Study on Start Time of Parametric Study for Channel Analysis under SBLOCA/LOECI

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Abstract

The channel behavior under SBLOCA with LOECI is analyzed. A small break is postulated to occur in the PHTS and the coolant discharges continuously without makeup. Eventually the inventory in the broken loop depleted and the loop begins to be filled with steam. For the analysis of channel behavior under this condition, the parametric study based on steam flow is conducted for the consideration of limiting condition. The channel does not fail as decay heat is transferred to moderator through ballooning or sagging contact. In this analysis, the effect of start time of parametric study on the contact behavior is estimated for 2.5% RIH break for Wolsong-2 NPP using CATHENA 3.5.4.4.

1. Introduction

The fuel channels should not fail under a loss of coolant accident (LOCA) with a subsequent loss of emergency core coolant injection (LOECI). The 2.5% reactor inlet header (RIH) break, which is the largest size break among small break LOCA (SBLOCA), is analyzed in this analysis.

Without emergency coolant injection, the coolant inventory in the broken loop continues to decrease and the void is increased in primary heat transport system (PHTS). The core flow decreases by the degraded heat transport (HT) pump and stratified flow would develop in some channels. Eventually the channels become filled with steam. A wide variety of conditions in fuel channels can exist with fuel channels receiving various steam flow rates. Eventually, the fuel at decay power would begin to heat up. The channel at this condition is analyzed as late-heatup behavior. The analysis methodology is changed from deterministic analysis approach to parametric study based on constant steam flow rates to find the limiting heat-up condition. The fuel and fuel channel behavior is estimated under limiting flow rates because the temperature decreases if the channel flow changes with time. ECC leak through D_2O isolation valve is assumed to supply the steam to the channels. This paper estimates the effect of starting time of parametric study on the late-heatup behavior.

In this period the fuel elements are expected to fail and fission products are released from the fuel. If fuel sheath temperature increases sufficiently, hydrogen is generated from exothermic zircaloy-steam reaction and pressure tubes (PT) also heat up and deform. The late-heatup analysis is to estimate the channel behavior under this condition.

2. Analysis Methodology

The fuel channel behavior is examined using slave channel model. The analysis is performed from the time of break until the decay heat is well removed and fuel heatup is not expected. To provide the boundary conditions for the fuel channel analysis the circuit analysis is performed until the PHTS pressure decreases to atmospheric pressure. The circuit and fuel channel behavior are analyzed using CATHENA 3.5.4.4[1].

2.1 Circuit Analysis

The 2.5% RIH size (5.375×10^{-3} m^2) break is assumed to occur at the inlet header IHD8. The pressure in the broken loop decreases as the coolant discharges through the break and steam generator crash cooldown (Figure 1). The pressure falls to containment pressure at 1083s and discharge flow almost stops. The coolant inventory continues to decrease and void fraction is increased (Figure 2) without inventory makeup. The coolant is supplied to broken inlet header from intact loop and pressurizer as HT pump is operating. So, the void at broken inlet header starts to increase when the pressurizer inventory is almost depleted after reactor trip. The void fraction at the broken header is higher than 0.95 at about 350s. Eventually the broken loop begins to be filled with steam generated by decay heat. The channel behavior is estimated in this late-heatup period through parametric study based on the steam flow.

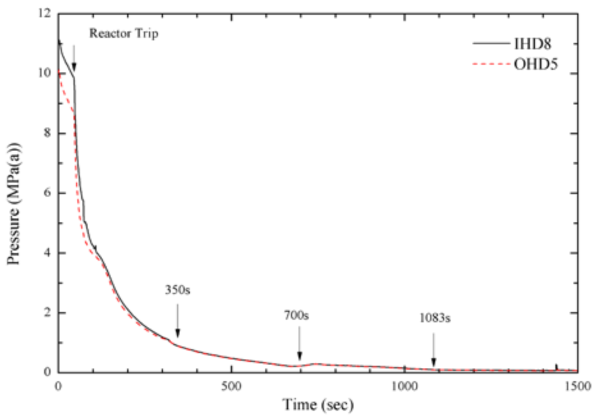

Figure 1 Pressure at broken header and its downstream outlet header

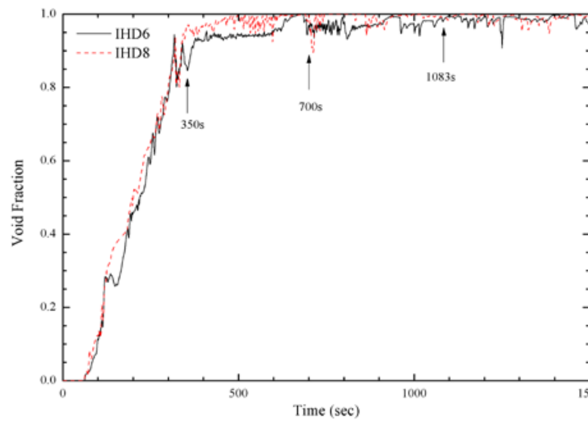

Figure 2 Void fraction at inlet headers of broken loop

Some channels start to receive pure steam at about 300s and most of channels receive pure steam at about 1000s. To estimate the effect of start time of parametric study, constant steam flow is assumed from 350s, 700s and 1083s, respectively.

2.2 Channel Analysis

The heat generated in the fuel bundles is transferred primarily by radiation to the pressure tube. Pressure tubes are assumed to strain uniformly (balloon), driven by the internal channel pressure, and to sag down due to their own weight and that of the fuel bundles under the low system pressure. The PT transfers its stored energy into the moderator through contact wall of calandria tube. In this way, the moderator provides a sink for the decay heat under LOECI condition.

Fuel channels in critical core pass which is the downstream of the break are divided into six channel power groups as shown in Table 1. The channel behavior is represented by representative channel of the each group.

Table 1 Grouping of Channels for Analysis of LOCA with LOECI

Channel Power Group	Channel Power Range (MW)	Number of channels in quarter core	Representative Channel and Power (MW)
1	7.0 ~ 7.3	2	O06M (7.3)
2	6.6 ~ 7.0	15	O06 (7.0)
3	6.0 ~ 6.6	32	S10 (6.6)
4	5.0 ~ 6.0	17	G05 (6.0)
5	4.0 ~ 5.0	16	B10 (5.0)
6	0.0 ~ 4.0	13	W10 (4.0)

The representative fuel channels of each channel in broken loop are shown in Figure 3.

	1	2	3	4	5	6	7	8	9	10	11
A									W10	W10	W10
B						W10	W10	W10	B10	B10	B10
C					W10	B10	B10	G05	G05	G05	G05
D				W10	B10	B10	G05	G05	S10	S10	S10
E			W10	B10	B10	G05	G05	S10	S10	S10	S10
F			B10	B10	G05	G05	S10	S10	S10	S10	S10
G		W10	B10	G05	G05	S10	S10	O06	O06	S10	O06
H		B10	G05	G05	S10	O06	O06	O06	S10	O06	S10
J	W10	B10	G05	S10	O06	O6M	O06	O06	O06	S10	S10
K	W10	B10	G05	S10	S10	S10	S10	O06	S10	S10	S10
L	W10	B10	G05	S10	O06	O6M	O06	O06	S10	S10	S10
M	W10	B10	G05	S10	O06	O6M	O06	O06	S10	S10	S10
N	W10	B10	G05	S10	S10	S10	S10	O06	S10	S10	S10
O	W10	B10	G05	S10	O06	O6M	O06	O06	O06	S10	S10
P		B10	G05	G05	S10	O06	O06	O06	S10	O06	S10
Q		W10	B10	G05	G05	S10	S10	O06	O06	S10	O06
R			B10	B10	G05	G05	S10	S10	S10	S10	S10
S			W10	B10	B10	G05	G05	S10	S10	S10	S10
T				W10	B10	B10	G05	G05	S10	S10	S10
U					W10	B10	B10	G05	G05	G05	G05
V						W10	W10	W10	B10	B10	B10
W									W10	W10	W10

Figure 3 Representative Channel of Each Channel in Broken Loop

For the parametric analysis, the constant steam flow is assumed to enter the channel and the limiting flow rate is identified as that which maximizes the fuel temperatures, and hence hydrogen generation and fission product releases. The exothermic reaction between Zircaloy and steam occurs at high fuel sheath temperature and the fuel sheath temperature increases more by this reaction. Thus, very low steam flow (~ 5 g/s) condition is limiting as the steam flow is high enough to contribute to the Zircaloy-steam reaction but low enough for steam cooling. As a result of Zircaloy-steam reaction, hydrogen is produced. The integrated hydrogen production from broken loop with various steam flow rates is shown in Figure 4. The results with steam flow rate of 5 g/s show limiting condition from the point of hydrogen production.

2.3 Fuel Analysis

During the late-heatup period, the fuel in the broken loop heats up sufficiently so that fuel failures occur. Consequently, the fission products are released into reactor building. This release includes fission product inventory bound in UO_2 fuel and that in the gap. It is assumed that the fuel element releases their gap inventories when the sheath temperature of any fuel element in any channel group reaches 800℃. And the fractional release of bound inventories from each element is estimated by using the CORSOR correlation as described in Reference 2. The fuel sheath temperature is calculated from channel analysis using CATHENA. I-131 release with various steam flow rate is shown in Figure 5. The results with steam flow rate of 5 g/s show limiting condition from the point of fission products release.

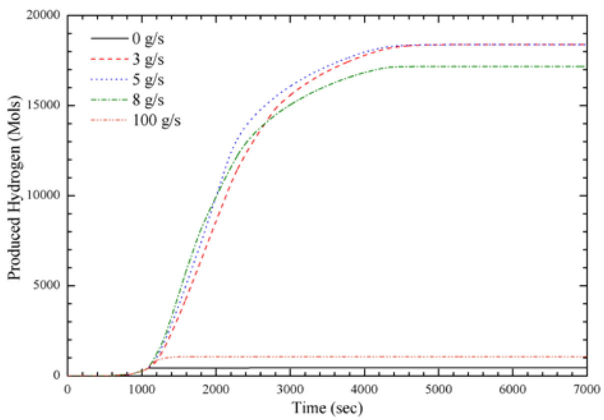

Figure 4 Integrated hydrogen production with various steam flows

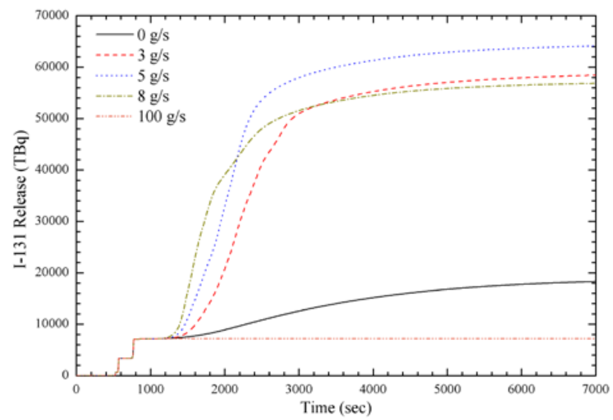

Figure 5 I-131 release with various steam flows

3. Analysis Result

It is shown that the channel behavior with steam flow rate of 5 g/s shows limiting condition according to the analyses in section 2. To assess the effect of the start time of parametric study, the channel analysis is performed by applying constant steam flow from 350s, 700s, and 1083s with steam flow rate of 5 g/s.

As the fuel channels are grouped into six groups and six representative channels are sub-divided into 12 axial nodes, the PT deformation by ballooning or sagging is calculated for each of these 72 pressure tube sub-divisions. The PT/CT contact results moderator heat load spikes. A ballooning contact results in higher peak compared to sagging contact. Figure 6 shows the moderator heat load with various start time of parametric study. If the constant steam flow is assumed from 350s ballooning contact occurs very early because the pressure of PHTS is relatively high. The trend of 700s shows that ballooning contact occurs later than the case of 350s. From the results of 1083s, it is shown that only sagging contact occurs.

If PT/CT contact occurs then the heat inside PT transfers to moderator and the fuel cools down. The heat transfer through ballooning contact is higher compared to sagging contact. Thus, it is expected that the high fuel temperature is sustained for 1083s case. Figure 7 shows I-131 release with the start time of constant steam flow and the results with 1083s gives highest I-131 release as expected.

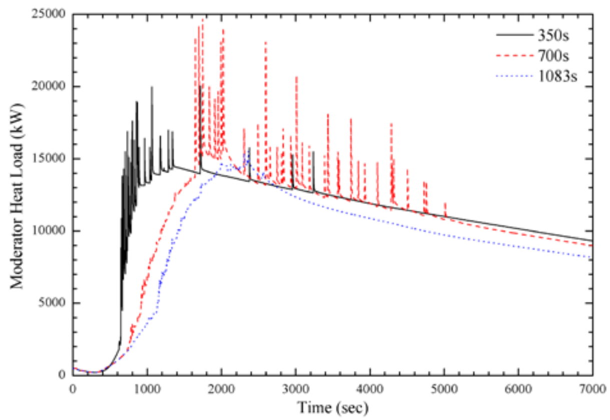

Figure 6 Moderator heat load with various start time of parametric study

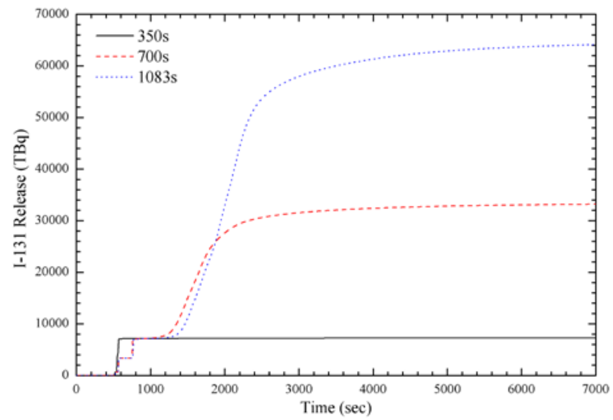

Figure 7 I-131 release with various start time of parametric study

4. Conclusion

The late-heatup analysis following SBLOCA with LOECI is performed with various start time of parametric study. As a conclusion, the parametric study is recommended to start at the time when the PHTS pressure decreases to containment pressure and the coolant does not discharge into containment any longer.

5. References

[1] T.G.Beuthe and B.N.Hanna, Editor, "CATHENA 3.5.4.4 INPUT REFERENCE", 153-112020-UM-006, Rev.0, October 2013.

[2] M.R.Kuhlman, et. al., "CORSOR User's Manual," NUREG/CR-4173, March 1985.