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Assessment of a Pressure Tube Rupture with a Poisoned Moderator

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1. Introduction

The postulated in-core LOCA has been analyzed and evaluated while the reactor is operating normally with a low moderator poison concentration for CANDU. However, when the reactor is operating with a relatively large amount of boron and/or gadolinium poison in the moderator, an assessment of the fuel integrity was required for the pressure tube rupture (PTR) accident [1]. Poisoned moderator exists mainly during a startup after a prolonged shutdown lasting for more than one day.

For the case of a reactor regulating system (RRS) working, the methodology of the PTR assessment with a poisoned moderator has been developed to determine the effective trip parameters, evaluate the fuel integrity, and establish the standard reactor start-up model for the Wolsong Nuclear Power Plants recently. The developed methodology and results are presented.

2. Methods and Results

2.1 Analysis Method

The level of poison concentration affects the net reactivity change of the core during the accident. Upon the postulated PTR, the coolant is discharged into the moderator. It results in a decrease of the poison concentration in the core due to a dilution of heavy water moderator by an un-poisoned coolant discharge.

The developed process of a safety assessment is shown in Figure 1. The thermal-hydraulic response of the primary heat transport system is analyzed by a computer code CATHENA [2]. The coolant discharge rate and enthalpy obtained from CATHENA are used as input data for the MODSTBOIL code to calculate the transient moderator temperature and density [3].

Reactivity transients due to the moderator conditions are inputted into the CATHENA code to calculate the reactor power transient and to obtain the position of the reactivity devices in the core. For a realistic assessment, it is assumed that the RRS is working.

The coolant conditions and reactivity device position obtained from the CATHENA code are provided for the RFSP code input data to analyze the channel power distribution of the core. The determined channel power transient at each time step by the RFSP during the accidents is used as input data for the CATHENA single channel model to analysis the onset of a fuel dryout time [4].

O6 channel in the core was selected for the broken position to maximize the coolant discharge rate. A guillotine break of the pressure tube at the inlet side of the channel (O6) is assumed since the break location which gives the highest break discharge rate was identified as the worst break location [1]. The calandria tube is assumed to fail and the fuel is ejected into the calandria vessel to maximize the coolant discharge rate into the moderator.

CATHENA single channel model idealizes only a specific fuel channel by using the boundary conditions at the reactor inlet and outlet header provided by the CATHENA circuit analysis.

It is assumed that the actuation of the shutdown system is inhibited for assessment purposes even though the times are all recorded.

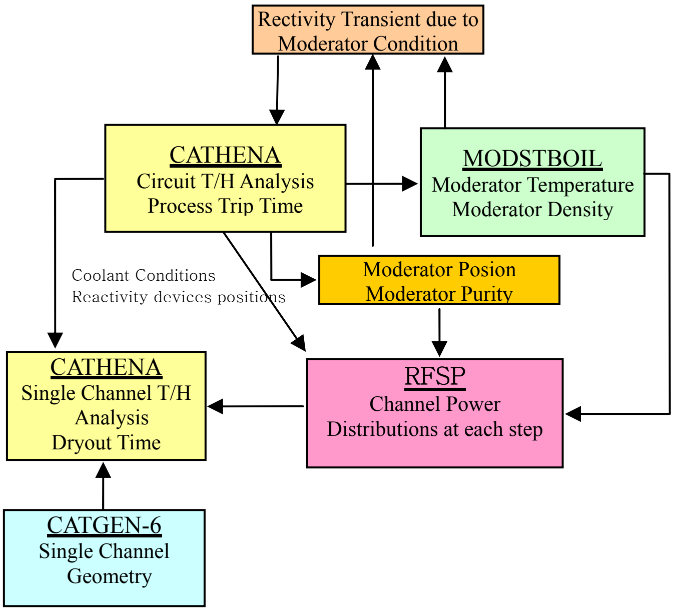

Figure 1. PTR Assessment Process

The PTR accident assessments at 75%FP and 100%FP with poisoned moderator are performed, respectively.

2.2 Physics Results

The reactivity device positions such as the liquid zone controller (LZC) and the mechanical control absorbers (MCA) are affected by the channel power distribution. In the core, the RRS is acting to compensate for the positive reactivity and to maintain the reactor power during the accidents. With considering the RRS configuration in the core determined from the CATHENA code, the channel S13 is selected as the worst channel which has the maximum power increasing rate in the power regions. Figure 2 shows the power distribution of the S13 channel during the transient. A 10 % uncertainty of the power increasing rate is considered to conserve the safety margin.

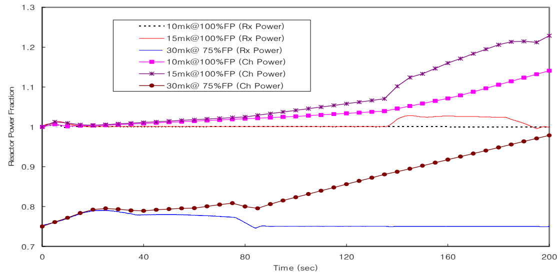

Figure 2. Channel & Reactor power transient

2.3 Thermal-hydraulics Results

The geometry of the S13 channel is generated from the CATGEN-6 code [5]. Modified S13 (S13_mod) channel is modeled for CATHENA single channel analysis. Channel S13_mod has the same geometry as S13 but the channel power and the bundle power of the two center bundles have been modified to the licensing limits of 7.3 MW and 935 kW, respectively. The S13 channel flow rate applies the design value of 26.62 kg/s.

Figure 2 shows the reactor power transient at 75%FP and 100%FP during the accident. The RRS compensates the positive reactivity added due to the dilution of the moderator poison concentration by the un-poisoned coolant being discharged and the increase of the moderator temperature during the early period. But the moderator purity is degraded due to the discharged coolant having a lower initial isotopic purity than the moderator, which introduces a negative reactivity. Also it is shown that the increase of the reactor power depends upon the moderator poison concentration. The reactor power is relatively stable and controllable within the RRS capacity during the transient. As shown in Figure 3, a fuel dryout does not occur at 10mk@ 100%FP and at 30mk@75%FP, but at 176.1 seconds at 15mk @100%FP.

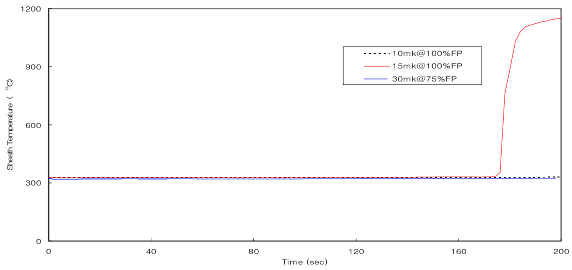

Figure 3. Reactor power and fuel temperature transient

2.4 Moderator Analysis Results

The bulk moderator temperature is shown in Figure 4. Throughout the entire transient, no moderator bulk boiling is predicted. The bulk moderator temperature increases up to around 101 °C at 200 seconds. The bulk moderator temperature increment is higher for the over-poisoned moderator case.

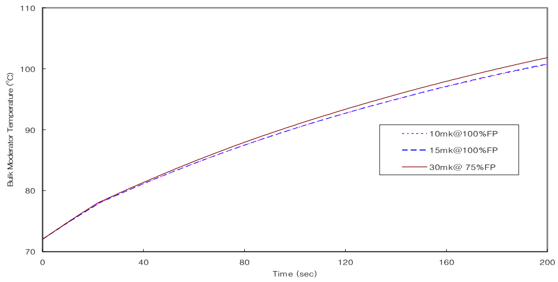

Figure 4. Bulk moderator temperature transient at 100%FP

2.5. Assessment Results

The effective trip parameters and trip times derived from the assessment of a PTR are shown in Table 1. The effective trip parameters are the low PHT pressure (LP) and the pressurizer low level (PLL) signals for both the SDS1 and SDS2 prior to an onset of a fuel dryout. As listed in Table 1, the results show the existence of enough margins to a fuel dryout at the second trip time for each shutdown system within the limited poison concentration of the moderator (30 mk at 75%FP and 10 mk at 100%FP).

Table 1. Effective trip parameters and trip times

Reactor Power	*75%FP*	*100%FP*	
Poison Concentration in Moderator (mk)	30	10	15
SDS1 LP Trip (sec)	165.15	176.93	190.03
SDS2 LP Trip (sec)	165.25	177.03	190.13
SDS1 PLL Trip (sec)	165.35	184.93	194.03
SDS2 PLL Trip (sec)	165.45	185.03	194.13
Onset of Dryout Time (sec)	No Boiling	No Boiling	176.1

3. Conclusion

With the working RRS, at least two trip parameters for each shutdown system are effective in preventing a fuel dryout. The reactor power stability is maintained in the event of a PTR while the moderator contains substantial amounts of neutron absorbing poisons. Significant margin to a dryout exist at the time of the second trip signal under the given moderator poison concentration.

REFERENCE

[1] KHNP, "Final Safety Reports for Wolsong NPPs 2, 3 & 4".
[2] AECL, "CATHENA MOD-3.5: Theoretical Manual, COG-93-140", Rev 00, 1995.
[3] AECL, "MODSTBOIL MOD-2.1: Manual and Program Description", TTR-560, 1995.
[4] AECL, "RFSP Manual: User's Manual for Microcomputer Version", TTR-321, Rev.1/COG-93-104, July 1993.
[5] AECL, "CATGEN-6 Users Manual", 86-03500-AR-014, July 1992.