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Transient Thermal Hydraulic Analyses of Heavy Water System

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1. Introduction

A research reactor core surrounded by a heavy water (D_2O) vessel uses heavy water as a reflector. A Heavy Water System (HWS) is installed to remove the heat generated in heavy water and the vessel itself [1]. The HWS is separated from the primary cooling system of the core. Postulated Initiating Events (PIEs) in the HWS are evaluated for safety purposes [2,3]. In the present study, transient thermal hydraulic analyses of HWS such as (1) loss of heavy water flow owing to a pump failure, (2) dilution of heavy water owing to a pipe rupture inside a pool, (3) heavy water leakage owing to a pipe rupture outside a pool, and (4) loss of heat removal owing to a secondary cooling system failure are analyzed.

2. Description of HWS

The HWS designed as a completely closed system removes heat produced in the heavy water vessel and circulates heavy water through ion-exchangers to maintain the heavy water quality during the normal operation. The HWS, as shown in Fig.1, consists of two circulation pumps, a heat exchanger, two ion-exchangers, an expansion tank, a collection tank, and associated pipes and valves. Two safety relief valves are installed on the top of the expansion tank to prevent from an over-pressurization of the system.

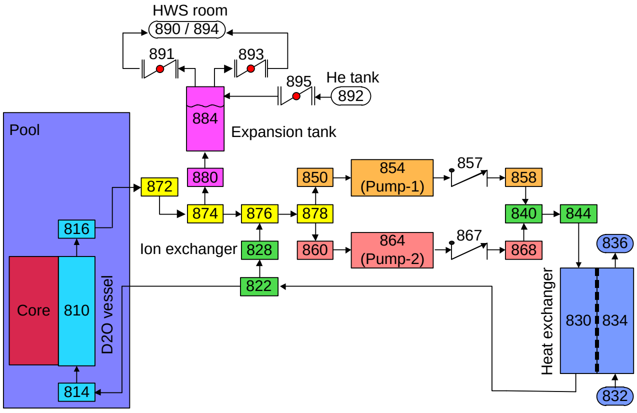

Fig.1. RELAP model of the HWS

Table 1. Major components of the HWS

Element no.	Component	Type
810	Heavy water vessel	Pipe
828	Ion exchanger	Pipe
830	Heat exchanger	Pipe
834	Heat exchanger secondary side	Pipe
854	Pump (main)	Pump
864	Pump (standby)	Pump
884	Expansion tank	Pipe
891	Pressure relief valve 1	Valve
893	Pressure relief valve 2	Valve
895	Pressure control valve	Valve

3. Results

3.1 Loss of heavy water flow

A loss of heavy water flow occurs if there is a failure of a component such as a HWS pump. Since the HWS is separated from the primary cooling system, the cooling capacity of the primary cooling system is maintained during the loss of the heavy water system flow. The loss of the heavy water system flow initiates at 10 s owing to a failure of the primary pump. A standby pump starts operating if the pressure at the outlet of the primary pump is less than 380 kPa (the pressure at the outlet of the pump during normal operation is approx. 414 kPa). This low pressure trip is triggered at 0.12 s from the initiation of the event. As a result of this analysis, it is concluded that a failure of the HWS flow does not affect the safety of the HWS as well as the reactor core.

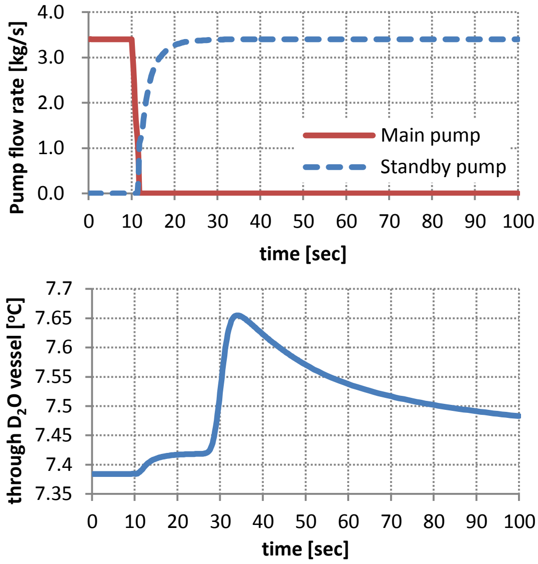

Fig.2. Transient behaviors during a HWS pump failure

3.2 Dilution of heavy water

The dilution of the heavy water occurs if there is a failure at an inadequate welding point or a pipe rupture in the HWS inside the reactor pool. The light water flows into the heavy water cooling system and the heavy water begins to be diluted. This may raise the reactor power since the dilution of heavy water in the heavy water vessel provides a sheltering effect on the neutron detectors located outside the periphery of the heavy water vessel. Therefore, how fast and how much of the light water flowing into the HWS need to be evaluated to predict the reactor power increase if there is a piping rupture inside the reactor pool. Fig.3 shows the transient behaviors of the HWS when there is a pipe rupture. A positive flow rate is the flow out of the

HWS, and a negative flow rate is the flow into the HWS. With time, the expansion tank level decreases until the pressure inside and outside the HWS is balanced.

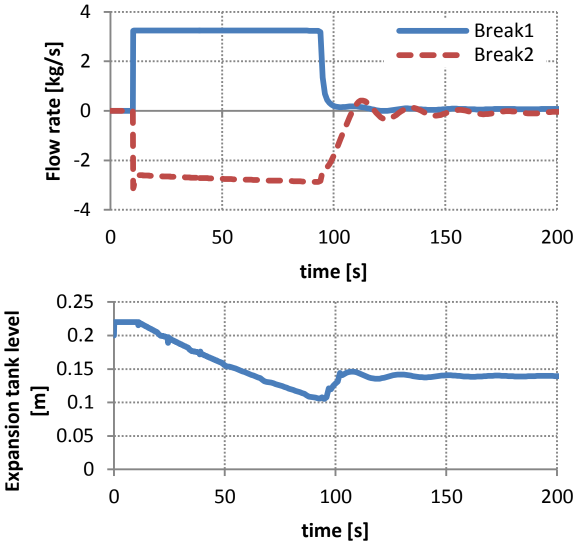

Fig.3. Transient behaviors with a break inside pool

Fig.4 shows the D_2O purity changes over time. With a longitudinal small break, H_2O does not instantaneously flow into the HWS, but H_2O instantaneously flows into the HWS with a guillotine break. Since the D_2O impurity is only considered inside the heavy water vessel, the D_2O purity change by a break at the outlet of the heavy water vessel is delayed for the flow circulation time in the HWS.

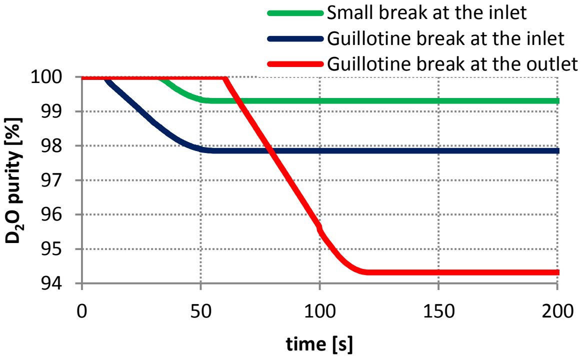

Fig.4. Heavy water purity change with various pipe ruptures

3.3 Loss of secondary cooling flow

A loss of secondary cooling flow event occurs if there is a malfunction of the secondary cooling system. If this event happens, then the sequence of this event is different from other events previously discussed in this document. Since the HWS loses cooling capacity, the coolant temperature increases until it reaches the high temperature RRS setback point. The D_2O temperature to trigger an RRS setback signal is detected at the outlet of the heavy water vessel. Because the heat generated in the heavy water vessel is about 100 kW, the temperature at the outlet of the heavy water vessel slowly reaches the RRS setback point of 50 ^{o}C at 784.0 s from the event initiation.

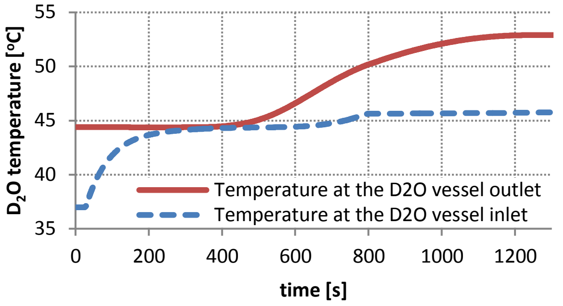

Fig.5. Transient behavior with a loss of secondary cooling flow

3.4 Heavy water leakage

The heavy water in the HWS can leak out owing to a failure of a seal or pipe rupture outside the pool. In this analysis, a pipe rupture (guillotine type break) outside the pool at the lowest location is assumed to evaluate the heavy water leakage. The lowest location in the HWS is the outlet of the heat exchanger. At the moment of a pipe rupture, the pressure at the outlet of the primary pump dramatically decreases, lower than the low pressure set value, to switch the primary pump to the standby pump. After around 7 s after the standby pump starts, the low expansion tank level RRS setback signal stops the standby pump. During the transient, the temperature rise inside the heavy water vessel is less than 2 ^{o}C.

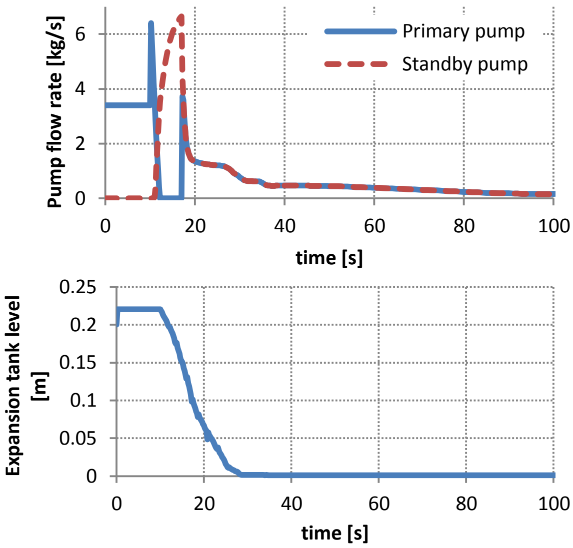

Fig.6. Transient behavior of pipe rupture at the outlet of the heat exchanger

REFERENCES

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