Assessment of Refuelling Effects in High Power Channel on Fission Product Releases Following an End-Fitting Failure

by

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ABSTRACT

A more realistic fuel bundle power history considering the refuelling effect was used for the assessment of fission product releases during an end-fitting failure accident. The high power channels were selected as a conservatism, based on the instantaneous power/burnup distributions during 0 to 610 Full Power Days (FPDs) in the core, which was calculated from the fuel management study for Wolsong 2/3/4 plants. For each fuel bundle, the volume-average temperature in the UO_2 pellet and fission product inventory distribution in the fuel element were calculated by ELESTRES code.

When compared with the case using the current overpower envelope based on the time-average physics simulations, higher fuel temperature and more fission product inventory were predicted for the low power bundles located at bundle positions 1, 2, 11 and 12. However, the results for high power bundles at bundle positions 4 to 9, where the most fission products are released following an end-fitting failure event, confirmed the conservatism made in the current analysis methodology since they showed a very high fission product inventory.

Submitted for presentation at the 20th Nuclear Simulation Symposium, 1997 September 7-9, Niagara on the Lake, Ontario, Canada

1. Introduction

The CANDU fuel channels consist of the pressure tubes 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 end fitting failure in a single channel, which is Class 2 event in AECB consultative document C-6, would result in behavior similar to that of a small reactor header break with respect to the thermohydraulic response of the primary circuit and the containment building. This event differs from a small header break in that all the fuel bundles in the affected channel could be ejected into the fuelling machine vault, causing a heavy damage by the impact and prompt release of fission products to the containment atmosphere. Thus, the focus is on the behavior of the ejected fuel, as opposed to the primary circuit.

In the current analysis methodology, overpower-envelope power history and power/burnup data from time-average physics simulation are used to calculate the fission product releases. Actual power histories for fuel bundles are complicated depending on fuelling history and reactor power level. In the methodology, the power history for each fuel element is not accounted for during refuelling. The reference fuelling scheme is an eight bundle shift in which eight new bundles are loaded into the channel. The current fuelling rate from operating station is slightly less than 2 channels per FPD. With the eight-bundle refuelling scheme, four of these bundles will reside in two positions in the channel while the other four bundles will reside in one position only. Bundles in positions 1 to 4 will be moved to positions 9 to 12 respectively upon refuelling. These bundles are irradiated for 2 dwell periods at different positions in the channel. During normal refuelling operations, the bundles will receive a power increase or decrease depending on fuelling direction and bundle positions. Therefore, the shifted overpower envelope methodology used in the current safety analysis report cannot represent the actual power history and could lead to underpredicton or overprediction for fission product releases for an end-fitting failure.

In this study, an analysis for the end-fitting failure accident was performed to evaluate effect of selecting representative high power channels during refuelling process based on the instantaneous power/burnup simulations. The fuel temperature and fission product inventory from ELESTRES [Reference 1] runs based on more realistic power history were compared with the case using the current analysis methodology.

2. Analysis Methodology

2.1 Selection of High-Power Channels

For the estimation of fission product release using the current methodology, the burnups of the twelve bundles in the channel are assumed to be their respective burnups before the time the channel is about to be refueled, less than the "limiting burnup". The limiting burnup distribution is determined from the maximum bundle average burnup for each bundle location among the 380 channels as predicted in the time-average fuel management simulations. The shape of the overpower envelope is chosen for all ELESTRES runs. The envelope is shifted up and down to derive input for different power/burnup points.

A more realistic approach was taken for the calculation of fission product release from 0 to 610 FPDs with intervals of 10 FPDs. 62 sets of power/burnup data for every fuel bundle in the reactor power of 100 percent were obtained from the instantaneous simulation for Wolsong 2/3/4 fuel management study. At each FPD, a particular fuel channel was selected to include the maximum bundle powers; for example, maximum bundle power of 678 kW at 100 FPDs and 875 kW at 320 FPDs. At each FPD, the channels corresponding to the maximum sum of bundle power at bundle positions from 5 to 8 were selected, which are four times 666.6 kW at 100 FPDs to four times 843.4 kW at 320 FPDs. This is because the fission product releases occur mainly among Bundle Position (BP) 5 to 8, especially from their outer elements. At each FPD, the maximum channel powers were selected; 6.6 MW at 100 FPDs and 7.1 MW at 20 FPDs.

Analyzing the results from the instantaneous physics simulations results in bundle power and burnup data from 62 x 3 high power channels. 8 % of power uncertainty accounted for refuelling process was already included. Here, additional 3% of power increase was included in the selected channels to consider the uncertainty in the power measurement (103% full power).

2.2 Derivation of Limiting Power Envelope

For each bundle position, limiting power history based on more realistic physics simulations was obtained using the bundle power/burnup distribution for the channels selected in Section 2.1. As a conservatism, a bounding approach was used, which selects the highest power for a given burnup, even though it is based on the realistic power/burnup data.

It is expected that the fuel bundles located at bundle positions 9, 10, 11, and 12 change their positions during refuelling and burn up at two locations. The fuel bundles located at bundle positions 11 and 12 decreased their power as they change their positions in the core while the fuel bundles located at bundle positions 9, 10 increased power. Thus, the calculation overpredicts the amount of fission product release for fuel bundles located at bundle positions 9 and 10, however, it tends to underpredict for the fuel bundles located at bundle positions 11 and 12 if the shape of overpower envelope is used for the calculation of fission product inventory.

2.3 Fission Product Inventory Distribution & Fuel Temperature Calculations

To calculate the amount of fission product release during an end-fitting failure accident, pellet temperature and fission product inventory distribution at gap, grain boundary and grain bound inventories were calculated by ELESTRES code (ELESTRES_m11c_w) [Reference 1] code for the fuel elements located at twelve fuel bundles in the limiting channel.

The input data used in the calculation are the fuel element specification and material properties of CANDU 6 standard 37-element fuel bundle and the thermohydraulic conditions from the CATHENA analysis for Wolsong 2/3/4 were used. The power history of each fuel element obtained from the above was used and it calculated at each history point. For a fuel element, the fission product inventory and pellet temperature data calculated at each history point were surveyed to obtain maximum fission product inventory and volume-average pellet temperature.

3. Analysis Results

Figure 1 shows core status of the channels during 0 to 610 FPDs, selected as high- power channels to calculate the amount of fission product release conservatively. It was found out that the channels located close to, but a little outward the center of the core.

Figure 2 shows the bundle power/burnup data for the high power channel located at bundle position 6. To obtain the limiting power history for the bundle position, a procedure of selecting the highest power at each burnup was performed. The resulting power history of the fuel bundle at each bundle position is shown in Figure 3. Overall power history distribution shows a symmetrical shape and the power increase close to the center of channel, in other words, at bundle positions 6 and 7. The highest discharge burnup was occurred at bundle positions 3 and 10, which produce the medium power level. It was observed that the maximum discharge bundle burnup reached about 5100 MWh. As expected, the fuel bundles located at bundle positions 11 and 12 decreased power during refuelling in the core. In case of fuel bundle located at bundle position 12, the bundle was burned at high power about 700 MWh, then decreased suddenly to 200 kW at 3000 MWh. Thus, using existing shape of overpower envelope as a power history, it is expected that the calculation may underpredict fission product inventory at these positions significantly.

As listed in Table 1, the maximum volume-average temperatures among the limiting power history points were predicted from the ELESTRES runs for each bundle and element ring. It was observed that the fuel bundle temperatures at bundle positions 1, 2, 11 and 12 were higher than those from Wolsong 2/3/4 design, calculated using the overpower envelope. Thus, the fuel elements ejected to the containment get oxidized faster at these fuel bundle locations and it is expected that the release fraction for the fission products gets larger. Furthermore, in case of the high power bundles, if more realistic power history is used, the pellet temperature is predicted lower.

As shown in Figure 4, the fission product (iodine-131) distribution in the pellet shows similar trend to the fuel temperature. In case of high power bundle (bundle positions from 4 to 9), if existing overpower envelope is used, the iodine-131 inventory gets higher while in the case of low power bundle located at bundle positions 1, 2, 11, and 12, more realistic power history is used, it gets higher iodine-131 inventory. The final iodine-131calculated by both methods were 7977 and 7709 TBqs, respectively, which tells that the inventory gets higher if more realistic power history is used. The differences in the fuel temperature and fission product inventory are due to power refuelling effect, i.e. the change in the bundle power, and longer burnup if more realistic power history is used. Existing methodology predicted conservative fuel temperature and fission product inventory only for the high-power bundles.

The amount of fission product release after the end-fitting failure accident is calculated by the REDOU code [Reference 2] using the predicted temperatures and fission product inventory distributions. The REDOU code simulates the temperature transient of the fuel fragments as well as the fission product releases due to oxidation. The effect of high temperature at bundle positions 1, 2, 11, and 12 is expected small when using a more realistic power history since the REDOU code calculates oxidation conservatively at the condition of lower temperatures. The fission product release fractions due to oxidization at those locations are predicted to be 0.04. Also, because most of release occurs at high-power bundle region, where fuel temperature or release fraction is high, the difference in the fission product inventory from the low-power bundle does not affect the final fission product release amount. Therefore, the power history using the overpower envelope predicts conservatively in terms of final release amount because it shows higher fission product inventory and release fraction for high-power bundles.

4. Conclusions

A more realistic power history considering the refuelling effect from instantaneous physics simulations for Wolsong 2/3/4 core was applied by selecting high-power channel as a conservatism to calculate fission product release after an end-fitting failure took place.

The higher fuel temperature and more fission product inventory were predicted for low-power bundles (bundle positions 1, 2, 11 and 12) than the case using the current overpower envelope based on the time-average physics simulations. However, the case of high-power bundles, where most fission product releases are occurring, confirmed the conservatism in the current methodology by showing a very high fission product inventory release.

5. References

1) M. Tayal, "Modelling CANDU Fuel Under Normal Operating Conditions: ELESTRES Code Description", AECL-9331, February 1986.

2) 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, January 1992.

Table 1 Pellet Temperature from the High-Power Channel (Volume-average, °C) (Wolsong/Present Study)

Bundle Position	Outer Element	Inter Element	Inner Element	Centre Element
1	610 / 698	597 / 669	591 / 653	588 / 648
2	818 / 896	764 / 823	736 / 786	725 / 772
3	1020 / 1018	915 / 915	862 / 863	844 / 844
4	1394 / 1131	1036 / 990	961 / 924	935 / 902
5	1548 / 1321	1188 / 1032	1019 / 959	987 / 934
6	1633 / 1440	1177 / 1093	1028 / 1010	997 / 981
7	1642 / 1448	1231 / 1105	1036 / 1018	1005 / 990
8	1580 / 1346	1240 / 1063	1042 / 990	1011 / 964
9	1451 / 1243	1108 / 1016	1010 / 950	982 / 928
10	1185 / 1065	986 / 958	927 / 905	906 / 884
11	936 / 1005	862 / 913	824 / 866	810 / 848
12	719 / 1167	695 / 993	681 / 932	676 / 910

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
A									1	2	3	4	5	6								
B						7	8	9	10	11	12	13	14	15	16	17	18					
C					19	20	21	22	23	24	25	26	27	28	29	30	31	32				
D				33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48			
E			49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66		
F			67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84		
G		85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	
H		105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	
J	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146
K	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
L	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190
M	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
N	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234
O	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256
P		257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	
Q		277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	
R			297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314		
S			315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332		
T				333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348			
U					349	350	351	352	353	354	355	356	357	358	359	360	361	362				
V						363	364	365	366	367	368	369	370	371	372	373	374					
W									375	376	377	378	379	380								

Figure 1 : High Power Channels within the Core from 0 to 610 FPDs

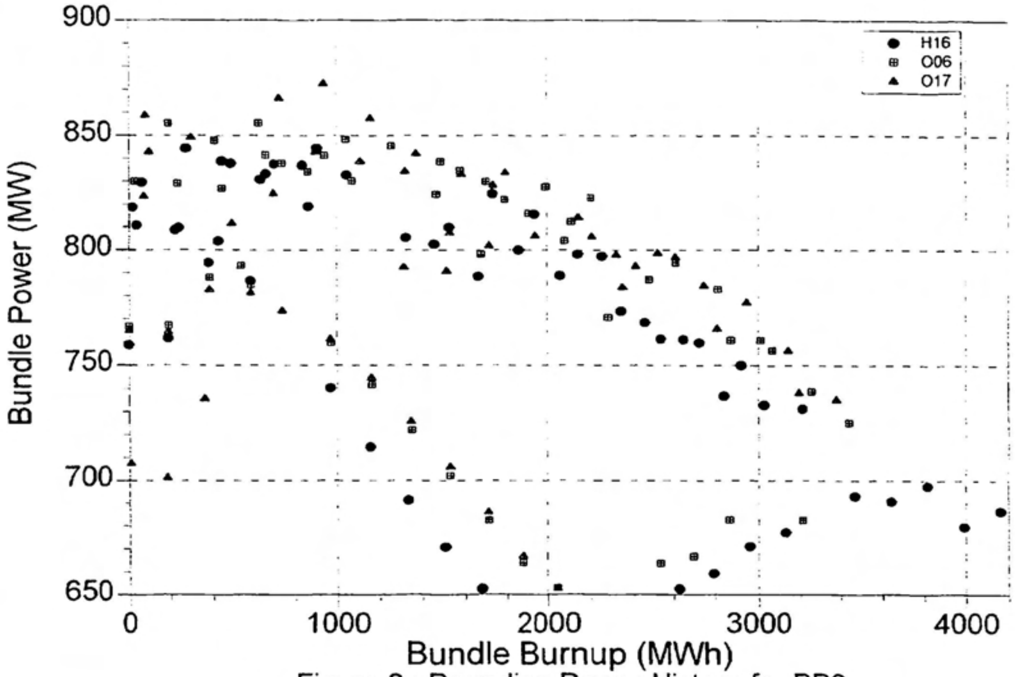

Figure 2 : Bounding Power History for BP6

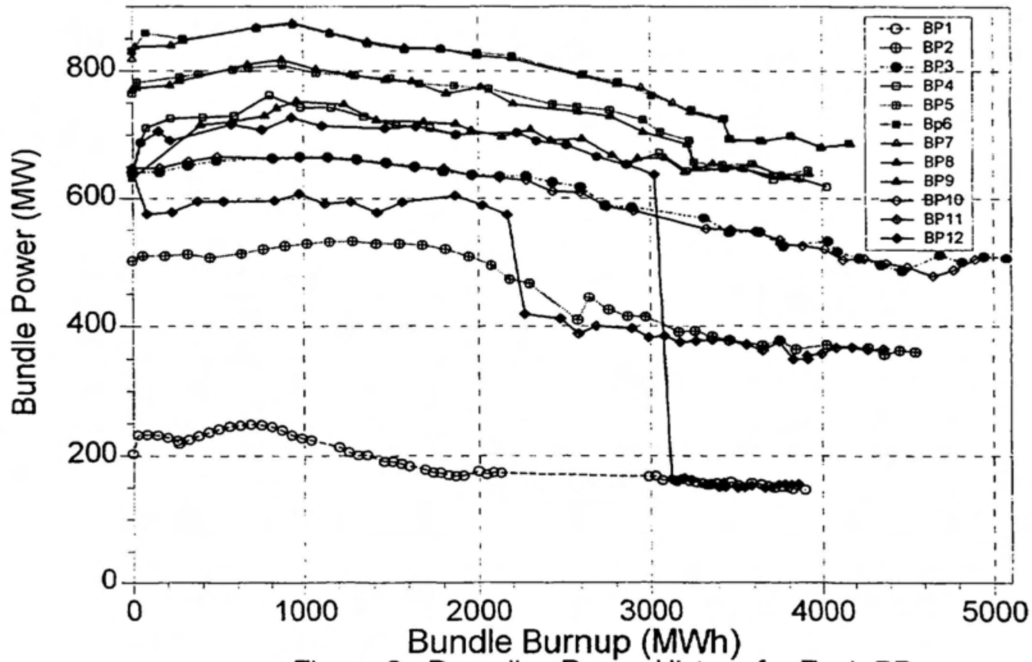

Figure 3 : Bounding Power History for Each BP

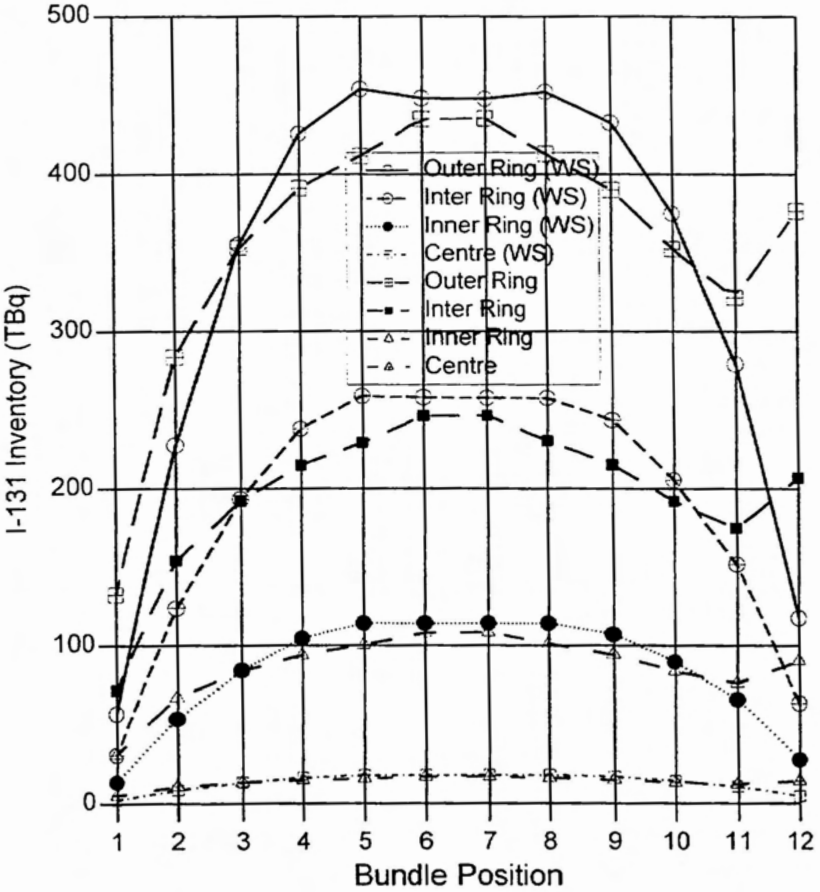

Figure 4 : I-131 Bound Inventories Distributions in the High-Power Channel