Proceeding of the Korean Nuclear Society Autumn Meeting
Taegu, Korea, October 1997

FISSION PRODUCT RELEASE ASSESSMENT FOR END FITTING FAILURE IN CANDU REACTOR LOADED WITH CANFLEX-NU FUEL BUNDLES

Dirk Joo Oh, Chang Joon Jeong, Kang Moon Lee* and Ho Chun Suk
Korea Atomic Energy Research Institute

ABSTRACT

Fission product release (FPR) assessment for End Fitting Failure (EFF) in CANDU reactor loaded with CANFLEX-natural uranium (NU) fuel bundles has been performed. The predicted results are compared with those for the reactor loaded with standard 37-element bundles.

The total channel I-131 release at the end of transient for EFF accident is calculated to be 380.8 TBq and 602.9 TBq for the CANFLEX bundle and standard bundle channel cases, respectively. They are 4.9% and 7.9% of the total inventory, respectively. The lower total releases of the CANFLEX bundle O6 channel are attributed to the lower initial fuel temperatures caused by the lower linear element power of the CANFLEX bundle compared with the standard bundle.

1. INTRODUCTION

Currently, the Korea Atomic Energy Research Institute (KAERI) and Atomic Energy of Canada Limited (AECL) are jointly developing an advanced Canada deuterium uranium (CANDU) fuel, called CANDU Flexible Fuelling (CANFLEX). The CANFLEX 43-element bundle design has two major design improvements over the standard CANDU-6 37-element bundle while maintaining compatibility with the existing CANDU reactor fuel-handling systems and all other fuel performance characteristics. First, the CANFLEX bundle contains 43 elements of two different diameters, thereby reducing peak linear element power by 20% (i.e., < 50 kW/m). The lower linear element power not only enables a 200% increase in average discharge burnup (i.e., 21000 MWD/MTU) with the use of slightly enriched uranium compared with the standard natural uranium bundle but also improves the safety margins of CANDU reactors. Second, the CANFLEX bundle has the attachment of critical heat flux enhancement pads called buttons. The buttons increase critical channel power by about 5%, which leads to the improvement of the operating margins for CANDU reactors.

The CANDU fuel channel consists of the pressure tube that are rolled into end fittings at each end of the channel, where large residual stresses exist due to wall thinning and tube expansion process during the fabrication process. An EFF in a single channel, which is a design base accident specific to CANDU reactors, would result in behaviour similar to that of a small break in a reactor inlet or outlet header with respect to the thermalhydraulic response of the primary circuit and the containment building. However, this event differs from the small header breaks in that all the fuel bundles in the affected

---

* Present Address: Korea Nuclear Fuel Company

channel are assumed to be ejected into the fuelling machine vault, heavily damaged by the impact and release radioactive fission products into containments. Thus, the main focus is on the behaviour of the ejected fuel, as opposed to the primary circuit.

This paper describes the FPR assessment results for EFF in CANDU reactor loaded with CANFLEX-NU fuel bundles compared with those for the reactor loaded with standard 37-element bundles.

2. Analysis Methodology

The EFF analysis concentrates on the behaviour of the fuel ejected from the broken channel.

A survey of the fission product release behaviour is made for the different sizes of the fuel fragments. All of the UO_2 pellets are conservatively assumed to be ejected from the sheaths and break into fragments of varying sizes, from an equivalent unbroken pellet size to 1.0 mm. The fragments are assumed to be spherical.

For the prompt (time zero) release estimation, the gap inventory of all of the fuel elements in the channel is assumed to be released at the time of sheath failure (time zero). The remaining fission product inventory is bound within the grains or on the grain boundaries of the fragments of UO_2. When a fuel pellet fractures into many small fragments, the surface area of exposed UO_2 increases. It is assumed that this increase in exposed surface area causes additional prompt release of fission products which were previously on grain boundaries. The fraction of the grain boundary inventory released after fuel fragmentation is assumed to be equal to the ratio of exposed surface area to the total grain surface area in the pellet. It is estimated to be 0.03 for an assumed fragment size of 1 mm diameter sphere (Reference 1).

Transient FPR calculations consist of three parts: (i) the fission product inventory in the channel is estimated using the ELESTRES (References 2 and 3) computer code to simulate the operating history of the fuel elements in the channel; (ii) the temperature transients for each assumed fuel fragment size is estimated; (iii) based on the predicted fuel temperatures, the oxidation and FPR for each assumed fuel fragment size is estimated. The REDOU code (Reference 4) is used to perform both the parts (ii) and (iii). The fractional release transient from each element is then multiplied by the bound inventory of iodine for that element to obtain the iodine release transient. However, the grain bound inventories of noble gases are assumed to be instantly released at the time of accident.

3. Analysis Results

The prompt I-131 releases which consists of gap inventory and 3% of grain boundary inventory are given in Table 1. The prompt releases for the CANFLEX bundle case is fairly lower than those for the standard bundle case due to the lower gap and grain boundary inventories of CANFLEX bundle compared to the standard bundle case. The lower gap and grain boundary inventories of the CANFLEX bundle case are attributed to the lower initial fuel temperatures caused by the lower linear element power of the CANFLEX bundle compared with the standard bundle.

The transient fission product release is determined by fuel temperature and extent of oxidation. Using the temperature transient, the extent of oxidation of fuel pellet pieces from the O6 channel is obtained. By the end of the simulations (600 s), all fragments from the channel are completely oxidized and release rate goes to zero, regardless of fragment sizes and initial temperatures.

For the 7.3 MW O6 channel with the two 935 kW bundles, the initial temperatures of fragments used to perform the oxidation analysis following ejection of the bundles are given in Table 2. Fuel fragment temperatures for both outer and intermediate elements of the CANFLEX bundle are lower than the corresponding element temperatures for the standard bundle, but the opposite is true for both inner and center element cases. The results are attributed to the magnitude of the initial linear power of each ring element for the two bundles.

For the O6 channel, a series of iodine release transients are estimated by using the various assumed initial UO_2 fragment sizes. Critical fragment sizes are defined as the ones which give the highest releases. I-131 releases and release fractions for iodine isotopes for the standard and CANFLEX bundle cases are given in Table 3 for the critical fragment sizes for each ring of fuel elements in the channel. Releases from the fuel matrix for the standard and CANFLEX bundle cases are limited to 10.9% and 5.1% of the bound inventory, respectively, in outer elements of bundle 7. For the high power bundles (bundles 4 to 9), the releases from the outer and intermediate rings for the CANFLEX bundle case are lower than those for the standard bundle case and the opposite is true for the inner ring and center pin. However, the bundle releases for each of high power bundles are higher for the standard bundle case compared with the CANFLEX bundle case. For the remaining low power bundles (bundles 1 to 3 and 10 to 12), the releases from each ring of both bundles are similar each other and so bundle releases from each bundle are. In all, the total channel release for the CANFLEX bundle channel is lower than that for the standard bundle channel.

Figure 1 shows the total I-131 channel release transients. The total releases are composed of the prompt releases upon fuel fracture and transient releases from the remaining grain boundary and bound inventories. The total channel I-131 release at the end of transient (600 s) is calculated to be 380.8 TBq and 602.9 TBq for the CANFLEX bundle and standard bundle channel cases, respectively. They are 4.9% and 7.9% of the total inventory, respectively. Table 4 gives the total channel releases for the iodine isotopes. The entire channel inventories of the noble gases are assumed to be released at the beginning of the transient.

4. Conclusions

The total channel I-131 release at the end of transient for EFF accident is calculated to be 380.8 TBq and 602.9 TBq for the CANFLEX bundle and standard bundle channel cases, respectively. They are 4.9% and 7.9% of the total inventory, respectively. The lower total releases of the CANFLEX bundle O6 channel are attributed to the lower initial fuel temperatures caused by the lower linear element power of the CANFLEX bundle compared with the standard bundle.

5. References

1. K.M. Lee et al., "Analysis Report for End Fitting Failure", 86-03500-AR-046, Rev. 1, May 1995.
2. M. Tayal, "Modelling CANDU Fuel Under Normal Operating Conditions: ELESTRES Code Description", AECL-9331, February 1987.
3. M. Tayal, "ELESTRES" Performance of Nuclear Fuel, Circumferential Ridging and Multiaxial Elastic-Plastic Stresses in Sheaths", International Conference on CANDU Fuel, Chalk River, Ontario, October 1986.
4. R. Aboud, "REDOU Version 1.0: Fractional Fission Product Releases Due to Oxidation of Uranium Dioxide-Program Description, User's Manual and Validation", TTR-378, Volume 1, 1992 January.

Table 1

Bundle and Ring Distributions of I-131 Isotope Prompt Releases (TBq)
from the O6 Channel for End Fitting Failure Accident

Bundle Position		Outer Ring	Intermediate Ring	Inner Ring	Centre Element	Total
1	S^*	0.1	0.0	0.0	0.0	0.1
	C^*	0.0	0.0	0.0	0.0	0.0
2	S^*	0.4	0.2	0.1	0.0	0.7
	C^*	0.3	0.1	0.1	0.0	0.5
3	S^*	1.6	0.4	0.1	0.0	2.1
	C^*	0.5	0.2	0.2	0.0	0.9
4	S^*	14.9	1.1	0.2	0.0	16.2
	C^*	1.6	0.4	0.6	0.1	2.6
5	S^*	23.3	2.6	0.4	0.1	26.3
	C^*	3.5	0.5	1.3	0.1	5.4
6	S^*	24.1	2.8	0.5	0.1	27.4
	C^*	3.8	0.6	1.4	0.1	5.9
7	S^*	24.7	3.0	0.5	0.1	28.2
	C^*	4.1	0.6	1.4	0.1	6.2
8	S^*	25.1	3.2	0.5	0.1	28.8
	C^*	4.2	0.6	1.5	0.2	6.5
9	S^*	17.9	1.8	0.3	0.0	20.0
	C^*	2.6	0.5	0.9	0.1	4.1
10	S^*	3.8	0.6	0.2	0.0	4.6
	C^*	0.9	0.3	0.3	0.0	1.5
11	S^*	0.7	0.3	0.1	0.0	1.1
	C^*	0.5	0.2	0.1	0.0	0.8
12	S^*	0.3	0.1	0.1	0.0	0.5
	C^*	0.2	0.1	0.1	0.0	0.4

Note:

S^*=37-element Bundle Channel and

C^*=CANFLEX Bundle Channel

Table 2
Initial Temperatures of the Fragments from the O6 Channel
at the Time of End fitting Failure Accident

Bundle Position	Outer Element		Intermediate Element		Inner Element		Centre Element	
	S*	C*	S*	C*	S*	C*	S*	C*
1	337	325	324	315	318	324	315	322
2	515	467	468	434	444	471	434	463
3	686	582	587	527	544	598	528	584
4	1047	680	700	599	623	707	602	683
5	1257	807	853	665	701	841	669	798
6	1355	862	904	702	749	904	713	856
7	1366	875	915	709	760	914	720	869
8	1289	839	893	689	736	877	694	833
9	1083	720	757	620	646	753	624	719
10	739	586	595	539	556	609	542	598
11	532	485	490	458	468	498	460	492
12	366	355	356	349	351	358	349	357

Note:
S*=Standard 37-element Bundle Channel and
C*=CANFLEX Bundle Channel

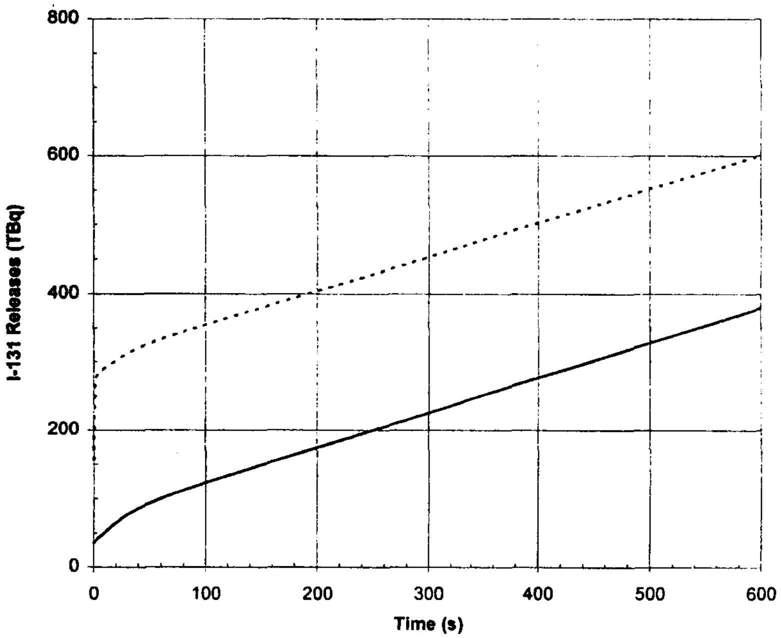

Figure 1: **Accumulated I-131 Release Transients for 7.3 MW Channel for End Fitting Failure Accident; CANFLEX (solid line) & Standard (dotted line) Bundles.**

Table 3

Bundle and Ring Distributions of I-131 Isotope Bound Inventory Releases (TBq) and Release Percentages from the O6 Channel for End Fitting Failure Accident

Bundle Position		Outer Ring	Intermediate Ring	Inner Ring	Centre Element	Total
1	S*	2.3 (4.0%)	1.2 (4.0%)	0.6 (4.0%)	0.1 (4.0%)	4.2
	C*	2.2 (4.0%)	1.2 (4.0%)	0.7 (4.0%)	0.1 (4.0%)	4.2
2	S*	9.1 (4.0%)	4.9 (4.0%)	2.2 (4.0%)	0.3 (4.0%)	16.5
	C*	8.7 (4.0%)	4.7 (4.0%)	2.9 (4.0%)	0.4 (4.0%)	16.7
3	S*	15.6 (4.4%)	7.9 (4.1%)	3.4 (4.0%)	0.5 (4.0%)	27.4
	C*	14.0 (4.1%)	7.4 (4.0%)	4.7 (4.1%)	0.6 (4.1%)	26.7
4	S*	25.0 (5.9%)	10.5 (4.4%)	4.4 (4.2%)	0.7 (4.1%)	40.6
	C*	18.6 (4.5%)	9.5 (4.2%)	6.3 (4.5%)	0.8 (4.4%)	35.2
5	S*	40.6 (8.9%)	12.6 (4.9%)	5.0 (4.4%)	0.8 (4.3%)	59.0
	C*	21.9 (4.9%)	10.9 (4.4%)	7.4 (4.9%)	1.0 (4.8%)	41.2
6	S*	49.0 (10.7%)	13.0 (5.0%)	5.3 (4.6%)	0.8 (4.5%)	68.1
	C*	22.7 (5.1%)	11.3 (4.6%)	7.7 (5.1%)	1.0 (4.9%)	42.7
7	S*	49.9 (10.9%)	13.1 (5.1%)	5.3 (4.7%)	0.8 (4.5%)	69.1
	C*	22.8 (5.1%)	11.3 (4.6%)	7.7 (5.1%)	1.0 (4.9%)	42.8
8	S*	42.9 (9.4%)	12.8 (4.9%)	5.1 (4.5%)	0.8 (4.4%)	61.6
	C*	22.0 (5.0%)	11.0 (4.5%)	7.5 (4.9%)	1.0 (4.9%)	41.5
9	S*	26.5 (6.1%)	11.1 (4.6%)	4.5 (4.2%)	0.7 (4.1%)	42.8
	C*	19.3 (4.6%)	9.8 (4.2%)	6.6 (4.6%)	0.9 (4.4%)	36.6
10	S*	16.8 (4.5%)	8.4 (4.1%)	3.6 (4.0%)	0.6 (4.0%)	29.4
	C*	14.9 (4.1%)	8.0 (4.0%)	5.0 (4.1%)	0.7 (4.1%)	28.6
11	S*	11.2 (4.0%)	6.1 (4.0%)	1.9 (4.0%)	0.4 (4.0%)	19.6
	C*	10.9 (4.0%)	5.9 (4.0%)	3.6 (4.0%)	0.5 (4.0%)	20.9
12	S*	4.7 (4.0%)	2.6 (4.0%)	1.1 (4.0%)	0.2 (4.0%)	8.6
	C*	4.8 (4.0%)	2.5 (4.0%)	1.4 (4.0%)	0.2 (4.0%)	8.9

Note:

S*=37-element Bundle Channel and
C*=CANFLEX Bundle Channel

Table 4

Total Channel Releases of Iodine Isotopes Following an End Fitting Failure

Isotope	Half Life (s)	Total Release (TBq)	
		Standard	CANFLEX
I-131	6.95E+05	602.9	380.8
I-132	8.23E+03	948.3	597.4
I-133	7.49E+04	1290.3	903.5
I-134	3.16E+03	1351.6	1002.8
I-135	2.37E+04	1172.0	844.6
I-137	2.45E+01	598.7	450.2