INVESTIGATION OF TIME-AVERAGED CHANNEL POWERS VERSUS CHANNEL POWERS FROM TIME-AVERAGED BUNDLE BURNUPS

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ABSTRACT

This paper presents the results of a comparison of time-averaged channel powers with the channel powers obtained from using time-averaged burnups. The analysis was carried out on a Bruce A and Bruce B reactor using the core tracking SORO program, which calculates the flux, burnups, bundle powers, and channel powers. The time-averaged channel powers from the two methodologies were found to be in good agreement.

1. INTRODUCTION

The time-averaged channel power has been widely used in different kinds of safety analysis, such as NOP analysis. The current methodology to generate the time-averaged channel power consists of calculating the average channel power over years of operating history on each channel, based on the production simulation data from the SORO (Simulation Of Reactor Operation) program. The SORO program calculates the flux, burnups, bundle powers, and channel powers, and is used for core tracking the reactors operated by Bruce Power. Another possible approach to calculating the time-averaged channel power is to calculate the time-averaged bundle burnups and import the time-averaged burnups into SORO and generate the channel power distribution.

This paper presents a summary of the results obtained from the two methodologies used to calculate the time-averaged channel powers. The relationship to the fuelling scheme and end-bundle effect is also discussed.

2. COMPUTER PROGRAMS

The SORO program is used at Bruce Power by fuelling engineers and analysts for: (i) channel selection for fuelling, (ii) generating reports for monitoring performance and compliance, and (iii) archiving reactor core history.

The SORO program includes the following:

- Lattice cross-sections generated from WIMS-IST version 2-5d with ENDF/B-VI library
- 2-Group approximation
- Local fuel temperature effects
- 7 saturating fission products (Rh105, Cd113, Xe135, Sm149, Sm151, Eu155, and Gd157).
- Coarse mesh

AUTOSORO is a module of the SORO program and is used by analysts for longer term fuelling studies. However, fuelling engineers do not generally use AUTOSORO for channel selection. AUTOSORO provides an automatic generation of a list of suitable channels to be fuelled, by using an input file that specifies the options for channel selection, which includes Absolute rules and Scored rules. Absolute rules are hard rules, such as the Maximum Channel Power (MCP) and Maximum Bundle Power (MBP) target limits. If it fails the Absolute rule, the channel is not fuelled in this cycle. Scored rules are a form of fuzzy logic, in which a channel is tested against each scored rule and given a score for passing the rule. The total of all the scored rules is compared to the input value for passing. If the total score is too low, the channel is not fuelled in the current cycle. An example of a scored rule is the lattice distance to the MCP channel.

AUTOSORO repeatedly performs Shift, Flux, Burn, Flux for one AUTOSORO cycle, where Shift denotes the fuelling of the channels, Flux is the calculation of the flux, bundle and channel powers, and Burn denotes the update of the energy clock for the bundle burnups.

The AUTOSORO input options that relate to the Burn and Flux operations are: (i) how long to simulate (i.e., number of AUTOSORO cycles), (ii) reactor power, (iii) average zone level (AVZL), and (iv) target reactivity.

AUTOSORO uses channel burnup sorting to select the highest burnup channels. A fuelling region map, which has the number of bundles to be pushed into the channel, and a burnup regions map are required. The burnup target values for each burnup region are established based on historical fuelling practices.

3. METHODOLOGY

A SORO snapshot state was selected from the production SORO historical database for Bruce A Unit 4 and Bruce B Unit 8, which were used as the starting state for the AUTOSORO fuelling simulations. Units 4 and 8 were chosen for this analysis, since the other units were undergoing either core conversion to fuelling with the flow (Units 5, 6, and 7 in Bruce B) or selective defuelled channel program (Unit 3 in Bruce A).

A 1-year AUTOSORO simulation was carried out first, in order to remove any depleted bundles (i.e., bundles with 0.4 wt% isotopic U235) from the simulation starting states. Depleted bundles are used along with 0.7 wt% isotopic U235 in channels that were defuelled for inspection and then refuelled, in order to keep the channel powers under the operating limits.

A 3-year fuelling simulation was then performed with AUTOSORO to provide adequate fuelling history for averaging. AUTOSORO module was used to simulate continuous operation to eliminate variations in the core states due to outages or other operational changes. The current Bruce reactor cores require approximately 1 year to refresh the fuel in the inner core and approximately 3 years for the outer core. PERL scripts were used to extract the data from the 3-year simulations and perform the time-average calculations and burnup update.

The resulting channel powers from the 3-year AUTOSORO simulation were averaged for each channel and are denoted as CP_{TA}. Similarly, the bundle powers were also averaged for each fuelling position and are denoted as BP_{TA}.

The bundle burnups for each fuelling position from the AUTOSORO simulation were averaged, and then imported into a SORO snapshot state. The channel powers and bundle powers were calculated with SORO and are denoted as CP_{burnup} and BP_{burnup}, respectively.

The percentage differences were calculated for each channel by using the following formula:

$$\%\text{difference} = (CP_{burnup} - CP_{TA})/ CP_{TA}$$

where CP_{TA} is the time-averaged channel power over states
CP_{burnup} is the time-averaged channel power from time-averaged burnup

When the percentage difference is positive, the time-averaged channel power from time-averaged burnup is over-estimated compared to the time-averaged channel power over states, and when the percentage difference is negative it is under-estimated. A corresponding percent difference formula is used for the bundle powers.

4. RESULTS

4.1 Comparison of the Results

The percent difference results from the two approaches used to calculate the time-averaged channel powers and bundle powers are given in Table 1. The Unit 8 average percent differences for the channel powers and bundle powers are smaller than those of Unit 4. The maximum and minimum range of the channel power differences for Unit 8 was approximately 1.5% to 3% smaller than the Unit 4 results respectively. Similarly, the maximum and minimum range of the bundle power differences was approximately 1.6% to 2.5% smaller than the Unit 4 results respectively. The average and standard deviation of the differences over the whole core for Unit 8, which are 0.1% and 0.7% for channel power and 0.05% and 0.9% for bundle power, are also

smaller than that in Unit 4, is 0.3% and 2.0% for both channel power and bundle power. Note that the end-bundles are excluded from the bundle power comparison calculation and will be discussed in Section 4.2.

Figures 1 and 2 present the channel power differences in a core map format. It was found that the distribution of percentage differences is related to the fuelling regions. There are 3 types of fuelling regions (2-bundle-push, 4-bundle-push and 8-bundle-push) in Unit 4 and the 2 types of fuelling regions (4-bundle-push and 8-bundle-push) in Unit 8. The channel power percentage difference in the 8-bundle-push region was positive, and it became negative in the 4-bundle and 2-bundle-push regions. The maximum channel power difference was located in the 8-bundle-push region, and minimum difference was located in the center of the core for both units.

4.2 End-Bundles Effect on Bundle Power Comparison Results

Table 2 shows the maximum and minimum bundle power percent differences on different fuelling planes. There were several channels in Unit 8 in which the bundle in the 13th fuelling position had particularly high bundle power differences of approximately 11%. This end-bundle issue only occurred in Unit 8 for the 13th bundles in the 8-bundle-push region (see Figure 5). Table 3 shows how much the end-bundle impacts the bundle power comparison results. Since the end-bundles are of low power and are not in the CPPF region, the end-bundle data was excluded from the bundle power differences calculations.

In order to explore more of the relationship between the number of fuelling visits on a channel (i.e., fuelling frequency) and the high differences on the 13th bundles, a 4-year AUTOSORO simulation was carried out based on the same methodology presented in Section 3. The channel fuelling frequency map from the 3-year AUTOSORO simulation showed that the 13th bundles having more than 3% differences had a low fuelling frequency. In the 4-year AUTOSORO simulation, the fuelling visits on the 8-bundle-push channels were higher, due to longer simulation period. As a result, the percentage differences of all the 13th bundles were reduced by approximately 0.2% to 3% as shown in Figures 3 and 4.

5. CONCLUSION

In this analysis, the time-averaged channel power distribution was derived from a 3 year fuelling simulation for Bruce Unit 4 and Unit 8 by using: (i) the average of the channel powers over the simulation states, and (ii) the channel powers calculated from the time-averaged burnups. The Unit 8 channel power differences were found to be smaller than the Unit 4 results, when comparing the two methodologies for calculating the time-averaged channel powers. There was a systematic trend to the channel power differences, in which the outer 8-bundle-push channels had a positive difference and the channels in the center of the core had a negative difference. Overall, the time-averaged channel powers from the two methodologies were in good agreement, and the differences ranged between 3.5% to -3.6% for Unit 4 and 1.9% to -0.7% for Unit 8. The average and standard deviation of the differences over the whole core are 0.3% and 2.0% for Unit 4, 0.1% and 0.7% for Unit 8

The Unit 8 bundle power differences were found to be smaller than the Unit 4 results, although, several of the 13-th bundles in Unit 8 were found to have differences of up to approximately 11%. It was shown that longer simulation period could eliminate the differences. The final bundle power results for Unit 8 excluded the end-bundles from the calculations. The time-averaged bundle powers from the two methodologies were also in good agreement, in which the differences ranged between 4.2% to -4.5% for Unit 4 and 2.5% to -2.1% for Unit 8. The average and standard deviation of the differences over the whole core are 0.3% and 2.0% for Unit 4, 0.05% and 0.9 for Unit 8.

Table 1: Summary of Percentage Difference from 3-year Simulation (Excluding End-Bundle Results from the Bundle Power Calculations)

	B4				B8			
Parameters	**MAX**	**MIN**	**Average**	**STDEV**	**MAX**	**MIN**	**Average**	**STDEV**
Channel Power	3.5%	-3.6%	0.3%	2.0%	1.9%	-0.7%	0.1%	0.7%
Bundle Power	4.2%	-4.5%	0.3%	2.0%	2.5%	-2.1%	0.05%	0.9%

Table 2: Maximum and Minimum Percentage Differences on Bundle Power

Bruce A Unit 4													
Plane	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
MAX	1.5%	1.5%	2.0%	2.7%	3.7%	4.2%	4.2%	4.2%	4.1%	3.7%	3.1%	2.1%	1.4%
MIN	-3.1%	-3.0%	-2.9%	-3.2%	-3.8%	-4.3%	-4.5%	-4.3%	-3.7%	-3.0%	-2.6%	-3.1%	-3.3%
Bruce B Unit 8													
Plane	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
MAX	11.0%	0.6%	0.9%	1.3%	2.2%	2.5%	2.5%	2.5%	2.5%	2.3%	1.8%	0.9%	0.1%
MIN	-1.1%	-0.9%	-0.5%	-0.9%	-1.0%	-1.8%	-2.1%	-1.6%	-0.3%	0.2%	-0.1%	-0.9%	-1.3%

Table 3: End-Bundles Effect on Unit 8 Bundle Power Results

	B4				B8			
Parameters	**MAX**	**MIN**	**Average**	**STDEV**	**MAX**	**MIN**	**Average**	**STDEV**
With End-Bundles	4.2%	-4.5%	0.2%	1.9%	11.0%	-2.1%	-0.03%	1.0%
Without End-Bundles	4.2%	-4.5%	0.3%	2.0%	2.5%	-2.1%	0.05%	0.9%

Figure 1: Percentage Difference on Unit 4 Channel Power from 3-year Simulation [1]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
a	MAX =	3.5%						3.0%	2.8%	2.7%	2.6%	1.9%	1.9%	2.5%	2.6%	2.7%	2.9%								a
b	MIN =	-3.6%				3.4%	2.9%	2.7%	2.5%	2.2%	2.2%	2.1%	2.0%	2.1%	2.1%	2.3%	2.5%	2.8%	3.3%						b
c					3.2%	3.1%	2.7%	2.3%	1.5%	1.2%	1.1%	0.9%	0.9%	1.0%	1.1%	1.4%	2.1%	2.5%	3.0%	3.2%					c
d				3.1%	2.9%	2.5%	1.6%	1.2%	0.8%	0.6%	0.4%	0.3%	0.3%	0.3%	0.5%	0.8%	1.1%	1.5%	2.5%	2.8%	3.1%				d
e			3.1%	2.9%	2.4%	1.4%	1.0%	0.5%	0.2%	-0.1%	-0.3%	-0.4%	-0.4%	-0.3%	-0.1%	0.1%	0.5%	0.9%	1.4%	2.3%	2.8%	3.1%			e
f		3.0%	2.8%	2.4%	1.4%	0.8%	0.3%	-0.1%	-0.4%	-0.7%	-0.9%	-1.0%	-1.0%	-0.9%	-0.8%	-0.5%	-0.1%	0.3%	0.8%	1.4%	2.3%	2.7%	3.1%		f
g		2.8%	2.4%	1.4%	0.9%	0.3%	-0.2%	-0.6%	-1.1%	-1.4%	-1.6%	-1.7%	-1.7%	-1.6%	-1.4%	-1.1%	-0.7%	-0.3%	0.2%	0.8%	1.4%	2.4%	2.7%		g
h		2.5%	1.5%	1.0%	0.4%	-0.2%	-0.7%	-1.2%	-1.7%	-2.0%	-2.3%	-2.3%	-2.3%	-2.3%	-2.0%	-1.6%	-1.2%	-0.7%	-0.2%	0.4%	0.9%	1.5%	2.4%		h
j	2.8%	2.3%	1.2%	0.6%	0.0%	-0.6%	-1.1%	-1.6%	-2.1%	-2.5%	-2.8%	-2.9%	-2.9%	-2.8%	-2.5%	-2.1%	-1.6%	-1.1%	-0.6%	0.0%	0.6%	1.2%	2.2%	2.6%	j
k	2.6%	2.1%	0.9%	0.3%	-0.3%	-0.9%	-1.4%	-2.0%	-2.4%	-2.9%	-3.1%	-3.3%	-3.3%	-3.2%	-2.9%	-2.4%	-1.9%	-1.5%	-0.9%	-0.3%	0.3%	0.9%	2.0%	2.4%	k
l	2.4%	1.9%	0.8%	0.1%	-0.5%	-1.1%	-1.7%	-2.2%	-2.8%	-3.1%	-3.4%	-3.5%	-3.5%	-3.4%	-3.2%	-2.8%	-2.2%	-1.7%	-1.1%	-0.5%	0.0%	0.7%	1.8%	2.3%	l
m	2.2%	1.2%	0.6%	0.0%	-0.7%	-1.2%	-1.8%	-2.3%	-2.9%	-3.3%	-3.5%	-3.6%	-3.6%	-3.5%	-3.3%	-2.9%	-2.3%	-1.8%	-1.2%	-0.7%	-0.1%	0.5%	1.2%	2.1%	m
n	2.2%	1.2%	0.6%	-0.1%	-0.7%	-1.2%	-1.9%	-2.5%	-2.9%	-3.3%	-3.5%	-3.6%	-3.6%	-3.5%	-3.3%	-2.9%	-2.5%	-1.8%	-1.2%	-0.7%	-0.1%	0.5%	1.1%	2.0%	n
o	2.3%	1.9%	0.7%	0.1%	-0.5%	-1.1%	-1.7%	-2.4%	-2.8%	-3.1%	-3.3%	-3.5%	-3.5%	-3.3%	-3.1%	-2.8%	-2.4%	-1.7%	-1.2%	-0.6%	0.0%	0.6%	1.8%	2.2%	o
p	2.4%	2.1%	0.9%	0.3%	-0.3%	-0.9%	-1.5%	-2.2%	-2.6%	-2.9%	-3.1%	-3.2%	-3.1%	-3.1%	-2.9%	-2.6%	-2.2%	-1.5%	-0.9%	-0.4%	0.2%	0.8%	1.9%	2.2%	p
q	2.6%	2.2%	1.1%	0.5%	0.0%	-0.6%	-1.1%	-1.8%	-2.2%	-2.5%	-2.6%	-2.6%	-2.6%	-2.6%	-2.5%	-2.2%	-1.8%	-1.1%	-0.6%	-0.1%	0.5%	1.0%	1.9%	2.3%	q
r		2.4%	1.4%	0.9%	0.4%	-0.2%	-0.7%	-1.1%	-1.6%	-1.8%	-2.0%	-2.1%	-2.1%	-2.0%	-1.8%	-1.6%	-1.1%	-0.7%	-0.2%	0.3%	0.8%	1.3%	2.2%		r
s		2.0%	2.2%	1.3%	0.8%	0.3%	-0.2%	-0.6%	-0.9%	-1.2%	-1.4%	-1.4%	-1.5%	-1.4%	-1.2%	-0.9%	-0.6%	-0.2%	0.3%	0.8%	1.2%	2.1%	1.9%		s
t		2.2%	2.6%	2.3%	1.4%	0.9%	0.4%	0.0%	-0.3%	-0.6%	-0.7%	-0.8%	-0.8%	-0.8%	-0.6%	-0.3%	0.0%	0.4%	0.9%	1.3%	2.3%	2.5%	2.1%		t
u			3.0%	2.8%	2.4%	1.5%	1.0%	0.6%	0.3%	0.1%	-0.1%	-0.2%	-0.2%	-0.1%	0.1%	0.3%	0.6%	1.0%	1.5%	2.4%	2.8%	3.0%			u
v				3.2%	3.0%	2.6%	1.7%	1.3%	1.0%	0.8%	0.7%	0.6%	0.6%	0.7%	0.8%	1.0%	1.3%	1.7%	2.7%	3.0%	3.1%				v
w					3.3%	3.0%	2.7%	2.6%	1.8%	1.6%	1.5%	1.4%	1.4%	1.5%	1.6%	1.8%	2.5%	2.8%	3.1%	3.3%					w
x						3.3%	3.0%	3.0%	2.8%	2.9%	2.7%	2.7%	2.7%	2.8%	2.8%	2.9%	3.1%	3.1%	3.5%						x
y								3.4%	3.2%	3.3%	3.3%	3.2%	3.2%	3.2%	3.3%	3.3%	3.4%								y
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

Figure 2: Percentage Difference on Unit 8 Channel Power from 3-year Simulation [2]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
a	MAX=	1.9%						1.9%	1.8%	1.9%	1.9%	1.9%	1.9%	1.8%	1.7%	1.8%	1.9%								a
b	MIN=	-0.7%				1.4%	1.6%	1.5%	1.6%	1.6%	1.5%	1.0%	1.0%	1.5%	1.5%	1.6%	1.5%	1.8%	1.7%						b
c					1.4%	1.2%	0.8%	0.8%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.7%	0.7%	0.8%	0.9%	1.4%	1.5%					c
d				1.4%	1.2%	0.6%	0.5%	0.4%	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.5%	0.7%	1.3%	1.4%				d
e			1.3%	1.1%	0.5%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.3%	0.5%	1.1%	1.2%			e
f		1.2%	1.0%	0.4%	0.2%	0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%	-0.2%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.1%	0.2%	0.4%	1.0%	1.2%		f
g		1.0%	0.4%	0.2%	0.0%	-0.1%	-0.2%	-0.2%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.2%	-0.2%	-0.1%	0.0%	0.1%	0.4%	1.0%		g
h		0.8%	0.2%	0.0%	-0.2%	-0.3%	-0.3%	-0.4%	-0.4%	-0.4%	-0.5%	-0.5%	-0.5%	-0.5%	-0.4%	-0.4%	-0.4%	-0.4%	-0.3%	-0.2%	0.0%	0.1%	0.8%		h
j	0.9%	0.7%	0.0%	-0.2%	-0.3%	-0.4%	-0.5%	-0.5%	-0.5%	-0.5%	-0.6%	-0.6%	-0.6%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.4%	-0.3%	-0.2%	0.0%	0.6%	0.8%	j
k	0.7%	0.1%	-0.2%	-0.3%	-0.4%	-0.5%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.5%	-0.4%	-0.3%	-0.2%	0.1%	0.7%	k
l	0.5%	-0.1%	-0.2%	-0.4%	-0.4%	-0.5%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.5%	-0.4%	-0.3%	-0.1%	0.5%	l
m	0.0%	-0.2%	-0.3%	-0.4%	-0.5%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.7%	-0.7%	-0.7%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.5%	-0.4%	-0.3%	-0.2%	0.0%	m
n	0.0%	-0.2%	-0.3%	-0.4%	-0.5%	-0.5%	-0.6%	-0.6%	-0.6%	-0.6%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.6%	-0.6%	-0.6%	-0.6%	-0.5%	-0.5%	-0.3%	-0.2%	0.0%	n
o	0.4%	-0.1%	-0.2%	-0.4%	-0.4%	-0.5%	-0.5%	-0.6%	-0.6%	-0.6%	-0.7%	-0.7%	-0.7%	-0.7%	-0.6%	-0.6%	-0.6%	-0.5%	-0.5%	-0.5%	-0.4%	-0.2%	-0.1%	0.5%	o
p	0.7%	0.1%	-0.2%	-0.3%	-0.4%	-0.5%	-0.5%	-0.5%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.5%	-0.5%	-0.5%	-0.4%	-0.3%	-0.2%	0.1%	0.8%	p
q	0.7%	0.6%	0.0%	-0.2%	-0.3%	-0.4%	-0.4%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.6%	-0.6%	-0.5%	-0.5%	-0.5%	-0.4%	-0.4%	-0.3%	-0.2%	0.0%	0.7%	0.9%	q
r		0.8%	0.1%	-0.1%	-0.3%	-0.3%	-0.4%	-0.4%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.4%	-0.4%	-0.3%	-0.2%	-0.1%	0.1%	0.9%		r
s		0.9%	0.3%	0.0%	-0.1%	-0.3%	-0.3%	-0.3%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.3%	-0.3%	-0.3%	-0.2%	-0.1%	0.1%	0.3%	0.9%		s
t		1.1%	0.9%	0.3%	0.1%	-0.1%	-0.2%	-0.2%	-0.2%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.2%	-0.2%	-0.2%	-0.2%	-0.1%	0.1%	0.3%	0.9%	1.2%		t
u			1.1%	1.0%	0.3%	0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.1%	0.4%	1.0%	1.2%		u
v				1.2%	1.1%	0.4%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.4%	1.1%	1.2%				v
w					1.3%	1.0%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%	1.1%	1.4%					w
x						1.4%	1.2%	1.1%	1.3%	1.3%	1.2%	0.7%	0.7%	1.2%	1.2%	1.3%	1.2%	1.3%	1.4%						x
y								1.4%	1.4%	1.6%	1.7%	1.5%	1.5%	1.6%	1.6%	1.4%	1.4%								y
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

[1] Fuelling regions are defined by different colors: 8-bundle-push channels are Pink, 4-bundle-push channels are Yellow, 2-bundle-push channels are Blue.
[2] Fuelling regions are defined by different colors: 8-bundle-push channels are Pink, 4-bundle-push channels are Yellow.

Figure 3: Unit 8 Bundle Power Differences for 13th Bundle from 3-year AUTOSORO Simulation*

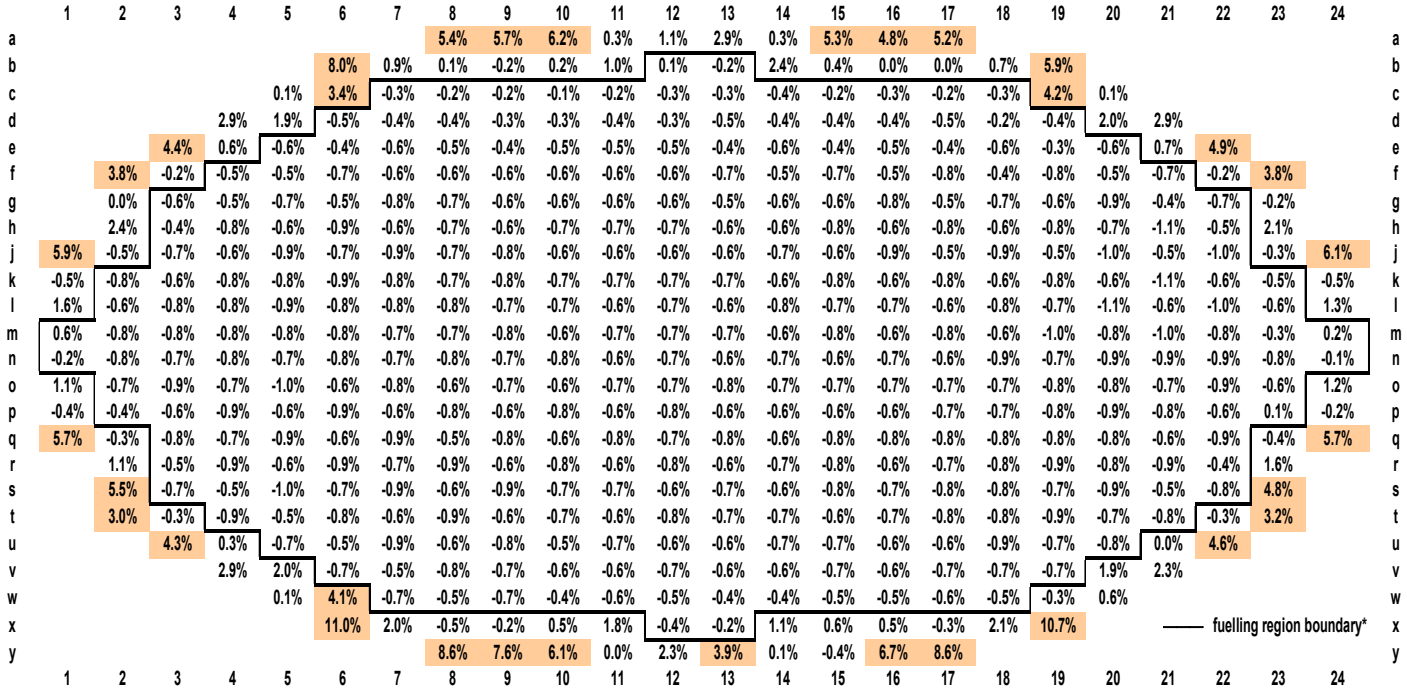
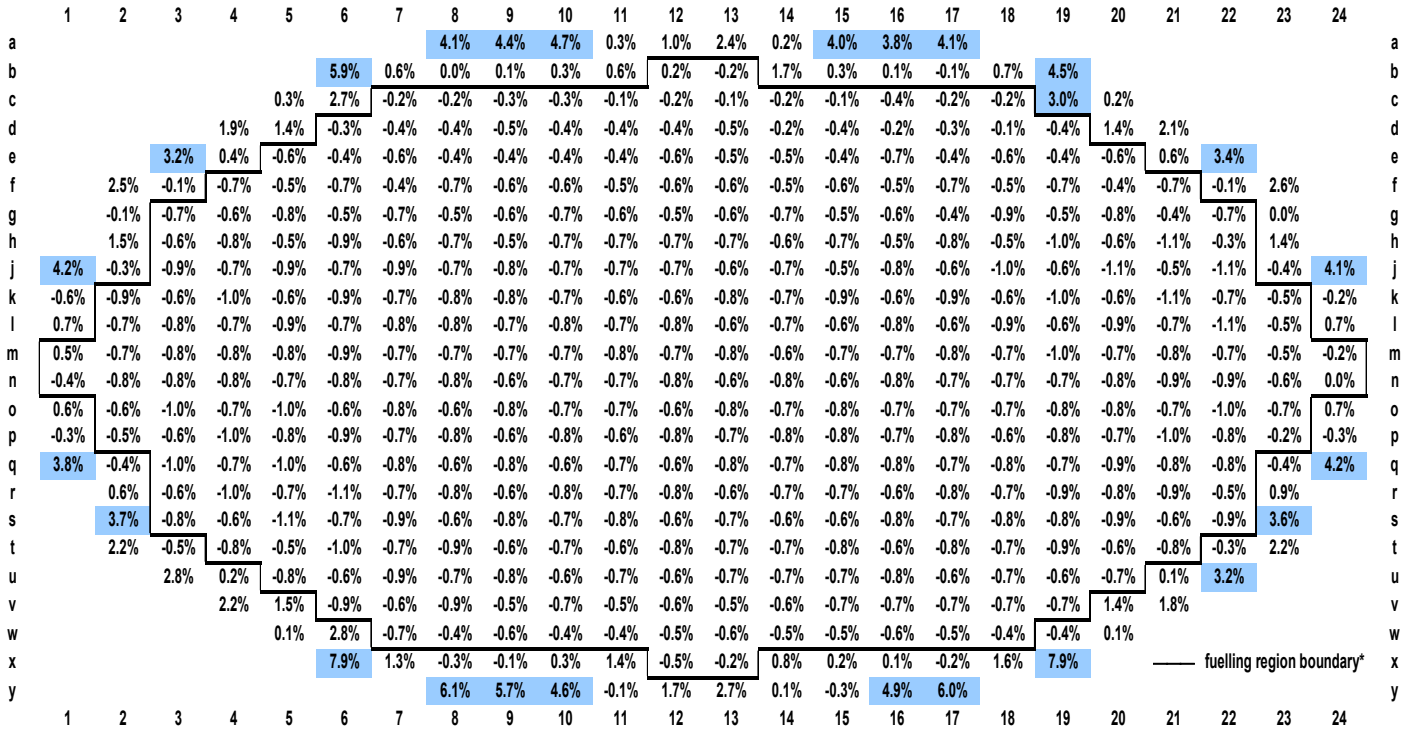


Figure 4: Unit 8 Bundle Power Differences for 13th Bundle from 4-year AUTOSORO Simulation *



* The boundary on the figure is the fuelling region boundary. Inside the boundary is 4-bundle-push region, outside the boundary is 8-bundle-push region.