Evaluation of Required Water Sources during Extended Loss of All AC Power for CANDU NPPs

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1. Introduction

Fukushima accident was caused by lasting long hours of Station Black-Out (SBO) triggered from natural disaster. This accident had resulted in the reactor core damage.

After the accident, the regulatory authorities of each country (Japan, US, EU, IAEA, and etc.) have recommended developing the required systems and strategies to prevent the Extended Loss of All AC Power (ELAP) such as Fukushima accident.

The purpose of this study is to evaluate the required water sources to maintain hot standby conditions until 72 hours during ELAP situation. The analysis was performed with CATHENA code. CATHENA code has been developed for the best-estimated transient simulation of CANDU plants. It has been used to analyze and simulate the consequences of transient and accident scenarios in CANDU reactors.

2. Modeling for Analysis

When SBO occurs in the plant, operator should take an action to cool down primary heat transfer system (PHTS) to prevent the reactor core damage. One of the actions is the opening of main steam safety valve (MSSV) manually. There is no active equipment available to supply water to Steam Generator (SG) in the early stage of the event except for gravity feed.

If operators open the MSSV and SG pressure drop down close to the atmospheric pressure, gravity feed from dousing tank to SG will be available. Gravity feed provides the water required for cooling PHTS through SG.

Gravity feed model is considered with water head difference between the dousing tank and SG. After SG inventory is restored to normal level, gravity feed flow rate is controlled to keep the SG level constantly.

If the dousing tank depletes, water can be supplied by the emergency water supply (EWS) pump, which could be served emergency power from mobile generator (MG) before the dousing tank depletion.

The nodalization model of CANDU NPP is shown in Fig. 1.

3. Assumption and Results

3.1 Assumptions

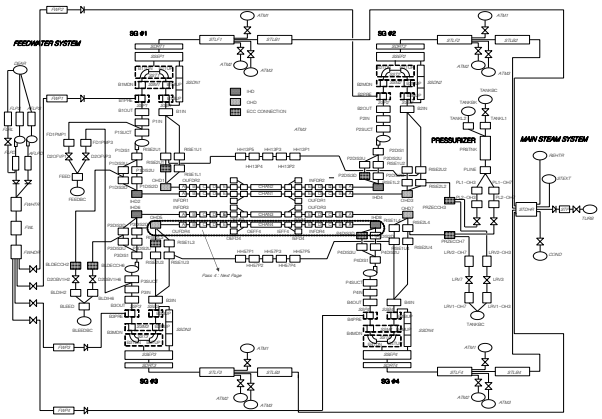

Fig.1. Nodalization Model of CANDU NPP

- ○ SBO in CANDU NPP means Loss of off-site power and standby diesel generator (SDG), emergency power supply system (EPS). So, it assumed loss of all power in analysis except for the class I, II.
- ○ Event is initiated from full power operation and considered beyond Design Basis.
- ○ Initiating event is a loss of off-site power with a concurrent loss of on-site AC power.
- ○ No other event will be in progress during the analysis time frame (fire, coincident equipment failure, etc.)
- ○ Coolant pump seal leak is not assumed. The integrity test result for RCP Seals shows that there is no leak up to 50 hours. After 50 hours, there is no seal leakage because PHTS cooled enough [1].
- ○ Pressure loss coefficient of gravity feed line is calculated considering maximum injection flow and water head [2]. The injection flow rate is controlled in accordance with the SG pressure. After the SG level is restored, the injection flow is controlled to maintain the normal level.
- ○ Emergency power for EWS pump and valve control can be restored before 2.5 hours after the accident [2].
- ○ MSSV opens at 1,200 seconds after the accident, and a total opening time is 60 minutes [2].
- ○ It is aimed at maintaining the hot standby conditions for 72 hours after the accident. After that time, the offsite support can be possible.

3.2 Analysis Results

When the operator opens the MSSV at 1,200 seconds after the SBO, the SG is cooled and depressurized. Moreover, the coolant pressure and temperature are

reduced as shown Fig 2 and 3. Fig 4 shows that PHTS inventory is constant. After opening the MSSV, SG pressure (Fig. 5) is reduced near atmospheric pressure, and then gravity feed to SG is initiated. So, PHTS temperature is reduced successively.

SG inventory (Fig. 6) is gradually reduced, because the Main Feedwater is stopped and the MSSV is opened at the set point. After 1,200 seconds, SG inventory is reduced rapidly because of MSSV opening. Then, SG inventory is depleted about 2,850 seconds. However, SG inventory is gradually restored by gravity feed and restored normal level at about 13,000 seconds. After that time, the SG level is kept by SG level control model. Fuel cladding temperature (Fig. 7) and pressure tube temperature decrease as well.

SG cumulative injection amount is utilized to calculate the required water. The cumulative injection amount (Fig. 8) shows a tendency to increase in proportion with time. After the SG inventory is restored normal level at 13,000 seconds, gravity feed flow rate is reduced slightly due to the residual heat of reactor core decreases.

Therefore, the total amount of the cumulative injection flow is about 1,750 tons to maintain the hot standby conditions up to 72 hours after the accident.

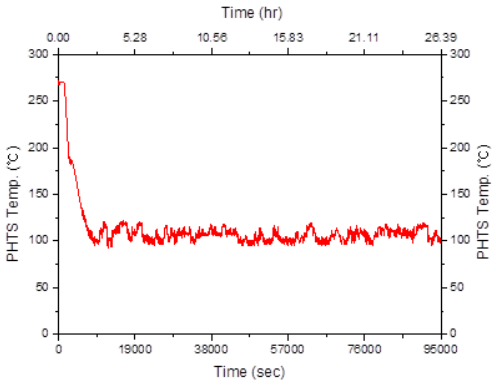

Fig.2. PHTS Temperature

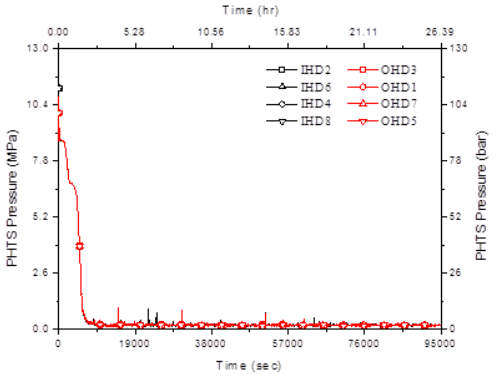

Fig.3. PHTS Pressure

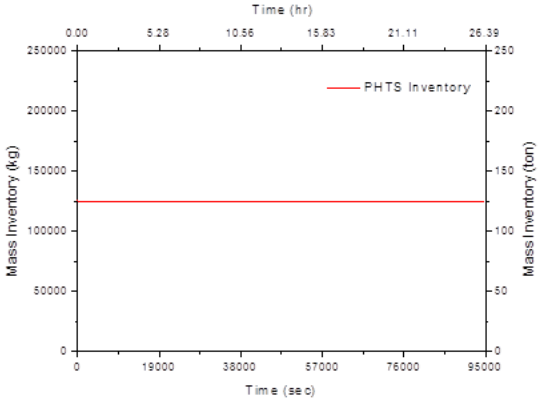

Fig.4. PHTS Inventory

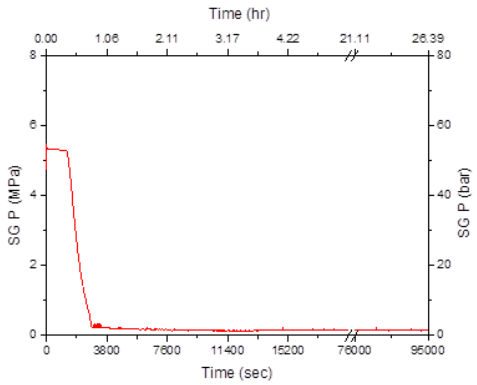

Fig.5. SG Pressure

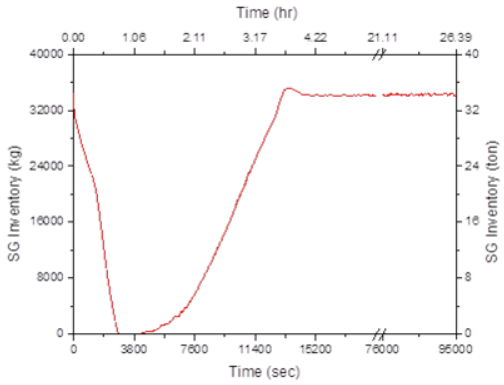

Fig.6. SG Inventory

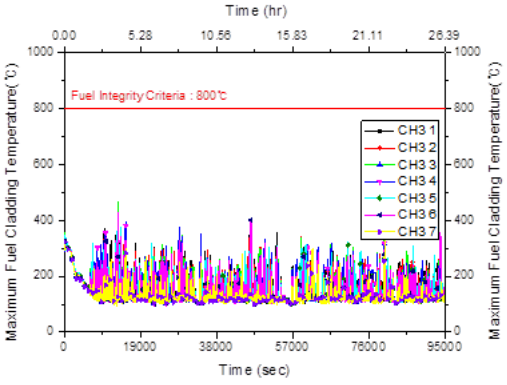

Fig.7. Fuel Cladding Temperature

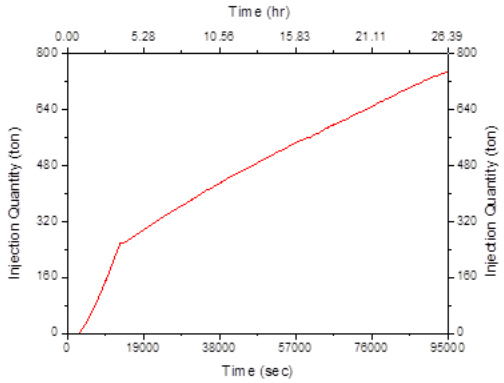

Fig.8. Cumulative Injection Amount

4. Conclusions

This study was carried out to evaluate the strategy to maintain hot standby conditions during ELAP situation in CANDU reactors.

In this analysis, water was supplied to SG by MSSV open and by the gravity feed. It can cool the core without damage until the dousing tank depletion. Before dousing tank depletion, the emergency water supply pump was available by emergency power restoration. The pump continuously fed water to SG.

So it is expected that the reactor core can be cooled down without damage for 72 hours if water source is enough to feed.

This result is useful to make a strategy against SBO including ELAP situation.

REFERENCES

[1] CE NPSD-1199-NP, Model for Failure of RCP Seals Given Loss of Seal Cooling, CEOG Task 1136, July 2000
[2] KHNP, Stress Test Report for Wolsong Unit 1, July 2013.