In-Core LOCA (PTR) Analysis with Poisoned Moderator

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1. Introduction

CANDU reactors have been analyzed and evaluated for the postulated in-core LOCA while the reactor is operating normally with low moderator poison concentration. However, when the reactor is operating with relatively large amounts of boron and/or gadolinium poisons in the moderator, the assessment for fuel integrity was required for pressure tube rupture (PTR) accident [1].

The methodology of in-core LOCA analysis with poisoned moderator is developed to determine the effective trip parameters, evaluate the fuel integrity, and establish the standard reactor start-up model for CANDU reactor 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 the decrease of poison concentration in the core due to the dilution of heavy water moderator by un-poisoned coolant discharge. The reduction of soluble poison concentration causes the uncontrolled power increase without reactor regulating system (RRS).

The developed process of safety analysis is shown in Figure 1. The thermal-hydraulic response of heat transport system is analyzed by computer code CATHENA [2]. The coolant discharge rate and enthalpy obtained from CATHENA are used as input data for MODSTBOIL code to calculate transient moderator temperature and density [3]. Also the average coolant density and fuel temperature determined by the CATHENA code are also provided as input data for the RFSP code to evaluate the neutronic response and hence the total power transient during the accidents [4].

The concentration of soluble poison and the change in isotopic purity in the moderator are inputted directly into the RFSP code. The determined power transient by RFSP is used as input data for CATHENA single channel model to calculate the onset of fuel dryout time. CATHENA single channel model idealizes only a specific fuel channel using boundary conditions at reactor inlet and outlet header provided by CATHENA circuit analysis.

Modified O6 (O6_mod) channel is modeled for CATHENA single channel analysis. Channel O6_mod has the same geometry as O6 but the channel power and the bundle power of the two center bindles have been modified to licensing limits of 7.3 MW and 935 kW respectively.

O6 was selected to the broken channel to maximize the rate of moderator temperature increase. A guillotine break of 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.

Also it is assumed that reactor regulating system (RRS) is not working. The actuation of shutdown system is inhibited for analysis purposes even though the times at which they are predicted to occur are all recorded.

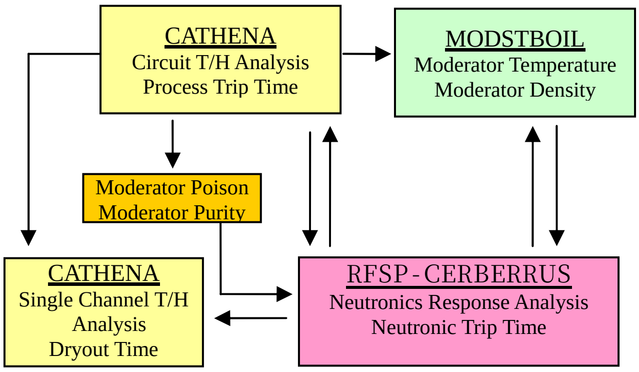

Figure 1. Safety analysis process

2.2 Physic Results

Figure 2 shows the reactor power transient at 100% FP during the accident. In case of without RRS working, the positive reactivity is added to the reactor due to the dilution of moderator poison concentration by the un-poisoned discharging coolant and the increase of moderator temperature. But the moderator purity is degraded due to the discharge coolant having a lower initial isotopic purity than the moderator, which introduces negative reactivity. Also it is shown that the increase of reactor power depends upon the moderator poison concentration.

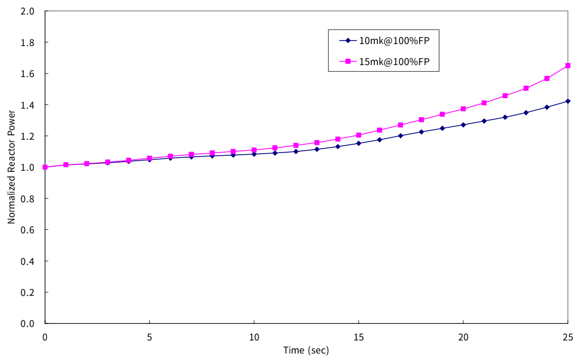

Figure 2. Reactor power transient at 100%FP

2.3 Theramlhydrauic Results

Figure 3 shows the temperature transient of fuel sheath during the accidents. The fuel dryout is occurred at 22.96 seconds at 10mk poisoned moderator and 20.76 seconds at 15mk poisoned moderator seconds for 100%FP.

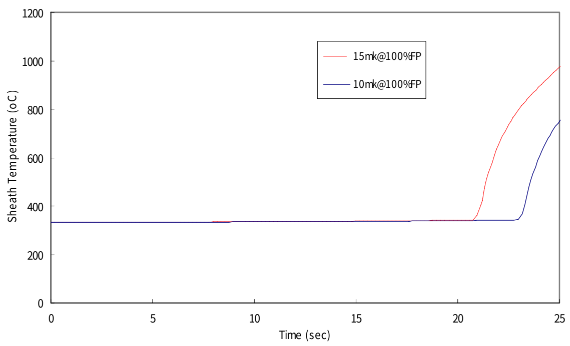

Figure 3. Fuel temperature transient at 100%FP

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 80 ^{o}C.

Also, the PTR accident analyses at 65% and 75% FP with poisoned moderator are performed. The effectiveness of the trip parameters for both SDS1 and SDS2 are analyzed for the following conditions:

- 100% Full Power with 10mk and 15 mk of moderator poison.
- 75% Full Power with 25mk, 30mk and 35mk of moderator poison.
- 65% Full Power with 40mk and 45mk of moderator poison.

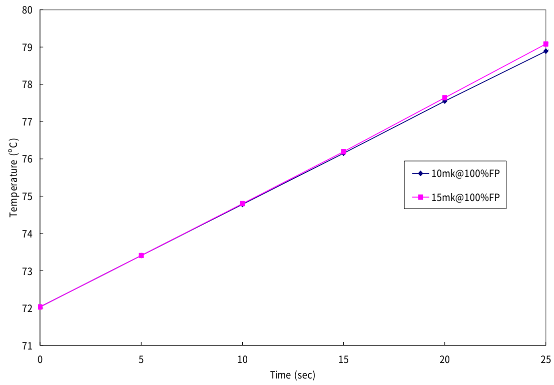

Figure 4. Bulk moderator temperature transient at 100%FP

The effective trip parameters and trip times derived from the RFSP and CATHENA code simulations are shown in Table 1. The effective trip parameters are the regional overpower protection (ROP) signal and the delayed high heat transport pressure signals (HP2) for both SDS1 and SDS2 prior to onset of fuel dryout. As listed in Table 1, the CATHENA single channel analysis shows the existence of enough margins to fuel dryout at the second trip time for each shutdown system

Table 1. Effective trip parameters and trip times

Trip Parameter	100%FP		75%FP			65%FP	
	10mk	15mk	25mk	30mk	35mk	40mk	45mk
SDS1 ROP (sec)	14.82	12.59	28.62	24.68	21.7	25.81	22.48
SDS2 ROP (sec)	14.82	12.59	28.61	24.63	21.64	25.1	22.44
SDS2 HP2 (sec)	21.05	18.49	31.53	27.17	24.11	29.21	26.57
SDS1 HP2 (sec)	21.33	18.75	31.73	27.37	24.25	29.31	26.73
Dryout Onset Time (sec)	22.96	20.76	33.42	30.22	27.72	30.69	27.09

3. Conclusion

At least two trip parameters for each shutdown system are effective in preventing fuel dryout in the event of PTR while the moderator contains substantial amounts of neutron absorbing poisons. Significant margin to dryout is shown to exist at the time of the second trip on each shutdown system under 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.