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Preliminary Analysis about SBO-induced severe accident at CANDU-6 using M-CAISER code

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1. Introduction

Canadian Deuterium Uranium (CANDU) type pressurized heavy water reactor (PHWR) has been under operation at Wolsong Unit II, III and IV in Korea. Since Fukushima accident, regulatory institute (KINS) has moved forward with legislation for the safety review based on Accident Management Plan (AMP) for all nuclear power plant under operation. Therefore, needs to analyze the severe accident in detail and to prepare the strategy about accident mitigation are important issues of growing interest.

KAERI recently developed the severe accident analysis code for PHWR reactor, so called, '*Candu Advanced Integrated SEveRe accident code* (CAISER)' [1,2] and its major feature is distinguishable to existing severe accident codes for PHWR such as MAAP-CANDU and MAAP[(1)]-ISAAC (*Integrated Severe Accident Analysis code for CANDU plants*): detail phenomena inside fuel channel (FC) and mechanistic model for core disassembly [3,4]. Present study is focused on the severe accident phenomena induced by station black out (SBO) scenario at CANDU reactor and introduces the preliminary results. For detail analysis for reactor thermal-hydraulics, MARS-KS code is coupled with CAISER code (so called, M-CAISER).

2. Methods and Results

2.1 Code-to-code coupling

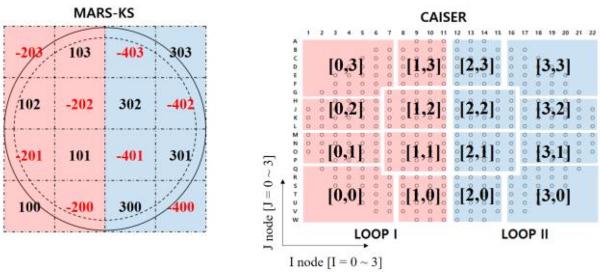

Fig. 1. Node mapping of reactor core at M-CAISER

MARS-KS (KINS Standard) is widely used for the thermal-hydraulic analysis of the reactor system under design basis accident and is coupled with the CAISER code with dynamic linked library (dll) [5]. Overall reactor system of CANDU type reactor is designed by MARS-KS code. Mass and energy balance of the solid part at the reactor core including 380 horizontal FCs (with fuel, clad, pressure tube and calandria tube) and calandria tank are designed by CAISER code to simulate the core failure (melting and relocation). Thermal-hydraulics of D_2O coolant is calculated by the MARS-KS. To achieve the code-to-code coupling, node mapping between codes is required. MARS-KS and CAISER describe the 380 FCs as 16 nodes (4 x 4 for I x J *Cartesian coordinate*) (Fig. 1). Twelve nodes (K) along the flow direction is also considered and 3-dimensional analysis about the fuel/clad and FC failures as well as the thermal-hydraulics are available by using M-CAISER code.

2.2 CANDU-6 modeling

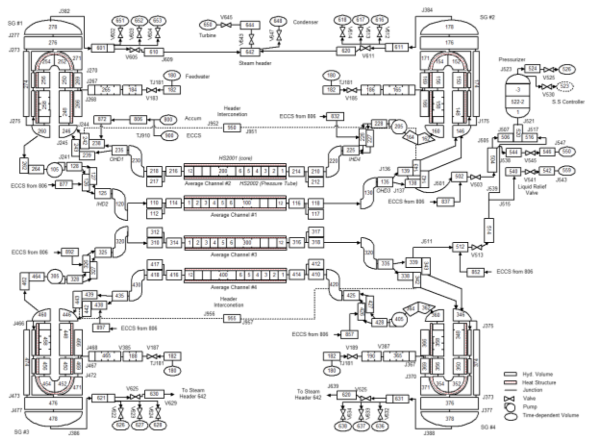

Fig. 2. Node system of general CANDU type reactor using M-CAISER

CANDU has unique feature of primary heat transport system (PHTS) as opposed to the PWR; a high-pressure coolant is independently flowed in each FCs and they submerged into low-pressure moderator of calandria tank. Each fuel channel has 37 fuel pins designed by 15 nodes (3 x 5 for M x N with axisymmetric *Cartesian coordinate*). We considered a distributed power and flow rate of 380 FCs and this facilitates an analysis of fuel channel failure depending on local power, flow and elevation at each FC. In case of MARS-KS, four outlet header (OHD) and four inlet header (IHD) are described with 16 outlet feeder (OF) and 16 inlet feeder (IF). Each FCs is described by the pipe component without heat structures by MARS-KS because the energy and mass balance at the solid part of the reactor core is only solved by CAISER. Steam generator, pressurizer, loop

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[(1)] MAAP is an Electric Power Institute (EPRI) software program that performs severe accident analysis for nuclear power plants including assessments of core damage and radiological transport. A valid license to MAAP4 and/or MAAP5 from EPRI is required interconnection and safety valve (i.e., Main Steam Safety Valve (MSSV), Liquid Relief Valve (LRV), and Pressurizer Relief Valve (PZR-RV)) are described by MARS-KS (Fig. 2). Present study does not consider the rupture disk of calandria tank as well as the reactor vault.

2.3 Steady state analysis

Based on the Wolsong Unit II Final Safety Analysis Report (FSAR), steady-state results obtained from the M-CAISER was evaluated under 103% reactor power [6]. All major parameters are reached to steady state values of FSAR with marginal deviation (Table I). In particular, the quality of outlet header (OHD) is about 4 % and this indicates that the void fraction can be as high as 30 % under normal operation pressure of CANDU 6 type reactor (~ 10 MPa) [7].

Table I: Steady state analysis

Parameter	FSAR	M-CAISER
RIH pressure (kPa)	11.42	11.83
ROH pressure (kPa)	10.00	9.81
RIH temperature (K)	541.15	541.15
ROH temperature (K)	583.15	583.50
ROH quality (%)	4.90	4.60
Suction pressure of PHTS pumps (MPa)	9.58	9.49
PZR level (m)	12.48	12.47
D_2O storage tank level (m)	1.40	1.42
Coolant flow rate per pass (kg/s)	1903.0	1899.6
Steam flow rate to turbine (kg/s)	1063.0	1064.0
SG steam temperature (K)	533.15	533.98
SG pressure (MPa)	4.7	4.7
SG level 'NR' (m)	2.5	2.5
SG recirculation ratio (-)	5.1	4.6

2.4 Transient analysis

For validation, we checked major sequences of event in SBO accident between M-CAISR and MAAP-ISAAC code. Sequence of event at SBO scenario is based on the IAEA-TECDOC [8] with loss of Class III and IV power. Most of the active safety systems (i.e., auxiliary feed-water system and emergency water supply system) are assumed to be failure. Shield cooling, dousing spray and local air cooler (LAC) are not applicable in the present study. LRV is available as the overpressure protection system of the PHTS due to credit for instrumentation air supplement (Table II).

After reactor trip, decay heat instantaneously decreases with loss of coolant flow rate. Main steam safety valve (MSSV) repetitively opens and close at the set point to protect an overpressure of secondary side, which results in decrease of steam generator (SG) inventory (Fig. 3,4). When the SG depletes, the pressure of pressurizer increases due to loss of heat sink at secondary side and the set point for LRV open reaches. Therefore, the coolant inventory at PHTS starts to decrease, which indicates the start of FC dryout.

Major difference between MAAP-ISAAC and M-CAISER is time for FC failure, which causes the difference of blowdown of PHTS. Failure of the FC is related to the failure of calandria tube (Fig. 5) and we expected two reasons. The first is due to difference of FC failure criteria between two codes. Under high pressure accident like SBO, the creep failure will be dominant among several failure criteria. Two codes adopt the method using Larson-miller parameter. Compared to the M-CAISER (1000K), MAAP-ISAAC have conservative criteria (2200K). The second is related to the moderator level. M-CAISER have simple model to describe the evaporation of moderator without pop-up phenomena by rupture disk. This will influence the decrease rate of moderator level and its dry-out time compared to MAAP-ISAAC (Table II).

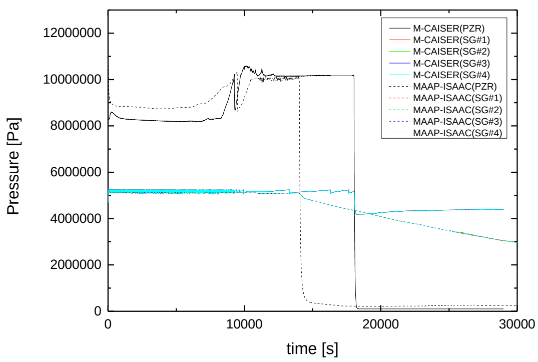

Fig. 3. Pressure of pressurizer and steam generator

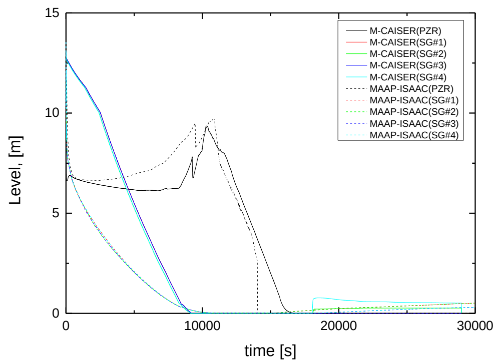

Fig. 4. Level of pressurizer and steam generator

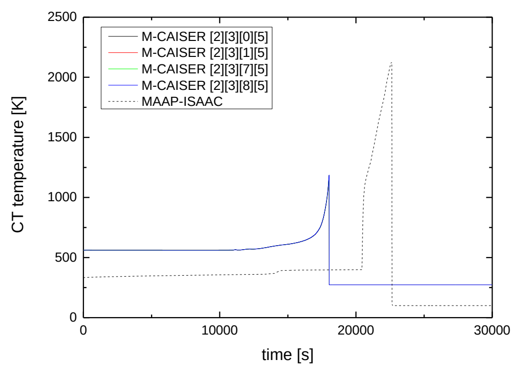

Fig. 5. Calandria tube temperature

Table II: Major sequence of event during SBO accident

SOE	MAAP-ISSAC	M-CAISER
Class III & IV power loss Reactor trip Reactor coolant pump trip Main feed water pump trip Turbine governor valve close	0	0
MSSV open [seconds]	0	0
SG dryout	10041	9188
LRV first open	9473	9258
PZR dryout	14034	16720
Single FC dryout	12751	11483
Single FC uncover	19414	18000
FC failure	22649	17795
CV dryout	40054	25687

3. Conclusions

Preliminary results about SBO-induced severe accident scenario were evaluated by M-CAISER code. Results of steady-state and transient calculation showed reasonable, compared with the FSAR and MAAP-ISAAC code, respectively. M-CAISER can predict the In-FC phenomena such as fuel/clad failure with local point view. MAAP-ISACC provides several failure criteria of the reactor core depending on user input with average temperature of fuel/clad/pressure tube/calandria tube, while M-CAISER facilitates an evaluation of their local failure based on symptom-based mechanistic models occurred during severe accident (i.e., sagging, slumping, non-uniform circumferential temperature gradient along the pressure tube and cladding tube).

Detail analysis into FC (i.e., local temperature of fuel/clad/pressure tube/calandria tube) is available and this indicates that an overestimation for fuel/clad or FC failure will be resolved by M-CAISER code. Further investigation are planning to evaluate the several weakness issues of CANDU-6 reactor recently arisen from the technical reports [11], coping with them by using the M-CAISER code to support the regulatory board;

- revisiting overpressure protection system of PHWR including degassing condenser relief valve (DCRV),
- carbon steel feeder pipe oxidation a potential risk with hydrogen gas against the containment integrity and
- sensitivity analysis about the core disassembly by considering the sagging and slumping model.

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