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The Effects of Bi-directional Refueling Scheme through CANDUCS-DEFENS Code System in a CANDU Reactor

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1. Introduction

The CANDUCS code generates the necessary CANDU cross sections for the time-average calculation and provides the DEFENS code with them. Currently, the CANDUCS code has various options for bi-directional refueling, incremental cross section treatment and management of the liquid zone control, which are required in a time-average model. Because the bi-directional refueling scheme gives the flattening of the power distribution of the core and enhancement of thermal-hydraulic conditions, it has been used as the standard refueling scheme in every CANDU-type reactor. In this research, the differences between the mono-directional refueling (MDR) and the bi-directional refueling (BDR) are discussed quantitatively with a multiplication factor and power distribution. In addition, by comparing the results from the CANDUCS-DEFENS code system with the RFSP results, the soundness of the CANDUCS code for a cross section generator will be verified.

2. Mono-Directional Refueling

2.1 Time-Averaged Cross Sections and Regional Exit Irradiation

The time-averaged cross sections are automatically generated by batch files using a perl script with a Physics Design Manual (PDM) [1]. For the T/A cross section generation, a series of utilities are used [4], such as microburn, condens, wrfsp, regav and pmat2lib. Also, time-averaging with the irradiation is done by the CANDUCS code [3]. The exit irradiation for each channel is required in this step [2].

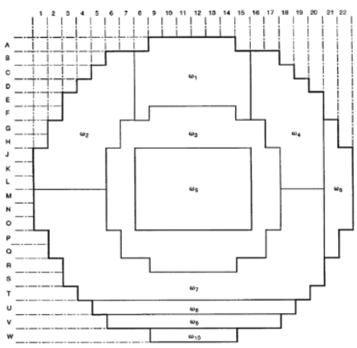

Fig. 1. Typical Regions for T/A Model of CANDU Reactor

Table I: Typical Exit Irradiation for Regions

Name of Region	Region Index	Exit Irradiation(#/kilo barn)
Outer Top	ω_1	2.460
Outer	ω_2 ω_4 ω_7	2.489
Middle	ω_3	2.750
Inner	ω_5	2.600
Right	ω_6	2.442
Bottom	ω_8	2.483
Bottom Mid	ω_9	2.323
Bottom Ext	ω_{10}	1.977

2.2 Numerical Results

Various calculation results are listed in this section such as eigenvalue, flux distribution, power errors, maximum power, and its location and maximum power prediction error.

Table II: Multiplication Factor for MDR

RFSP	1.03307
CANDUCS-DEFENS	1.03290

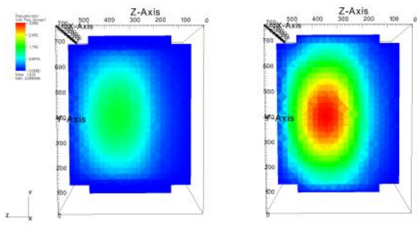

Fig. 2. Fast and Thermal Flux Distribution on yz-plane for MDR

XXXX RFSP (Reference)
X.XX FEM (Relative Error, %)

2689 3.77	2587 3.07	2462 1.78								
3647 -1.08	3539 -1.08	3335 -0.03	3064 1.76	2655 1.80	2227 -0.81					
4643 -1.36	4518 -1.09	4291 -1.07	3958 -1.42	3521 -2.18	3010 -2.47	2500 -1.59				
5562 -1.61	5441 -1.23	5201 -1.03	4848 -1.07	4385 -1.44	3831 -2.15	3206 -2.42	2586 -1.52			
6386 -1.59	6261 -1.15	6015 -0.82	5652 -0.73	5172 -0.84	4592 -1.16	3923 -1.70	3196 -1.87	2478 1.84		
7088 -1.66	6961 -1.16	6712 -0.79	6375 -0.70	5885 -0.74	5288 -0.87	4592 -1.00	3825 -1.50	3038 1.57		
7728 -1.66	7596 -1.19	7335 -0.83	6951 -0.59	6454 -0.49	5877 -0.57	5166 -0.51	4372 -0.62	3505 0.71	2678 5.96	
8284 1.69	8146 -1.35	7872 -1.05	7470 -0.80	6953 -0.59	6363 -0.46	5640 -0.28	4828 -0.20	3933 0.02	3043 4.07	
8750 -1.62	8605 -1.35	8318 -1.06	7895 -0.79	7334 -0.43	6696 -0.13	5991 0.07	5170 0.31	4255 0.87	3297 3.12	2383 9.53
9077 -1.41	8928 -1.26	8632 -1.04	8195 -0.72	7614 -0.36	6961 -0.09	6249 0.12	5421 0.41	4493 1.14	3514 2.05	2543 8.82
9236 -0.89	9085 -0.80	8785 -0.62	8341 -0.34	7753 0.00	7093 0.23	6376 0.47	5543 0.78	4610 1.56	3624 2.52	2645 9.54

Fig. 3. Power and Error Distribution of RFSP and DEFENS for MDR

Table III: Power Errors of DEFENS for MDR

Thermal Power (MW)	Fission Power (MW)	RMS Error (%)	Max. Error(%) /Pos.
2061.40	2156.01	1.64	2.60/E-8

Table IV: Max. Powers of Channel and Bundle for MDR

	RFSP	DEFENS
Max. Channel Power(KW)/Pos.	9238.14/M-12	9206.35/M-12
Max. Bundle Power(KW)/Pos	1457.35/M-12, Bundle 5	1453.06/M-12, Bundle 5

Table V: Rel. Errors of Max. Powers of Channel and Bundle for MDR

Rel. Err. of Max. Channel Power(%)	-0.34
Rel. Err. of Max. Bundle Power(%)	-0.29

3. Bi-Directional Refueling

In this section, bundle peaking factor results are added for a comparison. It can be calculated by dividing the maximum bundle power by the average bundle power.

Table VI: Multiplication Factor for BDR

RFSP	1.02748
CANDUCS-DEFENS	1.02750

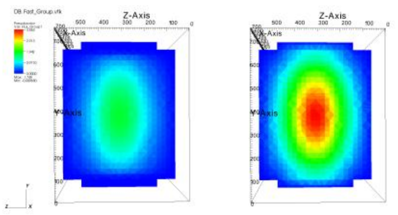

Fig. 4. Fast and Thermal Flux Distribution on yz-plane for BDR

XXXX: RFSP (Reference); X.XX: FEM (Relative Error, %)

2750 4.15	2648 3.56	2526 2.50								
3698 -0.69	3591 -0.76	3389 0.31	3121 2.17	2713 2.24	2289 -0.13					
4671 -0.98	4557 -0.80	4333 -0.81	4003 -1.12	3570 -1.84	3062 -1.92	2560 -0.88				
5578 -1.25	5460 -1.02	5225 -0.85	4878 -0.87	4421 -1.10	3875 -1.79	3256 -1.93	2646 -0.89			
6374 -1.23	6253 -0.94	6014 -0.71	5661 -0.60	5192 -0.64	4622 -0.85	3964 -1.34	3246 -1.41	2537 2.46		
7033 -1.20	6911 -0.91	6673 -0.68	6360 -0.65	5885 -0.62	5304 -0.64	4622 -0.66	3868 -1.09	3092 2.14		
7645 -1.20	7518 -0.87	7268 -0.67	6901 -0.44	6423 -0.29	5875 -0.26	5185 -0.17	4407 -0.19	3553 1.26	2737 6.85	
8182 -1.12	8049 -0.94	7786 -0.73	7399 -0.55	6904 -0.30	6346 -0.18	5647 0.06	4856 0.14	3976 0.50	3099 4.57	
8643 -1.07	8504 -0.84	8227 -0.70	7818 -0.49	7270 -0.17	6658 0.15	5988 0.33	5192 0.56	4294 1.19	3349 3.42	2444 10.00
8965 -0.94	8821 -0.83	8534 -0.64	8110 -0.50	7542 -0.18	6914 -0.04	6239 0.24	5437 0.50	4529 1.26	3565 2.06	2601 8.89
9122 -0.60	8976 -0.44	8684 -0.37	8253 -0.21	7676 0.03	7042 0.22	6363 0.40	5558 0.68	4645 1.48	3673 2.42	2703 9.46

Fig. 5. Power and Error Distribution of RFSP and DEFENS for BDR

Table VII: Power Errors of DEFENS for BDR

Thermal Power (MW)	Fission Power (MW)	RMS Error (%)	Max. Error(%) /Pos.
2061.40	2156.01	1.51	2.08/E-7

Table VIII: Max. Powers of Channel and Bundle for MDR

	RFSP	DEFENS
Max. Channel Power(KW)/Pos.	9124.56/M-12	9109.76/M-12
Max. Bundle Power(KW)/Pos	1465.88/M-12, Bundle 6	1473.83/M-12, Bundle 7

Table IX: Rel. Errors of Max. Powers of Channel and Bundle for MDR

Rel. Err. of Max. Channel Power(%)	-0.16
Rel. Err. of Max. Bundle Power(%)	0.54

Table X: Bundle Peaking Factors for Refueling Methods

	MDR	BDR
Avg. Bundle Power(KW)	452.06	452.06
Max. Bundel Power(KW)	1453.07	1473.83
Loc. of Max. Bundle Power	M-12 Bundle 5	M-12 Bundle 7
Bundel Peaking Factor	3.21	3.26

4. Conclusions

In this research, the results of RFSP and DEFENS codes are compared with each other for cases of MDR and BDR. For both cases, the multiplication factor error is extremely small, but the power errors are larger than those of mathematical initial core calculation. For the predictions of locations of max. rel. power err., max. channel power and max. bundle power, the DEFENS code prediction is matched well with the result of RFSP except for the prediction of location of max. bundle power for the BDR case. However, this is not a problem because the power difference between bundle 6 and 7 is negligible for the BDR case. In Fig. 2, Fig. 4, and Table X, it can be verified that the center of power distribution is moved to the centre of the core. Using the BDR, the max. bundle power increased while the avg. bundle power is not changed. In Table II and VI, it is also verified that the BDR can reduce the excess reactivity of the core. It seems that solving the realistic initial core problem is a way to investigate the soundness of the CANDUCS code.

5. Acknowledgement

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