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Analysis of Long Term Core Cooling Capability of the APR1400 Considering LOCA Generated Debris

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1. Introduction

In the event of a large break loss of coolant accident (LBLOCA), water discharged from the break can generate fibrous debris and chemical products. Above that debris could be ingested into the reactor core through a sump strainer in the recirculation mode. The fibrous materials may collect on the bottom nozzle of fuel assembly (FA) and would seriously impede flow into the core. Chemical products could be deposited on the surface of cladding. The debris effect causes a problem to remove decay heat from the core with the coolant. The concern described above is a real challenge to provide for long term core cooling (LTCC) capability.

In this study, an analysis of LTCC capability for APR1400 considering the effect of LOCA generated debris has been performed using the RELAP5 code.

2. Analysis Method

2.1 Core Inlet Blockage

The effects of 85% and 95% partial core inlet blockage were analyzed as bounding cases. The core inlet blockage was assumed that occurred after ECCS switchover to recirculation mode. This time is much faster than the anticipated time of the recirculation switchover to sump. This approach is conservative because the earlier switchover time to recirculation results in more decay heat generated in the core [1].

The core subdivided into five channels to simulate the core inlet blockage effect on the core. To allow cross flow between the channels were considered as shown in Fig. 1.

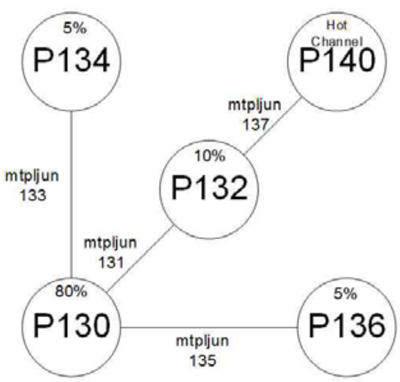

Fig. 1. Core channel model

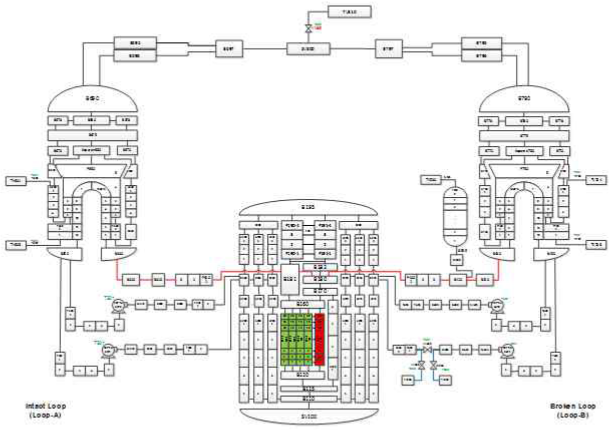

Fig. 2. RELAP5 nodalization for APR1400 LBLOCA

Table 1 : Simulation results of the steady state condition

Description	Reference	Calculated
Rx power [MWt]	3983.30	3983.30
PRZ pressure [MPa]	15.51	15.51
PRZ level [m]	5.30	5.30
RCS flow [kg/s]	10656.00	10656.00
RCS T_{avg} [K]	580.30	580.30
SG Pressure [MPa]	6.89	6.89

For 85% core inlet blockage, the channel P130 and P134 were assumed to be blocked. For 95% core inlet blockage, the channel P130, P132 and P134 were assumed to be blocked. Hot channel (HC) was assumed to be blocked in both cases.

The other components in the RELAP5 input model, reactor vessel, pressurizer, steam generators, cold legs and hot legs are modeled as shown in Fig. 2. Table 1 shows the steady state analysis results for the multi channel model as described in Fig. 1 with clean inlet condition.

2.2 Deposition on Fuel Cladding

In the present analysis, the effect of crud and chemical deposition were considered to evaluate the decay heat removal capability during the recirculation mode. Fig. 3 shows the debris deposition model on the fuel cladding. The limiting parameters for the thickness and the thermal conductivity were suggested in the Pressurized Water Reactor Owners Group (PWROG) report WCAP-16793 [2].

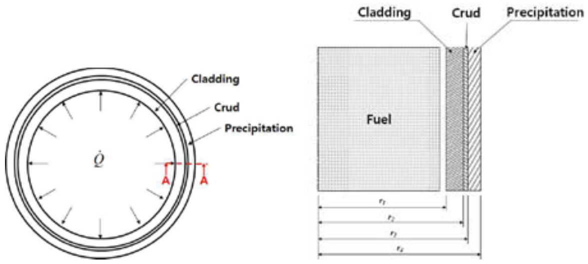

Fig. 3. Debris Deposition Model on fuel Cladding during recirculation mode

3. Analysis Results

The thermal hydraulic behavior of the reactor core during the LBLOCA was evaluated for 1,000 seconds. The first phase of the LBLOCA transient calculation was carried out for 500 seconds. In the second phase, the partial inlet blockage model adopted for the core inlet and the chemical deposition model on fuel cladding were activated from 500 seconds to 1000 seconds.

The inlet flow of the unblocked channel P136 was abruptly increased after the other channels were blocked by the fibrous debris as shown in Fig. 4. Figure 5 shows the inlet flow rate is relatively reduced in the blocked channel P130.

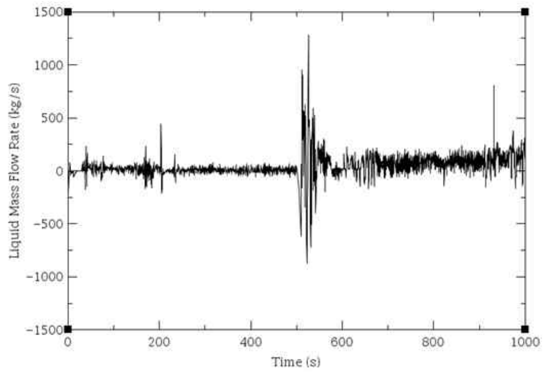

Fig. 4. Core Inlet Flow of Unblocked Channel (136) (95% Core Inlet Blockage)

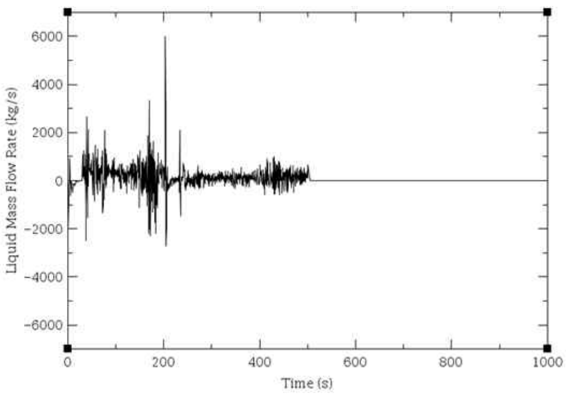

Fig. 5. Core Inlet Flow of Blocked Channel (130) (95% Core Inlet Blockage)

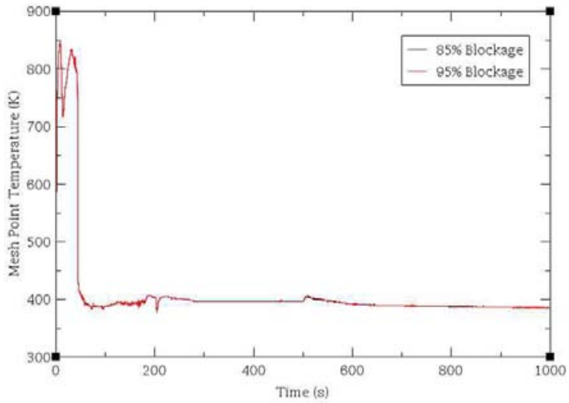

Fig. 6. Cladding temperature for the Vol. #4 of the hottest volume of the hot channel (Channel 140)

Fig. 6 shows cladding temperature curves at volume number four (4) of the hottest volume of the hot channel P140. The cladding temperatures for both 85% and 95% blockage model were maintained below not only critical temperature of 1,477 K (2200˚F) but also 699.8 K (800˚F). The figures above shows the continuous long term core cooling capability of the APR1400 by ECCS under both the core inlet blockage and the chemical deposition on the fuel cladding condition.

4. Conclusions

In this paper, the long term core cooling capability of the APR1400 was evaluated with the effect of LOCA generated debris. The partial inlet blockage model and the chemical deposition model were adopted to simulate the effect of LOCA generated debris.

The results indicate that the long term core cooling capability of the APR1400 can be maintained in the safe state after ECCS switchover to recirculation from the sump. The peak cladding temperature of the hot channel shows at much lower level than the critical temperature of the cladding.

REFERENCES

[1] C. H. Kim, S. Y. Kim, Evaluation of Long Term Cooling Capability of OPR-1000 Plant Considering Core Inlet Blockage and Deposition on Fuel cladding by LOCA Generated Debris, The Seventh Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety.

[2] WCAP-16793-NP, Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid Rev. 2, PWROG Report, pp. E-12~E-16, 2011.