An Evaluation of a Fission Product Inventory for CANDU Fuels

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1. Introduction

Fission products are released by two processes when a single channel accident occurs. One is a 'prompt release' and the other is a 'delayed release'. Prompt release assumes that the gap inventory of the fuel elements is released by a fuel element failure at the time of an accident. Delayed release assumes that the inventories within the grain or at the grain boundary are released after a accident due to a diffusion through grains, an oxidation of the fuel and an interaction between the fuel and the Zircaloy sheath. Therefore, the calculation of a fission product inventory and its distribution in a fuel during a normal operating is the starting point for the assessment of a fission product release for single channel accidents.

In this report, the fission product inventories and their distributions within s fuel under a normal operating condition are evaluated for three types of CANDU fuels such as the 37 element fuel, CANFLEX-NU and CANFLEX-RU fuel bundles in the 'limiting channel'.

To accomplish the above mentioned purposes, the basic power histories for each type of CANDU fuel were produced and the fission product inventories were calculated by using the ELESTRES code [1, 2].

2. Limiting Channel Data for Inventory Calculation

2.1. Limiting Power Envelop for Fuel Bundle

The amount of a fission product inventory and its distribution during a normal operating are dependent on the power-burnup history of a fuel bundle. The reference overpower envelop, which is the power-burnup history of bundles, is made on basis of refueling simulation results and it has the highest power value of 900 kW for the 37 element fuel and 800 kW for CANFLEX-NU and CANFLEX-RU fuel bundles. However, for a safety analysis, the limiting power envelop is used to obtain conservative results of a fission product inventory. Accordingly, the limiting power envelop for fuel bundles is derived by modifying the reference overpower envelop such that the maximum bundle power is equal to the limit operating condition [3]. This operational bundle power limit is 935 kW, therefore, the reference overpower envelop powers are multiplied by 935/900 for 37 element fuel and 935/800 for CANFLEX-NU and RU fuel bundles.

2.2. Limiting Element Power Envelop for Each Ring

CANDU fuel bundle consists of 4 rings that are center, inner, intermediate, and outer rings. Because each ring has a different power-burnup history, it is necessary to derive the limiting element power envelops for each ring. They can be obtained from the previously derived limiting bundle power envelop using the relative power and burnup conversion ratios (also known as radial power factor and radial burnup factor). Though the radial power factor varies with a burnup, the power factors at the time of a plutonium peak are used regardless of the burnup to obtain more conservative results. The radial power and burnup factors used in this report are summarized in Table 1.

Table 1 Radial Power and Burnup Conversion Ratios at Plutonium Peak

37 Element Bundle	Power Factor	Burnup Factor
Outer	1.131	1.124
Intermediate	0.9206	0.9239
Inner	0.8051	0.8161
Centre	0.7613	0.7746
CANFLEX-NU	Power Factor	Burnup Factor
Outer	1.058	1.1342
Intermediate	0.8707	0.9377
Inner	1.0800	0.8309
Centre	1.0325	0.7941
CANFLEX-RU	Power Factor	Burnup Factor
Outer	1.0808	1.1433
Intermediate	0.8613	0.9107
Inner	1.0390	0.7861
Centre	0.9745	0.7374

2.3. Assumption of Limiting Channel

The single channel accidents, such as a flow blockage, failure of an inlet feeder, failure of a channel end fitting and a pressure tube rupture, can be postulated to occur in any of the 380 channels in the CANDU reactor at any time during the reactor's operating history. One of the main objectives of the fuel analysis for each single channel accident is to conservatively estimate the fission product release from fuel in the affected channel. It is not efficient to analyze each of the 380 channels for each single channel accident. Instead, a 'limiting channel' is introduced such that releases can be over estimated relative to any real channel.

The maximum channel and bundle powers in an operating reactor must be maintained below their respective Limiting Conditions for Operation (LCO). The LCO for a channel power restricts the maximum channel power to 7.3 MW and for a bundle power restricts the maximum bundle power to 935 kW. Thus, the 'limiting channel' is assumed to have the channel power of 7.3 MW and to have two bundles which are at the power of 935 kW for 37 element and CANFLEX-NU fuels and one 935 kW bundle in the channel for CANFLEX-RU fuel. The axial power variation of the bundles in the 'limiting channel', as shown in Table 2, is based on an O06 channel which is a relatively high power channel.

Table 2 Bundle Power Distribution in the 'Limiting Channel'

A	Bundle Axial Power Distribution						B		
	37-elem. BD		CANFLEX-NU		CANFLEX-RU		37	NU	RU
	Ratios	*Power*	*Ratios*	*Power*	*Ratios*	*Power*			
1	0.0153	111.7	0.0153	111.7	0.0067	48.9	7.09	5.72	2.56
2	0.0556	406.1	0.0556	406.1	0.0685	500.3	25.8	20.7	26.1
3	0.0849	619.7	0.0849	619.7	0.1069	780.1	39.3	31.4	40.7
4	0.1043	761.4	0.1043	761.4	0.1244	907.4	48.3	38.5	47.4
5	0.1197	874.0	0.1197	874.0	0.1281	935.0	55.5	44.2	48.8
6	0.1281	935.0	0.1281	935.0	0.1202	877.8	59.3	46.7	45.8
7	0.1281	935.0	0.1281	935.0	0.1153	841.6	59.3	46.7	43.9
8	0.1200	875.6	0.1200	875.6	0.1127	823.0	55.6	44.3	42.9
9	0.1020	744.9	0.1020	744.9	0.0983	717.5	47.3	37.6	37.4
10	0.0791	577.5	0.0791	577.5	0.0734	536.1	36.6	29.1	28.0
11	0.0498	363.8	0.0498	363.8	0.0402	293.6	23.1	19.4	15.3
12	0.0131	95.3	0.0131	95.3	0.0052	38.1	6.05	4.81	1.99
	1.0	**7300**	**1.0**	**7300**	**1.0**	**7300**			

A : Axial Bundle Position
B : Corresponding Outer Element Linear Power (kW/m)

The bundle burnup also affects the fission product inventory. The maximum total and gap inventories of the long-lived isotopes will occur at the time when the channel is about to be refueled. On the other hand, the maximum total and gap inventories of the short-lived isotopes will occur when the power is highest. Therefore, for fission product release estimates only, the burnups of the twelve bundles in the 'limiting channel' are assumed to be their respective burnups at the time of the channel is about to be refueled.

The element linear power-burnup data for each ring in the 'limiting channel' are derived from the limiting power envelop with the similar method described in Sec. 2.2. In this way, total 144 element power-burnup data were produced for the each fuel type of 37 element fuel, CANFLEX-NU, and CANFLEX-RU fuels.

3. Calculation Results of Fission Product Inventory

The fission product inventories in the 'limiting channel' for each type of CANDU fuels were calculated by using ELESTRES code based on the previously derived linear power-burnup data.

Table 3 shows the fission product inventory results for the 18 isotopes of the 37 element fuel, CANFLEX-NU, and CANFLEX-RU fuels. As shown in this table, total inventories of the 37 element and CANFLEX-NU fuels are almost the same but the result from CANFLEX-RU is less about 8 %. Table 4 summarizes the gap, grain boundary, grain, and total inventories of 30 isotopes in the 'limiting channel' for the three types CANDU fuels. Total inventory results are similar to the result from Table 3, however, in the case of the gap inventory, the results from the CANFLEX-NU and CANFLEX-RU fuels are much less than that from the 37 element fuel. In the single channel accidents, it is assumed that the gap inventory is promptly released at the time of the accident. Therefore, this result implies that the CANFLEX fuels have a greater safety margin than the 37 element fuel in terms of a prompt release of the fission product.

Table 3 Total Inventory for Each Isotope in 'LimitingChannel'

Isotope	Half-life	Total Inventory (TBq)		
		37	NU	RU
I-131	$6.95x10^5$	7682.0	7725.28	7085.72
I-132	$8.23x10^3$	11870.52	12017.69	11016.75
I-133	$7.49x10^4$	18548.51	18780.86	17216.85
I-135	$2.37x10^4$	17417.45	17635.08	16166.43
I-137	$2.45x10^1$	9307.51	9440.10	8664.08
KR-83M	$6.70x10^3$	1435.51	1453.32	1332.26
KR-85M	$1.61x10^4$	3505.65	3549.38	3253.78
KR-85	$3.38x10^8$	23.79	22.85	25.73
KR-87	$4.56x10^3$	6819.05	6903.49	6328.22
KR-88	$1.01x10^4$	9634.02	9753.85	8941.50
KR-89	$1.90x10^2$	12647.38	12830.8	11776.95
XE-133M	$1.93x10^5$	524.42	530.94	486.74
XE-133	$4.57x10^5$	17061.66	17221.57	15786.22
XE-135M	$9.18x10^2$	2982.75	3021.26	2766.99
XE-135	$3.30x10^4$	1987.38	2012.24	1844.67
XE-137	$2.29x10^2$	17071.64	17321.68	15899.34
XE-138	$8.52x10^2$	17040.73	17265.03	15807.74
I-134	$3.16x10^3$	20762.21	21018.85	19266.49
Total		**176322.2**	**178504.3**	**163666.2**

Table 4 Fission Product Inventory from 'Limiting 'Channel' for Various CANDU Fuels

Fuel	Gap Inventory (TBq)	Grain Boundary (TBq)	Grain Inventory (TBq)	Total Inventory (TBq)
37	2,087	35,252	224,660	262,000
NU	368	24,436	240,047	264,851
RU	361	19,031	222,898	242,290

4. Conclusions

Basic power-burnup data for a assumed 'limiting channel' were produced for three types of CANDU fuels, which are the 37 element fuel, CANFLEX-NU, and CANFLEX-RU fuels. Fission product inventories for the three types of fuels were calculated in the 'limiting channel' and the results showed that the CANFLEX fuels are safer than 37 element fuel from the prompt release view point.

REFERENCES

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