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FUEL CHANNEL ANALYSIS FOR 35% RIH BREAK IN CANDU REACTOR LOADED WITH CANFLEX-RU FUEL BUNDLES

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ABSTRACT

A preliminary fuel channel analysis for 35% reactor inlet header (RIH) break in CANDU reactor loaded with the CANFLEX-RU fuel bundles has been performed. The predicted results are compared with those for the reactor compared with those for the reactor loaded with standard 37-element bundles.

The maximum fuel centerline and sheath temperatures for the CANFLEX-RU bundle channel were lower by 338 and 122 °C, respectively, than those for the standard bundle because of the lower maximum linear power of the CANFLEX-RU bundle in spite of the 0.4 FPS higher power pulse of the CANFLEX-RU bundle case. Fuel integrity margin to fuel breakup for the CANFLEX-RU bundle is about 50 J/g higher than that for the standard bundle. The PT/CT contact for the CANFLEX-RU bundle occurred 2 s later than that for the standard bundle. The PT/CT contact temperature for the CANFLEX-RU bundle was 2 °C lower than that for the standard bundle. These provide the CANFLEX-RU bundle with the negligibly enhanced safety margin for the fuel channel integrity in CANDU 6 reactor, compared with the standard bundle.

1. INTRODUCTION

Recovered Uranium (RU) is a by-product of conventional spent LWR fuel reprocessing and has a nominal U-235 content of 0.9%, and must be re-enriched to use it in LWR. However, RU can be burned as-is in CANDU reactors, without re-enrichment, to obtain about the twice the burnup of natural uranium (NU) fuel, which offers many economic benefits such as lower fuelling costs, reduction of spent fuel volumes, lower back-end costs, and reactor power uprating capability through flattening the radial channel power distribution, etc.

The CANDU Flexible Fuelling (CANFLEX) bundle is the optimal vehicle to facilitate the use of RU in CANDU reactors as it reduces linear element ratings, thereby reducing fuel temperatures and gas release and enabling the achievement of extended burnups. It also provides greater critical channel power margin (i.e., greater operating margin) than the 37-element bundle.

This paper describes a preliminary fuel channel analysis results for 35% reactor inlet header (RIH) break in CANDU reactor loaded with the CANFLEX-RU(0.9%) (Recovered Uranium having a U-235 content of 0.9%) fuel bundles, compared with those for the reactor loaded with standard 37-element bundles. The 35% RIH break is chosen because it is a limiting accident for fuel channel integrity.

2. ANALYSIS MODEL

The CATHENA "slave" single-channel simulations are performed to assess the channel response to the large break LOCA. The CATHENA slave channel model used in the current analysis is described in Reference 1.

A high powered channel O6 is selected for the analysis. The fuel channel is divided axially into 12 nodes corresponding to the 12 fuel bundles. Both the maximum channel and bundle powers (bundle 5 for the CANFLEX-RU bundle channel case, and bundles 6 and 7 for the standard bundle channel case) of channel O6 are normalized to the maximum operating limits of 7.3 MW and 935 kW, respectively. Table 1 gives the channel axial power distribution (APD). The relatively forward-peaked APD for the CANFLEX-RU O6 channel compared with that for the standard O6 channel is due to the refueling scheme change from the 8 bundle-shift scheme for the standard bundle case to the 4 bundle-shift one for the CANFLEX-RU bundle case.

All fuel bundles in the channel are assumed to have a bundle element ring power profile at a burnup corresponding to the plutonium peak. The profiles for the CANFLEX-RU and standard bundles are presented in Table 2, which give the most severe temperature transients for the fuel elements in the outermost ring.

The power pulses assumed for the current analysis are shown in Figure 1. The power pulse for the CANFLEX-RU bundle case is not currently available, and the one for the CANFLEX-NU bundle case is taken for the analysis and has an integrated power of 4.2 full power seconds (FPS) up to 3 seconds from the start of the accident. The choice is conservative because the CANFLEX-NU bundle has a slightly higher peak void reactivity (i.e., slightly higher power pulse) than the CANFLEX-RU bundle for the same bundle geometry (Reference 2). The power pulse analysis for the standard bundle was taken from a power analysis for the 35% RIH break in CANDU-6 reactor and has an integrated power of 3.8 FPS up to 3 seconds from the start of the accident. The 0.4 FPS higher integrated power of the CANFLEX-RU bundle case is due to the higher void reactivity of the CANFLEX-RU bundle compared with the standard bundle case.

Preliminary circuit analysis shows that both transient thermalhydraulic header boundary conditions for the 35% RIH break for each CANDU reactor loaded with either the CANFLEX-RU or CANFLEX-NU bundles are very similar each other because both CANFLEX-RU and CANFLEX-NU bundle channels are thermalhydraulically very similar. In this study, the header boundary conditions for the reactor loaded with the CANFLEX-NU bundles are used for the slave channel simulations of the CANFLEX-RU bundle channel. Transient thermalhydraulic header boundary conditions for the standard bundle case were obtained from the CATHENA full circuit analysis for the 35% RIH break.

3. ANALYSIS RESULTS

Table 1 gives the initial (steady-state) thermalhydraulic parameters for each of the reference analysis cases. The CANFLEX-RU bundle case has the lower fuel temperatures than the standard bundle case because the former has the lower linear power than the latter. Both the longer boiling length and the higher channel exit quality for the

CANFLEX-RU bundle case are due to the relatively more forward-peaked APD of the CANFLEX-RU bundle compared with the standard bundle case.

Figure 2 shows the temperature transients for the centerline, sheath of a top fuel element, the inside surface of a pressure tube (PT) top sector and the channel coolant at the axial node corresponding to the peak power bundle (i.e., the nodes 5 and 7 for the CANFLEX-RU and standard bundle cases, respectively). The fuel centerline temperature rapidly increases due to the short-lived power pulse (Figure 1) caused by the positive void coefficient of CANDU reactor. The maximum fuel centerline temperatures for the CANFLEX-RU and standard bundles are 2023 and 2361 °C, respectively and both occur at 1.6 s. The sheath and coolant temperatures show similar behaviour; an initial rapid increase up to about 9 s, a modest increase between about 9 and 18 s except the sudden drop between 14 and 16 s, and a decrease afterward. The behaviour is very closely related to the flow behaviour due to the strong flow velocity dependence of steam convective heat transfer in the stratified flow regime. The maximum sheath temperatures for the CANFLEX-RU and standard bundles are 1384 and 1506 °C, and they occur at 19 and 18 s, respectively. The lower fuel centerline and sheath temperatures of the CANFLEX-RU bundle in spite of the higher power pulse are attributed to the lower initial stored heat caused by the lower linear element power of the CANFLEX-RU bundle as compared with the standard bundle. In fact, the total energy stored in the hottest element (i.e., the top outer element of bundle 7) at 3 s (including the initial stored energy) for the CANFLEX-RU and standard bundles are estimated to be 550 and 600 J/g, respectively, assuming adiabatic fuel heating up to 3 s. Also, these energy contents are 290 and 240 J/g below the fuel breakup energy of 840 J/g for the CANFLEX-RU and standard bundles, respectively.

The maximum coolant temperatures for the CANFLEX-RU and standard bundles are 1165 and 1231 °C, and they occur at 18 and 16 s, respectively.

The PT top sector temperature monotonously increases up to the time of PT/CT contact and then rapidly cools down because of the heat loss to the surrounding moderator. The PT heatup rate for the CANFLEX-RU bundle is lower compared to the standard bundle. The PT contacts its CT at 21 and 19 s with the average contact temperatures and pressures of 810 and 812 °C and 3.9 and 4.0 MPa for the CANFLEX-RU and standard bundles, respectively. The maximum PT top sector temperatures at the time of each PT/CT contact for the CANFLEX-RU and standard bundles are 833 °C and 836 °C, respectively. The lower PT heatup rate and temperatures of the CANFLEX-RU bundle compared with those of the standard bundle are mainly due to the lower radiative heating by the lower temperature sheaths for a steam-exposed PT in a fully voided channel (Reference 1). The minimum top sector PT thicknesses at the end of the simulation (100 s) for the CANFLEX-RU and standard bundles are 81% and 83% of the original PT thickness, respectively. The slightly thinner PT thickness (i.e., the slightly higher PT hoop creep strain) for the CANFLEX-RU bundle is due to the about 2 s longer period of PT temperatures greater than the PT creep onset temperature 600 °C (Reference 3) as shown in Figure 2. The longer high PT temperature period for the CANFLEX-RU bundle is mainly attributed to the 2 s later PT/CT contact.

Table 2 summarizes the key transient analysis results.

4. SUMMARY & CONCLUSIONS

A preliminary fuel channel analysis for 35% reactor inlet header (RIH) break in CANDU reactor loaded with the CANFLEX-RU fuel bundles has been performed. The transient header boundary conditions and power pulse for the slave channel simulations are taken from those for the CANFLEX-NU bundle case. The predicted results are compared with those for the reactor compared with those for the reactor loaded with standard 37-element bundles.

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5. REFERENCES

1. D. J. Oh, H. S. Lim, M. Y. Ohn, K. M. Lee and H. C. Suk, "Fuel Channel Analysis for a Large Break LOCA in a CANDU Reactor Loaded with CANFLEX Fuel Bundles", Nuclear Technology, 114, 292 (1996).
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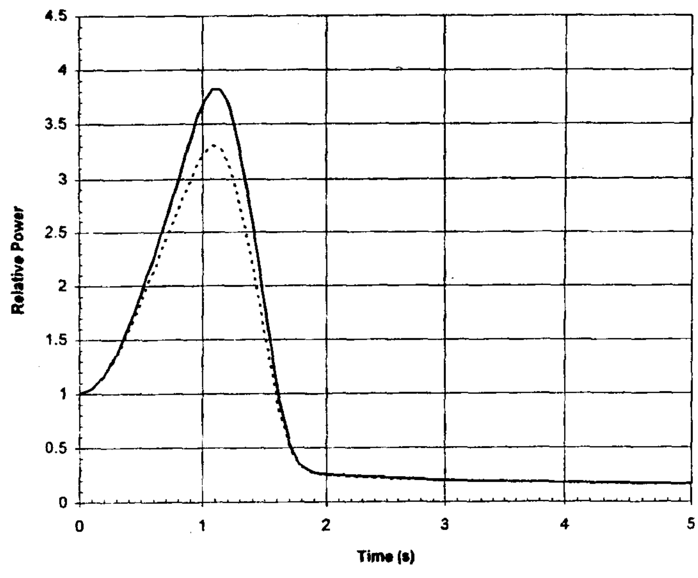

Figure 1: Power Pulses of O6 Channel for 35% RIH Break; CANFLEX-RU (solid line) & Standard (dotted line) Bundles

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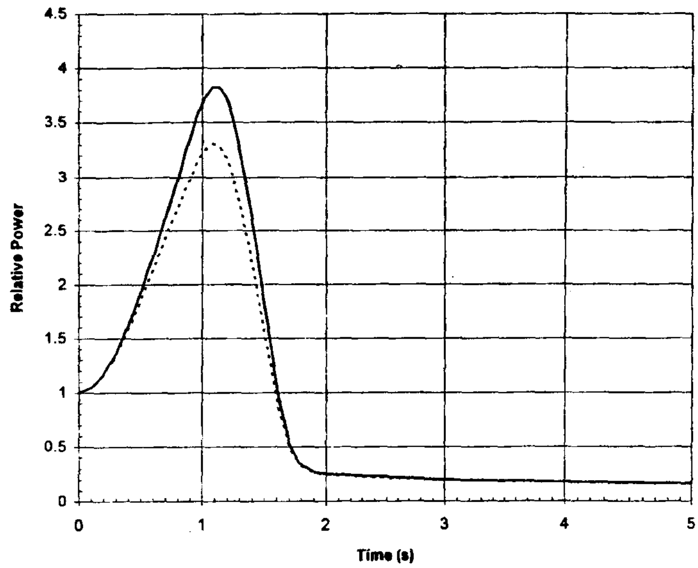

Figure 1: Power Pulses of O6 Channel for 35% RIH Break;
CANFLEX-RU (solid line) & Standard (dotted line) Bundles

Table 1
Axial Bundle Power Distribution for Channel O6

Axial Node	Fractional Axial Bundle Power	
	CANFLEX-RU	Standard-NU
1[a]	0.0119	0.0153
2	0.0647	0.0556
3	0.1008	0.0849
4	0.1217	0.1043
5	0.1281	0.1197
6	0.1201	0.1281
7	0.1151	0.1281
8	0.1138	0.1200
9	0.0990	0.1020
10	0.0761	0.0791
11	0.0451	0.0498
12	0.0036	0.0131
Total	1.0	1.0
Total Channel Power (MW)	7.3	7.3

Table 2
Bundle Element Ring Power Distribution at the Burnup of Plutonium Peak

Element	Radial Power Factor	
	CANFLEX-RU	Standard-NU
Outer Element	1.0651	1.131
Intermediate Element	0.8681	0.9206
Inner Element	1.0663	0.8051
Center Element	1.0163	0.7613

Table 3
Initial Thermalhydraulic Parameters

Parameter	CANFLEX-RU Bundle Case	Standard-NU Bundle Case
Bundle Position for Temperatures	5	7
Fuel Centerline Top Element Temperature (°C)	1745	2189
Sheath Top Element Temperature (°C)	320	329
Coolant Temperature (°C)	294	305
Channel Mass Flow Rate (kg/s)	23.7	24.1
Zero Quality Location from Channel Inlet (m)	3.8550	3.9833
Quality at Channel Outlet (%)	6.17	5.74

Table 4
Summary of Key Transient Analysis Results

Parameter	CANFLEX-RU Bundle Case	Standard-NU Bundle Case
Bundle Position for Parameters	5	7
Fuel Centerline		
Maximum Temperature of Top Element (°C)	2023	2361
Time (s)	(1.6)	(1.6)
Sheath		
Maximum Temperature of Top Element (°C)	1384	1506
Time (s)	(19)	(18)
Coolant		
Maximum Temperature (°C)	1165	1231
Time (s)	(18)	(16)
PT		
Maximum Temperature (°C)	833	836
Time (s)	(21)	(19)
PT/CT Contact		
Time (s)	21,	19,
Temperature (°C)	810,	812,
Pressure (Mpa)	3.9	4.0
Minimum PT Thickness in Percentage of the Original Thickness	81	83
Channel Refill Time (s)	91	87

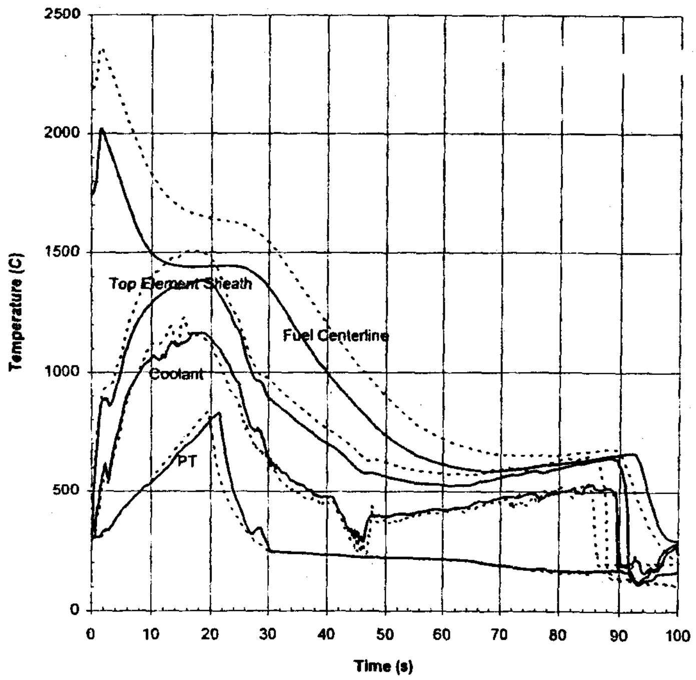

Figure 2. Temperature Transients for 35% RIH Break at Axial Node 5 for CANFLEX-SEU Bundle Case (solid line) and at Axial Node 7 for Standard Bundle Case (dotted line) of 7.3 MW (O6) Channel; Fuel Centerline, Sheath & PT Temperatures at the Top of the Bundles.