Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Analysis of PHT Pump Seal Leakage in CANDU Reactors Due to Fire-induced Multiple Spurious Operation

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1. Introduction

In the event of a fire, CANDU plants shall be capable to maintain the reactor safe shutdown in subcritical conditions, removing decay heat, maintaining the integrity of the boundaries, and limiting the release of radioactive materials [1]. As the regulatory body of nuclear safety in Korea requires Fire Hazard Analysis (FHA) including the analysis of multiple spurious operations (MSO), fire-induced spurious actuations are a new issue [2]. Barrier function to fission product release for fire safe shutdown functions of CANDU reactors is to maintain the integrity of the reactor building without leakage of coolant beyond the make-up capability [1].

The purpose of this paper is to identify the allowable leak rate of coolant to achieve the integrity of the reactor building for the fission product barrier, using Integrated Severe Accident Analysis code for CANDU plants (ISAAC).

2. Methods and Results

Coolant leakage can cause the increases of the core temperature and the reactor building atmospheric pressure. Although the leak rate of coolant is less than the maximum flow of a makeup pump, the rise of containment pressure due to the vapor of the leaked coolant can challenge the reactor building integrity. Accordingly, the leak rate to approach the containment design pressure should be confirmed. Particularly, as the leak rate in spite of the same size was expected to be decreased at the low pressure of Primary Heat Transport System (PHTS), the discharge rate at the high PHTS pressure was analyzed. Two MSO scenarios related to the PHTS leakage were one which was the PHTS pump seal failure scenario causing the fire-induced closure of the air-operated seal cooling water valves and the other which was the fire-induced opening of the air-operated liquid relief valves (LRV). The MSO scenario for the allowable leakage selected the release through PHTS pump seals.

2.1 Assumptions of ISAAC Analysis

For ISAAC analysis, we assumed that the reactor trip immediately occurred at the time point of coolant leakage and an auxiliary feed water pump started to supply cooling water to steam generators. Also we considered the operation of the PHTS filling system to make up for the leakage. We supposed that main steam safety valves (MSSV) actuated at the setpoints of MSSV to maintain the pressure in steam generators. We considered that the containment cooling systems such as the reactor building spray system and local air coolers were unavailable for analyzing the maximum containment pressure.

2.2 Analysis of Leakage Rate and Makeup Capacity

Cases for the ISAAC analysis were four; a) the leak rate 2 kg/s plus the makeup capacity 300 tons (case A), b) the leak rate 2 kg/s plus the makeup capacity 150 tons (case B), c) the leak rate 1 kg/s plus the makeup capacity 300 tons (case C), d) the leak rate 1 kg/s plus the makeup capacity 150 tons (case D).

In the results of case A analysis, the makeup water depleted at 44.3 hrs and the pressure of the reactor building was increased until the maximum pressure of 229 kPa(a). It showed that the containment integrity could not be maintained. Also the PHTS pressure was decreased at the depletion of the makeup water and the leak rate was dropped according to the reduction of the PHTS pressure. The core maximum temperature was continually 274 ℃ (547 K) and the fuel heats were removed, as shown in Fig. 1.

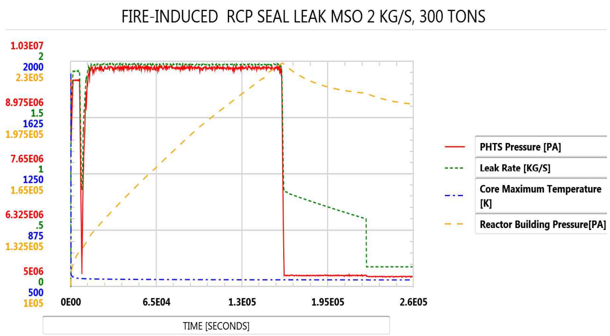

Fig.1. Analysis of Leakage 2 kg/s plus Capacity 300 tons

In the results of case B analysis, the makeup water depleted at 23.3 hrs and the pressure of the reactor building was increased until that time, and the maximum pressure of the reactor building was 183 kPa(a). It showed that the containment integrity could be maintained. Also the PHTS pressure was decreased at the depletion of the makeup water and the leak rate was dropped. The core maximum temperature was maintained within 274 ℃ (547 K) until 52.8 hrs and the core temperature started to be increased after the that time of 52.8 hrs as shown in Fig. 2. The rise of the core temperature showed that the fuel decay heat was not sufficiently removed.

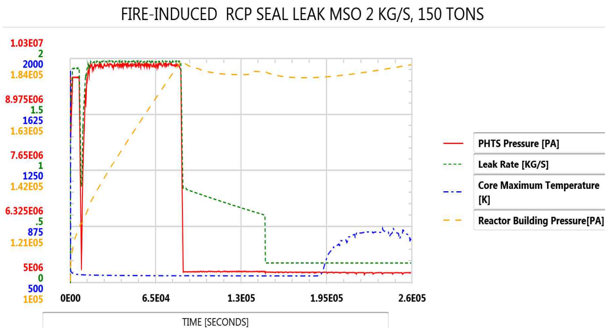

Fig.2. Analysis of Leakage 2 kg/s plus Capacity 150 tons

In the results of case C analysis, the makeup water did not deplete until 72 hrs. Although the pressure in reactor building was increased to 206 kPa(a), the integrity of reactor building could be achieved. Also the PHTS pressure was almost held and the core maximum temperature was maintained within 274 ℃ (547 K), as shown in Fig. 3.

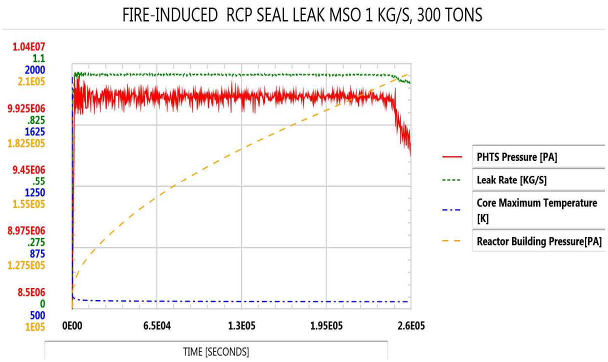

Fig.3. Analysis of Leakage 1 kg/s plus Capacity 300 tons

In the results of case D analysis, the makeup water depleted at 42.8 hrs and the pressure in reactor building was increased until that time, and the maximum pressure of the reactor building was 179 kPa(a). It showed that the containment integrity could be maintained. Also PHTS pressure was decreased at the depletion of the makeup water and leak rate was dropped. The core maximum temperature was maintained within 274 ℃ (547 K), as shown in Fig. 4.

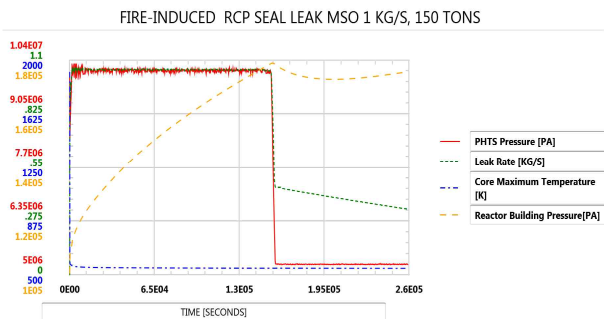

Fig.4. Analysis of Leakage 1 kg/s plus Capacity 150 tons

2.3 Considerations of MSO Scenarios for Barrier to Fission Product Release

As the integrity of the reactor building was achieved in the conditions of the leak rate of 1 kg/s and the makeup water of 300 tons, the containment cooling systems such as the air coolers and the containment spray system were not necessary for the barrier to fission product release for the fire safe shutdown as shown in Fig.3. If the leak rate was 2 kg/s and the makeup water was 300 tons, the containment cooling systems should actuate for the decreases of the containment pressure as shown in Fig.1. If the coolant makeup capacity was less than 300 tons, the barrier of the containment can be maintained but the core temperature can be increased. Accordingly, the less the makeup water capacity was, the better the containment integrity was. However, the systems for the rapid core cooling such as the secondary crash cooling down through steam generators should be considered for the core cooling.

3. Conclusions

As the regulatory body of nuclear safety in Korea requires Fire Hazard Analysis (FHA) including the analysis of multiple spurious operations (MSO), CANDU plants shall implement the MSO analysis for the fire safe shutdown. In particular, the evaluation of MSO scenarios for the barrier to fission product release should be necessary. As the results of the ISAAC analysis, the containment cooling systems should not be actuated under the conditions of the leak rate of 1 kg/s and the capacity of 300 tons, whereas the containment cooling systems should be operated under the leak rate of 2 kg/s and the capacity of 300 tons. Also if it is under the small makeup capacity, the integrity of the reactor building is maintained but the rapid core cooling systems for the decay heat removal function should be considered.

REFERENCES

[1] CAN/CSA N293-12, Fire Protection for Nuclear Power Plants, 2012.

[2] Notice of Nuclear Safety and Security Commission, No.2015-11, Technical Standard about Fire Hazard Analysis, 2015

[3] NEI 00-01, Guidance for Post Fire Safe Shutdown Circuit Analysis, 2011

[4] Integrated Severe Accident Analysis code for CANDU plants (ISAAC) Manual, KAERI

[5] Wolsong unit 2 Final Safety Analysis Report, KHNP