inlet and outlet header pressure is steadily reduced after MSSV opening. And the dousing tank water is feeding to SG at 1 hour; the pressure is decreased to 0.3MPa. The inlet/outlet header temperatures are also decreased as shown in Figure 6. And it maintains between 80 and 120℃ by SG cooling. The fuel cladding temperature increases to 400℃ partially, but does not exceeds the reference temperature of 800℃, which could damage the fuel cladding.

It shows that the core cooling, integrity of cladding and pressure tube can be maintained through the above response measures during ELAP condition.

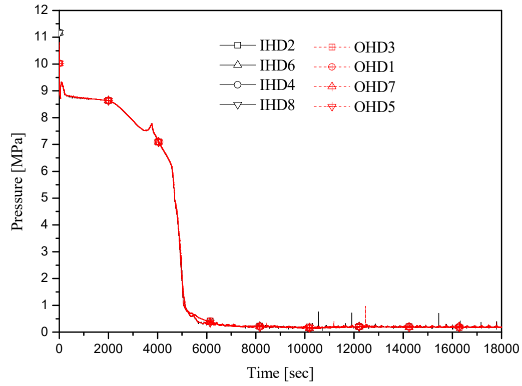

Fig.5. In/Outlet Header Pressure (case 2)

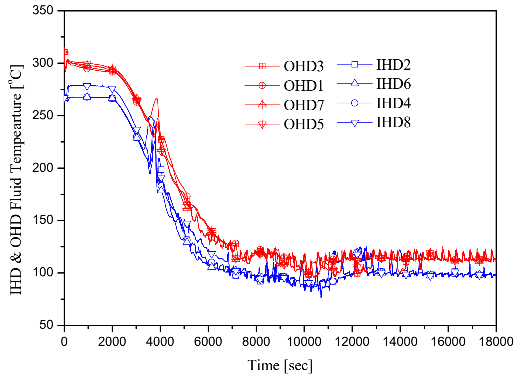

Fig.6. In/Outlet Header Temperature (case 2)

4. Conclusions

The analysis was performed to estimate behavior and response of CANDU 6 plant during ELAP condition such as the one occurred during the Fukushima accident. Without the operator action during ELAP, the fuel cladding and pressure tubes are damaged within 2 hours. However, if the operator acts appropriately with several available measures, the plant cooling could be maintained without core damage.

These results would be helpful for developing a strategy to cope with ELAP situation.

REFERENCES

[1] B.N. Hanna, CATHENA: A thermal-hydraulic code for CANDU analysis, Nuclear Engineering and Design 180,1998
[2] CE NPSD-1199-NP, Model for Failure of RCP Seals Given Loss of Seal Cooling, CEOG Task 1136, July 2000