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Simulation of SBO in CANDU-6 using MARS-KS Code

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1. Introduction

NPPs have multiple provisions of the heat sink such as pumps, heat exchangers, and the pipes connecting them, which can be a pathway for heat removal from the heat sources. The station blackout (SBO) is the transient initiated by a loss of off-site AC power with subsequent loss of all on-site standby and emergency electrical power supplies. When the system and equipment of a PHWR plant remain intact but all the AC power becomes unavailable, all active heat sink becomes inoperable. In such an accident, the primary passive heat sink would initially be the steam generators (SGs). Due to the high elevation of the SGs, the continuous natural circulation by the thermosyphoning in the loops can be formed shortly after the run-down of the PHTS pumps and will continue until the inventory depletion of the SG secondary-side. The maximum temperature of the fuel sheath can remain below the limit criteria for the fuel integrity as long as the inventory of the SG secondary-side is available. Moreover, the water make-up to the SG secondary-side can extend the duration of the natural circulation, which provides additional time for operators to take mitigation actions and then delays the accident progress.

However, considering the transient without any mitigation action of operators or recovery of safety systems, like the situation of the Fukushima Daiichi NPP, the inventory of the SG secondary-side will be eventually depleted due to the inoperable feedwater supply and the continuous steam discharge through the main steam safety valves (MSSVs), which can cause the heat sink function of SGs to get lost.

Since the recent actual occurrence of the severe accident [1,2], there have been much awareness and consensus that that the SBO is no longer a hypothetical transient and the fuel integrity can be threatened under the above harsh but possible conditions. There are many tasks that need to be quantitatively analyzed and identified, and the plant responses prior to the severe damage of the fuel channels should be understood in detail to establish and more reinforce the plans for preventing and mitigating such accident consequences through precise safety assessment.

Therefore, the purpose of the present study is to investigate the system responses of PHWR plants over the transient. In this study, the complete loss of AC power was selected as a representative transient and the simulation has been carried out using the system code of MARS-KS ver.1.5 for detailed analyses under the transient condition of no mitigation actions or recovery of safety systems.

2. Modelling CANDU-6 using MARS-KS code

The plant chosen for the accident analysis in the present study is Wolsong-2/3/4 unit, a typical CANDU-6 with 600 MW, and a detailed analysis model was envisioned into the MARS-KS input model [3]. The present model includes the PHTS with horizontal fuel channels connecting to feeders, headers, PHTS pumps, SG u-tubes, moderator system, and emergency core cooling system (ECCS). It also contains the SHTS including the feedwater system, the shell-side of the SGs, and several valves installed on the main steam lines for discharging the steam of high pressure.

Figure 1 shows the schematic nodalization of the CANDU-6 plants. As well as the major volume components consisting of the above systems, various control logics are included for stably achieving the steady state conditions of a normal power operation and for properly simulating the operation of the components during the transient.

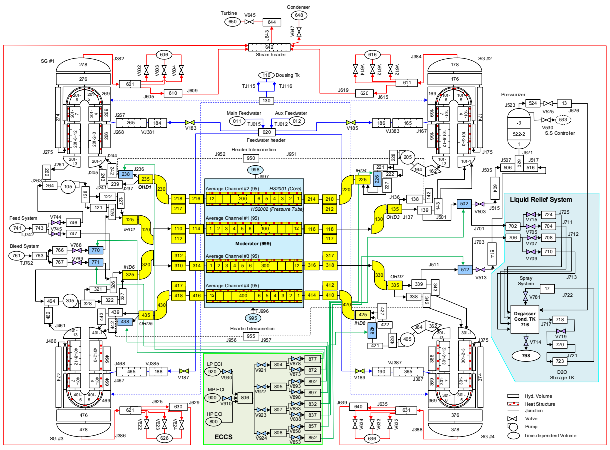
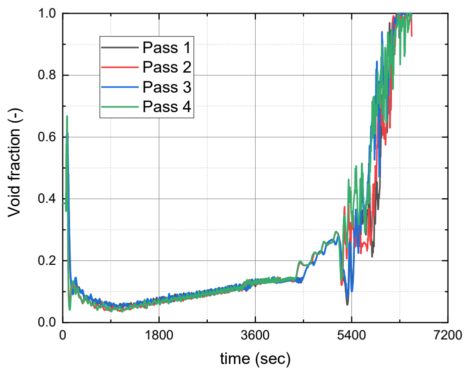


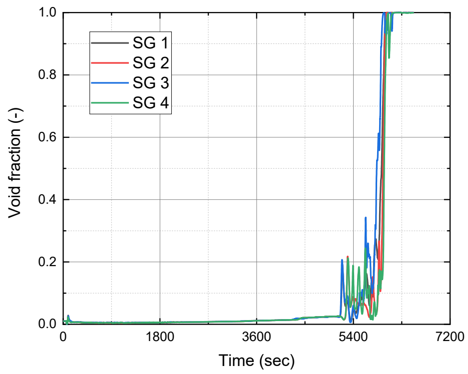
Fig. 1. Nodalization of CANDU-6 plants for accident analysis.

The 380 fuel channels of CANDU-6 are arranged horizontally in 22 columns and 22 rows inside a Calandria vessel. In the present study, the fuel channels were represented by 7-averaged channels per core pass. Figure 2 shows the grouping scheme of the fuel channels with a total of 14 sections parted by considering the elevation and power of the fuel channels.

such as the top of the u-tubes. So, the void fraction in the u-tubes increased, resulting in significantly increasing the flow resistance and then affecting the cooling of the fuel channels.



(a) ROH



(b) u-tubes of SGs

Fig. 4. Behaviours of void fraction.

In PHWR reactors, the deformation in the fuel channel may lead to PT-CT contact which allows for a direct heat removal pathway to the moderator under severe transient conditions. Figure 5 shows the peak cladding temperature (PCT). The simulations of the present study were terminated after the PCT had reached the limitation ensuring that significant channel deformation does not occur. While the coolant was present in the shell side of the SGs, the fuel channel was predicted to be cooled properly through the continuous heat transfer to the shell side of the SGs. After the inventory of the SGs was depleted, the PCT quickly increased to exceed the limitation after approximately 6,300 seconds, which could not be guaranteed for the fuel integrity.

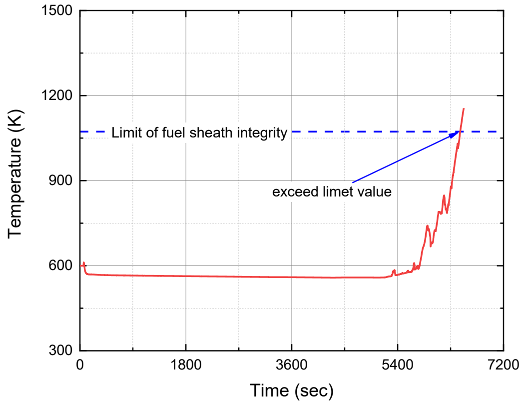


Fig. 5. Behaviour of PCT.

4. Conclusions

This study was performed to examine the overall system responses over the transient in PHWR plants. The complete loss of all the AC power or SBO was selected as a representative transient and the accident simulation was performed using MARS-KS code for detailed analyses under the transient condition without any mitigation actions of operators and recovery of safety systems. A steady state condition was achieved successfully by running for a long period to check out the stable convergence of the major parameters. Calculated results such as pressure, temperature, water level, and recirculation ratio, were in a good agreement with the target values of when they were in a normal power operation. The transient simulation was performed and the behaviours of the major parameters were quantitatively examined. Due to the depletion of the secondary-sided inventory, the coolant in the PHTS showed a complex flow patterns, such as flow stagnation and reversal flow, and consequently the PCT exceeded the fuel integrity criterion following the degradation of the cooling capacity of the fuel channel, which was the reasonable results confirmed through the code.

REFERENCES

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