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Thermal hydraulic behavior under Station Blackout for CANDU6

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ABSTRACT

To evaluate thermal hydraulic behavior under typical severe accident sequences for the CANada Deuterium Uranium (CANDU) in China, the model of CANDU6 Nuclear Power Plant (NPP) is built with the code of RELAP5/SCDAP. The plant model includes Primary Heat Transport System (PHTS) with a simplified model for balance pipes, Steam Generator (SG) secondary system, calandria vessel (CV) and moderator system, and calandria vault. The PHTS model consists of the inlet headers, feeders and end fittings, fuel channels, outlet headers, pressurizer, reactor coolant pumps, and SGs. Each PHTS has liquid relief valves (LRVs) at the reactor outlet header to relief the pressure. The core is modeled by a simplified nodalization with four channels representing the 380 fuel channels arranged in 22 rows and 22 columns. The fuel bundles are modeled as 12 axial nodes and the 37 fuel elements of each fuel bundle, PT, CT and gas-filled annulus are modeled with the SCDAP core components. When the fuel channels collapse onto the bottom of the CV, the debris and CV are modeled by the COUPLE module which generates two-dimensional finite element mesh. Station Blackout caused by the failure of off-site AC Power with subsequent loss of all on-site standby and emergency electric power including Class III and IV is selected and analyzed thermal hydraulic behavior during the accident sequence until the CV failure, including the PHTS and SG response, CV response and calandrial vault response. The results show that most phenomena, such as fuel channel dry-out, fuel channel failure, moderator boiling, core collapsing to CV, and CV failure, can be simulated. Model discussions provide some suggestions to pay attention on and model modification should be made in the near future. This work can give some technical support to severe accident management measures and to develop severe accident management guidelines.

1. Introduction

The core of the CANada Deuterium Uranium (CANDU) power reactor consists of 380 horizontal fuel channels in a large cylindrical calandria vessel (CV), which is surrounded by a water vault with large amount of light water. The CV with large inventory of subcooled moderator acts as the heat sink under severe accident sequences, holding melt debris for a period of time (Meneley et al., 1995). And the reactor vault containing CV which stores large inventory of light water can provide a potential heat sink to keep the integrity of CV for a period of time (Tong et al., 2010). When the single channel overheats due to loss of the coolant inside of fuel channel, the pressure tube may rupture and the core melt will fall into the CV, cooled by the subcooled moderator with the moderator cooling system available. When multiple channels lose coolant and moderator fails to be heat sink, the core will be severely damaged, which probably threatens the integrity of the containment (IAEA, 2008).

The CANDU-specific computer code (MAAP-CANDU) to predict the progression of severe core damage has developed and the mechanism for CANDU core melting has analyzed for typical severe accident sequences (Kwee et al., 2011; Petoukhov and Mathew, 2002). Experimental facilities to simulate thermal hydraulic behavior for CANDU reactor, such as RD-14 and RD-14M are built to investigate the typical phenomena, and RELAP5 code is used to simulate the RD-14 experiments. The reactor inlet header break experiment B9401 of RD-14M is used to evaluate the code applicability on CANDU6 thermal-hydraulics (Kim and Lee, 2000; Cho, 2003). Dupleac uses RELAP5 code to simulate the stratified flow in CANDU reactor fuel channel (Dupleac and Prisecaru, 2005).

Two units of CANDU6 nuclear power plant (NPP) are under operating in China. The Chinese National Nuclear Safety Administration (NNSA) has brought out higher safety requirements after the Fukushima accident. Therefore, severe accident management should be performed and severe accident management guidelines should be developed. Generally, there is lack of mechanical models

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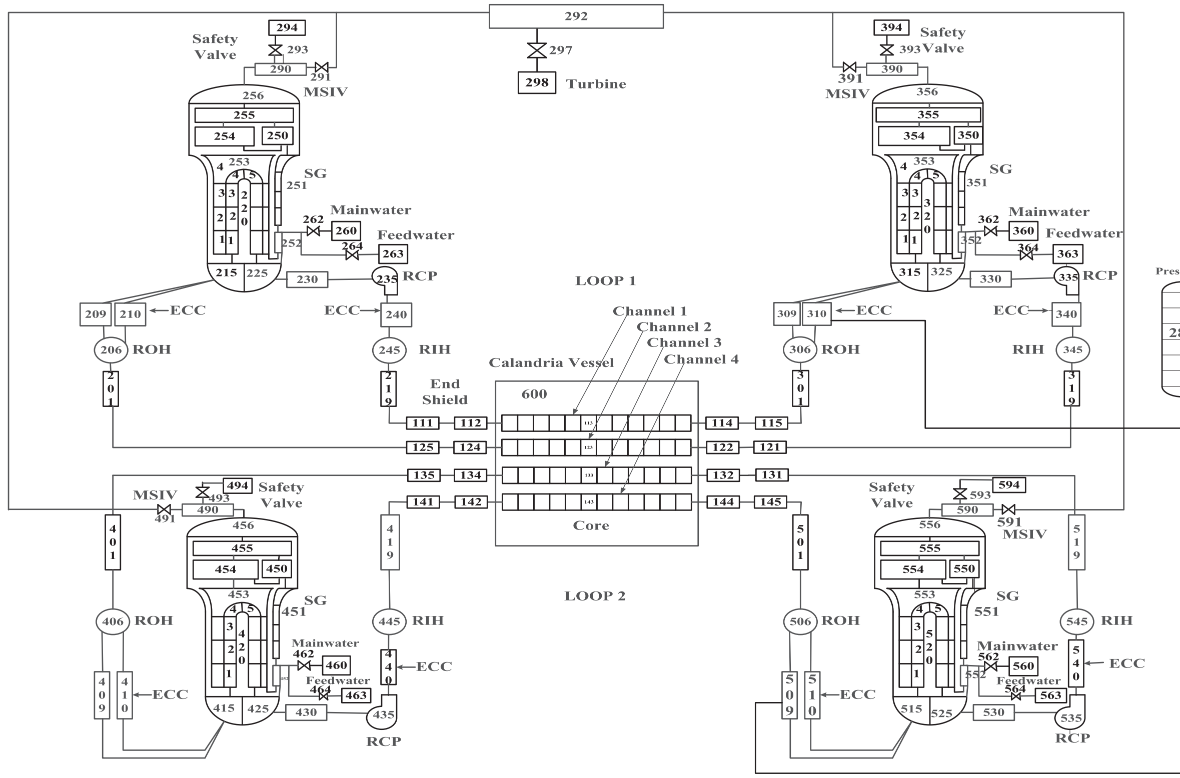

Fig. 1. Node of CANDU6 plant model.

for the core structure disassembly and the debris relocation onto the calandria vessel bottom. It's necessary to evaluate the capabilities of the existing computer code in order to understand the accident progressions and evaluate the mitigation measures for CANDU6 in China. This paper presents the construction of CANDU plant model for severe accident sequences and the severe accident sequence caused by Station Blackout (SBO) is discussed.

2. Plant model description

The CANDU6 plant model consists of Primary Heat Transport System (PHTS) with a simplified model for balance pipes, Steam Generator (SG) secondary system, calandria vessel (CV) and moderator system, and calandria vault. The PHTS model consists of the inlet headers, feeders and end fittings, fuel channels, outlet headers, pressurizer, reactor coolant pumps, and SGs, as shown in Fig. 1. The two PHTS loops are connected with the Pressurizer at one reactor outlet header (ROH) of each PHTS loop. A simplified nodalization with four channels of the core represents the 380 fuel channels arranged in 22 rows and 22 columns. The main steam system is modeled as volume control components and flow rate control valves, consisting of main steam pipes, main steam isolation valves and safety valves, and the turbine. The main feed water system is modeled as the time-dependent volume and time-dependent junction components. The steam lines and turbine are represented by the time-dependent volumes and the main steam isolation valves and safety valves are modeled with the valve components. The key parameters for CANDU6 NPP are shown in Table 1. Light water properties are used for heavy water in the simulations.

The fuel bundles in the fuel channel are modeled as 12 axial nodes and the 37 fuel elements of each fuel bundle are modeled with the SCDAP core components. And the pressure tube (PT), calandria tube (CT) and the CO_2 between the gap are modeled with the shroud component as shown in Fig. 2.

Table 1
Key input parameters for CANDU6.

Parameters	Unit	Value
Thermal reactor power	MW	2064
Coolant pressure and temperature in ROH	MPa (a)/K	9.99/583
SG secondary side pressure and water level	MPa (a)/m	4.7/12.6
Main steam temperature and moderator temperature	K	533/342
D_2O inventory in primary system (including pressurizer)	kg	121,099
D_2O inventory in calandria vessel	kg	226,136
H_2O in each SG secondary side	kg	38,000
H_2O inventory in reactor vault	kg	521,627
Free volumes inside containment	m^3	53,000

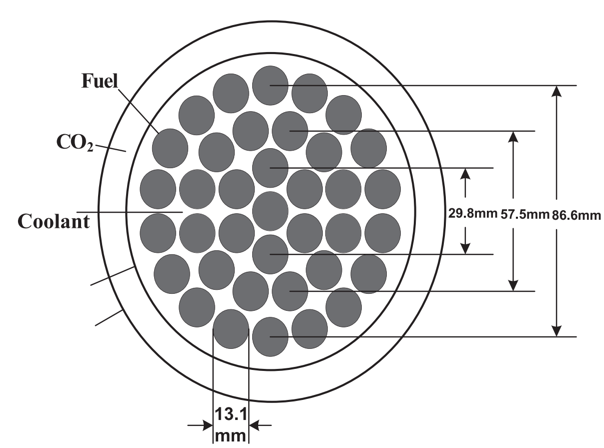

Fig. 2. Node of CANDU6 fuel bundle.