Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Comparison of Channel Behavior for Initial and Aged CANDU Core

Jong Yeob Jung*, Jun Ho Bae, Joo Hwan Park and Yong Mann Song
Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Republic of Korea
**Corresponding author: agahee@kaeri.re.kr*

1. Introduction

A feeder break is one of the postulated single channel design basis accidents occurring in a CANDU reactor. A break in an inlet feeder can lead to a reduction in the coolant flow in the adjacent fuel channel with the channel remaining under power. Depending on the break size, a complete stagnation of the channel flow can occur, resulting in rapid fuel and channel heat-up and channel failure.

The timing of the fuel channel failure is important for this accident because it determines the amount and temperature of molten material in the channel, which can be discharged into the moderator. Channel failure results in increased coolant flow through the channel, and therefore terminates the channel heat-up. This limits the fission product releases from the fuel as well as the mass of the molten material. Therefore, it is conservative to select assumptions that tend to delay a channel failure.

In this study, the channel failure timing and amount of molten material after the feeder stagnation break were evaluated for an initial core and an 11 EFPY (Effective Full Power Year) aged core of CANDU, respectively. Here, the aged core indicates that the core was assumed to be operated for 11 EFPY after the refurbishment and was considered the aging effect of the main heat transport system such as the pressure tube creep, magnetite deposition, and feeder orifice degradation [1]. This was carried out to verify the aging effect on the safety analysis, specifically in the case of the amount of molten material following the feeder stagnation break. Because conservative assumptions are the basic characteristics of a deterministic safety assessment, the conservativeness of the aged core assumption can be derived from the evaluation results.

2. Fuel Channel Failure Assessment

2.1 Pressure Tube Failure Criteria

Pressure tube (PT) failure prior to the contact between the pressure tube and calandria tube (CT) in a stagnation feeder break is almost certain to occur owing to circumferential temperature gradients and locally concentrated PT strain. The circumferential temperature gradients include the vertical temperature gradient within the steam from natural convection, flow stratification, sub-channel effects, and fuel element/PT contact [2]. Among these, the flow stratification is only modeled in the CATHENA [3] single channel model and the others are not modeled owing to uncertainty in the modeling and a lack of modeling capability. Therefore, the time of a PT failure is conservatively assumed as the time of PT/CT contact since the PT of a stagnated channel obviously fails prior to PT/CT contact. This criterion for PT failure is termed as the ballooning criterion.

2.2 Results of Fuel Channel Failure

Since the timing of a channel failure and the channel conditions at this time are a strong function of the break size, a parametric survey of the break size was performed for each initial and aged core. The parametric survey focuses on the limiting high power channel, the so-called 'O6_mod' channel, whose channel power and bundle power of the two center bundles have been modified to the licensing limits of 7.3 MW and 935 kW.

Table 1: PT/CT Contact Times and Locations (Initial Core)

Inlet Feeder Break Size (m^2)	Approximate Coolant Flow at 10 sec (kg/s)	PC/TC Contact (sec)	Location of 1st PT/CT Contact (BD position)
15.50×10^{-4}	3.02	75.63	12
16.00×10^{-4}	2.04	26.30	11
16.25×10^{-4}	1.85	20.86	11
16.35×10^{-4}	1.71	19.57	11
16.50×10^{-4}	1.62	18.08	11
16.75×10^{-4}	1.22	16.21	7
17.00×10^{-4}	0.83	12.72	7
17.25×10^{-4}	0.48	10.93	7
17.50×10^{-4}	-0.21	10.34	6
18.00×10^{-4}	-0.52	11.05	6
19.00×10^{-4}	-0.6	12.81	7
25.00×10^{-4}	-3.37	30.70	1

Table 2: PT/CT Contact Times and Locations (Aged Core)

Inlet Feeder Break Size (m^2)	Approximate Coolant Flow at 10 sec (kg/s)	PC/TC Contact (sec)	Location of 1st PT/CT Contact (BD position)
15.00×10^{-4}	2.9	31.07	12
15.50×10^{-4}	1.81	19.33	6
15.75×10^{-4}	1.39	15.31	6
16.00×10^{-4}	0.91	12.05	7
16.25×10^{-4}	0.35	10.08	7
16.35×10^{-4}	0.04	11.37	7
16.50×10^{-4}	-0.18	10.19	6
16.75×10^{-4}	-0.45	10.10	6
17.00×10^{-4}	-0.51	10.39	6
17.50×10^{-4}	-0.57	11.00	6
18.00×10^{-4}	-0.54	11.62	6
19.00×10^{-4}	-0.88	13.22	6
25.00×10^{-4}	-3.35	31.06	2

Tables 1 and 2 summarize the times and locations of the PT/CT contact for various break sizes of the initial and aged cores. The results from the aged core indicate that the pressure tube contact time does not vary monotonically with the break sizes. The PT/CT contact time is slightly longer when the coolant flow rate (at 10 seconds) is less than 0.1 kg/s compared with the PT/CT contact times when the flow rate is slightly greater than 0.1 kg/s. The most severe flow stagnation was observed at the break size of 17.50 cm^2 and the corresponding PT/CT contact time was 10.34 seconds for the initial core and 16.35 cm^2 and 11.37 seconds for the 11 EFPY aged core.

3. Molten Mass Assessment

3.1 Methodology for Molten Mass Assessment

The mass of molten fuel and sheath material at the time of a channel failure is calculated from the CATHENA results. For a conservative estimate of the molten mass, the fuel and channel heat-up was assumed to continue for an additional 2 seconds after the predicted time of channel failure. The melting temperature for the zircaloy sheath and UO_2 fuel were taken as 1760 ^{0}C and 2840 ^{0}C at the top fuel element, and an additional 5% of the fuel was assumed to interact with the molten sheath and form a molten eutectic.

3.2 Results of Molten Mass Assessment

Tables 3 and 4 show the amount of molten UO_2-Zr alloy, UO_2 and sheath 2 seconds after the channel failure time for the various ranges of inlet feeder break size of the initial and aged cores.

Table 3: Molten Material Inventory (Initial Core)

Inlet Feeder Break Size (m^2)	Mass of Molten Material Produced (kg)			
	UO_2-Zr	UO_2	Sheath	Total
15.50×10^{-4}	0	4.24	0	4.24
16.00×10^{-4}	0	0.42	0	0.42
16.25×10^{-4}	0	0	0	0
16.35×10^{-4}	0	0	0	0
16.50×10^{-4}	0	0	0	0
16.75×10^{-4}	0	0	0	0
17.00×10^{-4}	1.94	0	3.92	5.87
17.25×10^{-4}	5.42	0	10.94	16.36
17.50×10^{-4}	5.42	0	10.94	16.36
18.00×10^{-4}	3.95	0	7.97	11.92
19.00×10^{-4}	1.94	0	3.92	5.86
25.00×10^{-4}	0	0	0	0

The mass of the molten sheath and alloy was maximized for breaks, which resulted in a minimum (in magnitude) channel flow. The maximum total masses of the molten material were 16.36 kg for the initial core and 17.43 kg for the 11 EFPY aged core and the corresponding break sizes were 17.5 and 16.35 cm^2.

Table 4: Molten Material Inventory (Aged Core)

Inlet Feeder Break Size (m^2)	Mass of Molten Material Produced (kg)			
	UO_2-Zr	UO_2	Sheath	Total
15.00×10^{-4}	0	5.09	0	5.09
15.50×10^{-4}	0	0.85	0	0.85
15.75×10^{-4}	1.06	0	2.14	3.20
16.00×10^{-4}	2.30	0	4.64	6.94
16.25×10^{-4}	5.32	0	10.94	16.36
16.35×10^{-4}	5.77	0	11.65	17.43
16.50×10^{-4}	5.24	0	10.58	15.82
16.75×10^{-4}	5.42	0	10.94	16.36
17.00×10^{-4}	5.42	0	10.94	16.36
17.50×10^{-4}	4.12	0	8.32	12.45
18.00×10^{-4}	2.86	0	5.77	8.63
19.00×10^{-4}	1.41	0	2.85	4.26
25.00×10^{-4}	0	0.42	0	0.42

At the break size of a minimum channel flow, the sheath heat-up is rapid and sheath melting can occur even though the channel failure time is short. As shown in Tables 3 and 4, the mass of the molten material for the aged core is greater than that for the initial core.

4. Conclusions

Since the molten material in the channel can be discharged into the moderator after the channel failure, the more molten inventory for the aged core can have a bad influence on safety. Therefore, the aged core model was found to be more conservative, and it is reasonable to consider the aging effect in the safety assessment.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT, and Future Planning). (Project No. NRF- 2012M2A8A4025960)

References

[1] J.Y. Jung, J.H. Bae and J.H. Park, “Evaluation of Fuel Performance for Fresh and Aged CANDU Reactor”, KNS 2012 Autumn Meeting, Gyeongju, Oct. 25-26, 2012.
[2] T.K. Min, J.Y. Huh and N.H. Lee, “Feeder Break”, AECL Analysis Report, 86-03500-AR-048, Rev. 1, June, 1995.
[3] T.G. Beuthe and B.N. Hanna, "CATHENA MOD-3.5D/Revision 2 Input Reference", AECL Report, 153-112020-UM-001, August 2005.