Influence of the LOCA break size at failure time of CANDU fuel channel

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1. Introduction

Novel safety feature of the CANDU (Canadian Deuterium Uranium) reactor in the LOCA (Loss of coolant accident) is the loop isolation system. 380 horizontal fuel channels (FC) in the reactor core, each of which is consisted of the 37 fuel-sheath (clad), pressure tube (PT) and calandria tube (CT) respectively and are divided into two circuits (so called loop) showing bilateral symmetry. Each circuit (same to the loop) has 190 FCs and two circuits are connected through the reactor header to the pressurizer (PZR) under normal operation condition to share identical pressure boundary in the PHTS (Primary Heat Transport System). If the LOCA signal occurs (P_ROH < 5.516 MPa(g)), the inter-circuit motorized isolating valves (3332-MV1 and 3332-MV2) located at both ends of the PZR are closed to isolate the D2O coolant transport path between each circuit connected to the PZR. This strategy is effective in preventing the loss of the coolant inventory at the intact loop in case of the LOCA.

It is well known that the large break size indicates the fast dryout of the liquid coolant in all RCS (Reactor Coolant System) loops of the general PWR. On the other hands, the CANDU reactor existing the loop isolation strategy shows relatively different behavior in the coolant dryout depending on the loop condition (broken/intact). Present study is to evaluate the effect of the break size (large break (LB) vs. small break (SB)) at the LOCA scenario of the CANDU reactor accompanying with the loop isolation. M-CAISER (MARS-CAISER) code facilitates an evaluation of the thermal-hydraulics as well as the severe accident phenomena including the fuel channel failure.

2. Methods and Results

2.1 RCP trip criteria with loop isolation

In PHWR LOCA, RCP (Reactor Coolant Pump) trip in the intact loop will not occur by the low pressure trip signal because the ROH pressure cannot be below the set-value for the low-pressure trip of the RCP (P_ROH < 2.5 MPa(g)) after the loop isolation. Previous study set the RCP trip criteria of the LOCA [1,2], which considers the low pressure trip signal as well as the cavitation trip based on the void fraction of the RCP discharge. This results in RCP operation of the intact loop leading to the forced convection in the intact loop for thousands of seconds before the cavitation trip

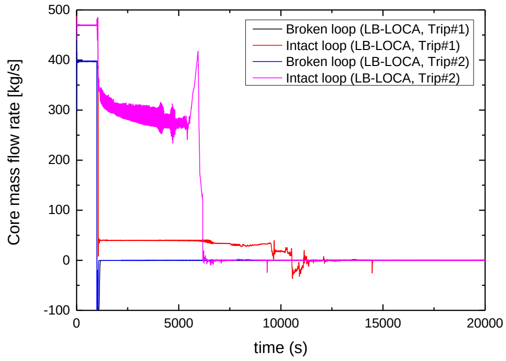

Fig. 1. Core mass flow rate during the LOCA depending on the RCP trip criteria: (trip#1 : cavitation trip based on the KHNP analysis report, trip#2 : Wolsong DM)

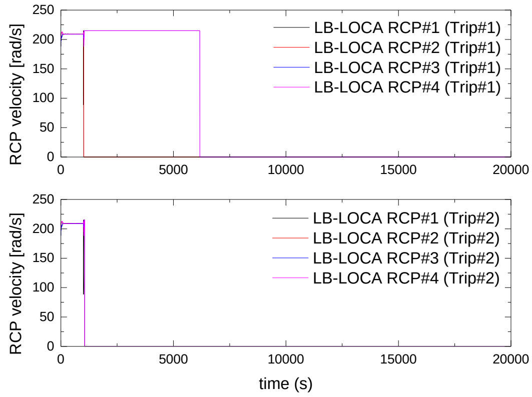

Fig. 2. Pump velocity during the LB-LOCA depending on the RCP trip criteria: (trip#1 : cavitation trip based on the KHNP analysis report, trip#2 : Wolsong DM)

However, the design manual of the Wolsong Unit-II suggested that all four RCPs (two RCPs in each broken/intact loop) are tripped regardless of the loop when the low-pressure trip signal is occurred in the broken loop [3]. These discrepancy results in a substantial difference of the thermal-hydraulics in the intact loop during LOCA and makes a distortion of the remaining coolant inventory and FC dryout time. Present study assumed the RCP trip based on the Wolsong Unit-II design manual (Trip#2 case).

2.2 Characteristics of the break flow

Selected accident scenarios are SB (RIH, 2.5%) and LB (RIH 35%) LOCAs. Sequence of event is identical in both cases; credit for the loop isolation system and no-credit for the emergency core cooling system (ECCS). The LOCA starts from the 1000 s and detailed description of the LOCA sequence of event is available in the previous study [4].

Characteristics of the break flow in both LOCA cases are represented by the mass flow rate. LB-LOCA and SBLOCA show reasonable results of the break flow characteristics compared to the Final Safety Analysis Report (FSAR) of the Wolsong Unit-II [5]. Peak values of the mass flow rate is 3,987 kg/s for the LB-LOCA and 463 kg/s for the SB-LOCA.

Interesting point is to show a remaining coolant inventory of the LB-LOCA is larger than that of the SB-LOCA at the intact loop. LB-LOCA have large break flow leading to fast depressurization of the PHTS, which results in faster loop isolation and larger remaining inventory at the intact loop. The sequence (delayed) logic to close the valve for the isolation is added 20 s after the LOCA signal. Time reaching to the LOCA signal in both cases is 1384 [s] and 1037 [s] for the SB- and the LB-LOCA, respectively. Accumulated discharged mixture inventory (liquid and vapor) until the loop isolation is about 50,000 [kg] and 70,000 [kg] for the LB- and SB-LOCA, respectively.

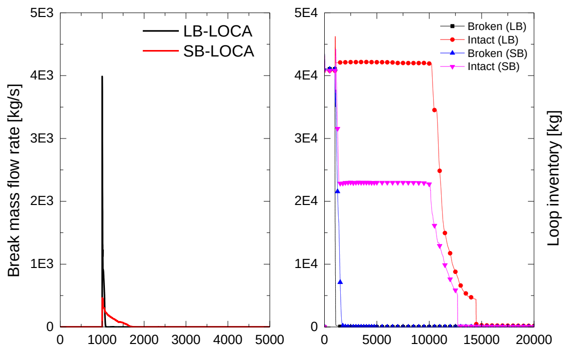

Fig. 3. Break flow and coolant inventory depending on the break size

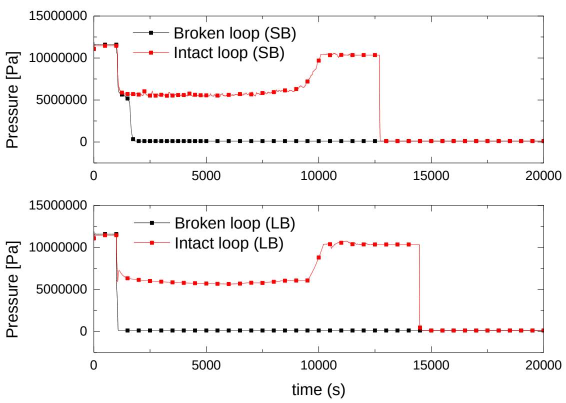

Fig. 4. Pressure of the PHTS depending on the break size

2.3 Fuel channel failure

It is natural that larger coolant inventory remaining in PHTS causes a time delay in the fuel channel failure at the intact loop; failure time of the first fuel channel at the intact loop is 12,702 [s] and 14,466 [s] for the SB- and LB-LOCA, respectively. When a fuel channel is failed, the pressure of the PHTS regardless of maintaining the LRV (Liquid Relief valve) opening value (P_ROH > 10.34 MPa(g)) is instantaneously decreased and superheated steam in the PHTS is discharged to the calandria vessel instead of the LRV (Fig.3)

Fuel channel failure of the M-CAISER code is defined by failure of the calandria tube based on the four mechanisms: average temperature-based failure, local temperature-based failure, creep-rupture failure and loss of the mechanical strength. In the broken loop, the SB and LB-LOCA shows the FC failure by the average temperature (user input value = 1000 K). This is reasonable because the PHTS pressure is nearly identical to the atmospheric pressure (exactly, same to the calandria vessel pressure). On the other hands, the intact loop shows the creep rupture failure of FC. Thermal hydraulic behavior of the intact loop during the LOCA is similar to the case of the station black-out (SBO) accident, which indicates the characteristics of a high-pressure accident.

3. Conclusions

LB-LOCA shows more delayed failure time of the fuel channel compared to the SB-LOCA scenario at the intact loop. This is explained by the combination of the break flow characteristics and the loop isolation, which means large amount of the remained inventory at the intact loop during the LB-LOCA. M-CAISER code is improving the diagnostic capability for the pending safety issues of the CANDU reactor with respect to the severe accident analysis and is updating several mechanistic models (i.e., PT-CT contact and corium pool analysis in the calandria vessel) and consideration of the containment analysis.

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REFERENCES

[1] Y.M. Song et. al., Preliminary Evaluation of Small LOCA under Severe Accident Conditions Using ISAAC and M-CAISER in Wolsong Plants, Transactions of the Korean Nuclear Society spring Meeting, JeJu, Korea, July 9-10 (2020).

[2] KHNP, Final Safety Analysis Report, Wolsong Unit II (Chp. 5), 2006
[3] AECL, Primary Heat transport system, Wolsong NPP-II (86-33100/63310-DM-000, Rev.5), 1999
[4] J. Kang et al., Preliminary analysis of SB-LOCA-induced severe accident at CANDU-6 reactor using M-CAISER code, Transaction of the Korean Nuclear Society, Autumn Meeting, 2020.
[5] KHNP, Final Safety Analysis Report, Wolsong Unit II (Chp. 15), 2006