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A Study on the Initial Fission Product Inventory for the Single Channel Event in CANDU Reactor

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1. Introduction

The initial fission product inventory and distribution within the fuel during normal operation are used to determine the starting point for the single channel event such as channel flow blockage, pressure tube rupture and feeder break. The factors affecting the fission product inventory are the fuel power and burnup at the time of the accident. The fission products are created initially within the UO_2 matrix. They can migrate by thermal or irradiation diffusion processes. This redistributes the fission gases within the grains of the fuel pellet. Some of the fission gas atoms migrate to the grain boundaries. The fission products at the grain boundaries can also migrate out of the fuel pellet to the gaps between the UO_2 fuel pellets and the sheath, as well as to the cracks within the fuel pellets. The ease with which the fission products may be released from the fuel element during an accident depends on whether they are in the gap, on the UO_2 grain boundary or within the UO_2 grain. The fission product release and migration models are well established, however, to the point of view from the power history, it has some controversial issues on the end power point and Pu-peak consideration between the analysis reports. This report is purposed to document the sensitivity study for various power history cases.

2. Analysis Methodology

2.1 ELESTRES code

Fission product inventories in the fuel at the time of the accident are estimated with the ELESTRES computer code which provides the fuel temperature and distribution of the various kinds of fission products within a fuel element. This information is used with the ANS 5.4 model [1] for a release estimate to the gap. The ANS 5.4 model is a Booth diffusion-type model [2] which is empirically fitted to experimental data. The gap fission product inventory predicted using the ANS 5.4 model has been compared with experiments on CANDU fuel. It has been shown that the ANS 5.4 model over-predicts the steady-state release of noble gases by several orders of magnitude since model parameters are fitted to predominantly light water reactor fuel data at low power and high burnup. To account for this over-estimation, the free inventory has been reduced to 20% of the ANS 5.4 value, and the grain boundary inventory has been correspondingly increased. The grain boundary inventories are estimated by assuming that the ratio of the grain boundary inventory to the total inventory of each isotope was equal to the ratio of the number of fission gas atoms on the grain boundary to the total number of fission gas atoms in the element. The maximum total and gap inventory of isotopes with a long half-life will occur at the time the channel is about to be refuelled. On the other hand, the maximum channel and gap inventories of isotopes with a short half-life will occur when the power is highest.

2.2 Power history

For safety analysis, the limiting power envelope is derived by modifying the reference overpower envelope such that the maximum power is equal to the limiting condition for bundle powers. The limiting power envelope for fuel elements in different rings is shown Figure 1. If the power/burnup point of the element is above the limiting power envelope then the element is assumed to have operated on the limiting power envelope itself. At the time of the accident, three different cases are investigated.

First, the element power is instantaneously boosted to coincide with the estimating discharge power and burnup. Such a combination of high power and high burnup results in an upper bound fission product inventory prediction. If the power/burnup point of a fuel element at the time of the accident is below the limiting envelope, the burnup history for that element is assumed to operate parallel to the limiting power envelope. The power of each of the 48 simulated elements is boosted by 5% to account for the increase in channel power due to channel coolant voiding (Fig. 2). The 5% power increase of all elements is assumed to last for 15 minutes. But bundle power redistribution before and after Pu-peak is not considered here.

Second, power history boosting following the referenced envelope power can not be realistic and has much overestimation. The power point at the time of accident will be ended within the envelope in this case. Bundle power redistribution before and after Pu-peak is not considered here either.

Third, Pu-peak power distribution is considered followed by the second case power history.

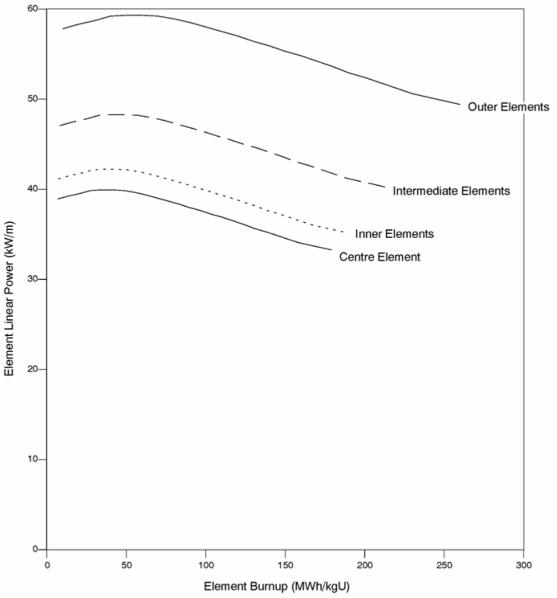

Figure 1. Limiting Power Envelopes for Each Ring of Elements

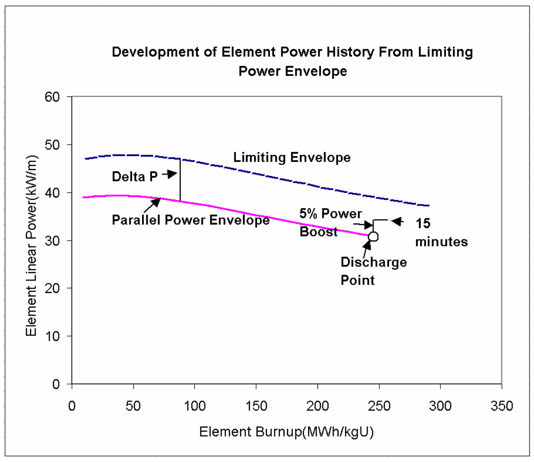

Figure 2. Development of Element Power History from Limiting Power Envelope

3. Results and discussion

To further bound the channel fission product inventories, each ELESTRES output was scanned and the maximum total inventory and the corresponding gap inventory of each isotope was recorded. This approach results in an over-prediction of the channel fission product inventory. The inventories within the individual grains were calculated using the total, gap and grain boundary inventories provided by the ELESTRES computer code. The fission product release results were showed in Table 1. The 1st case has 2946, 39492 and 220099 TBq at gap, grain boundary and grain respectively, which was the largest gap and grain boundary release amount among the three cases. The 2nd case has 2656, 39463 and 219856 TBq. The 3rd case has 2398, 39122 and 221618 TBq, which was the most in total bundle inventory. The typical single channel event, feeder break, was analyzed with the three initial inventory cases (Fig 3). The simulation time was determined to 12 seconds for the all bundle fission inventory release out after feeder break accident by CATHENA thermal hydraulic code. The fission product releases were 67506, 66713 and 66317 TBq for the 1st, the 2nd and the 3rd case respectively. The difference was negligible between them because the initial fission inventory recorded by maximum value after scanning the ELESTRES output file was not so much different.

Table 1. Fission Inventory Release from Gap, Grain boundary and Grain for each case

Case No.	Gap inventory (TBq)	Grain boundary (TBq)	Grain (TBq)	Total (TBq)
1	2,946	39,492	220,099	262,537
2	2,656	39,463	219,856	261,975
3	2,398	39,122	221,618	263,138

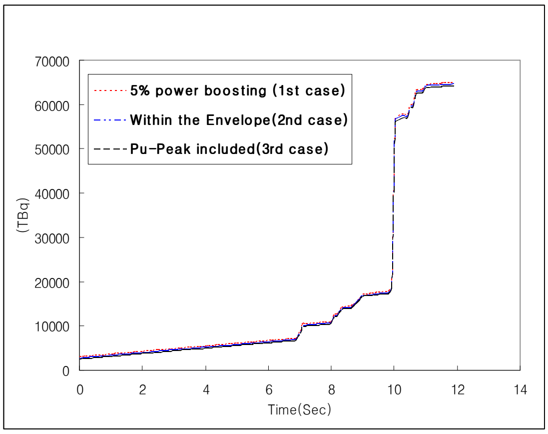

Figure 3. Fission Inventory Release after the Single Channel Event (Feeder Break) for each case

4. Conclusion

The initial fission product release was analyzed for three power history cases using the ELESTESS code. The 3rd case had the largest bundle inventory amount among the three cases, however the difference was too small to show distinguishable results after the single channel event. It was due to the record maximum value after scanning the ELESTRES output file for the conservatism.

REFERENCES

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3. M. Shad and H. Chow, “Fuel Management Report”, 98-03310-AR-003, Revision 0, 1991 December.