SIMULATION OF THE POINT LEPREAU CORE-FOLLOW HISTORY WITH SORO

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Abstract

The core tracking SORO program calculates the flux, burn-ups, bundle and channel powers, and is used for Ontario Power Generation and Bruce Power reactors. This paper presents the results of a comparison of the SORO cell fluxes against the Point Lepreau CANDU-6 measured flux data. A SORO model was created for the Point Lepreau reactor, and simulations were carried out to compare the SORO fluxes to the Travelling Flux Detector (TFD) scans and one year of operating history. Considering the good agreement between measured and computed fluxes, the results provide confidence that SORO accurately calculates the cell fluxes and bundle powers.

Keywords: SORO, WIMS, Reactor Physics, core tracking, flux scans, bundle powers.

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1. Introduction

The core tracking program SORO[1] calculates the flux, burn-ups, bundle and channel powers. SORO was developed by Ontario Hydro and is routinely used for the core tracking of reactors operated by Ontario Power Generation (OPG) and Bruce Power (BP).

This paper presents a summary of the results obtained from a comparison of the SORO calculated fluxes against CANDU-6 flux data, which are not available for OPG and BP reactors, i.e. flux mapping detectors and flux scans at high power. The study provides an independent measure of the ability of SORO to predict the bundle fluxes and axial flux profiles. SORO simulations of the Point Lepreau CANDU-6 reactor were carried out in order to compare the SORO predicted fluxes to the Travelling Flux Detector (TFD) scans completed in 1992 and one year of core-follow history at 100%FP. The same data had previously been analyzed by AECL with WIMS/RFSP as part of validation work of physics toolset performed for core following of Point Lepreau core.

2. Methodology

The following subsections provide an overview of the SORO model and WIMS fuel tables used in the SORO simulations for the Point Lepreau reactor. The same SORO model was used for both the TFD scans and the core-follow simulations. Separate SORO fuel tables were produced for the TFD scans carried out in 1992 and for the core-follow time period 1994 –1995.

2.1 SORO Model for the Point Lepreau Reactor

The SORO model provides the location of the in-core devices by specifying the device location in terms of the (i, j, k) coordinates, in which the origin is on the east face of the reactor, and the coordinates correspond to the (row, column, bundle position) respectively. The SORO model consists of one incremental cross-section parameter (ΔA) for each device, the device location coordinates, and the reference and default positions used to move the device vertically.

The SORO model for the Point Lepreau reactor was based on the 1.5-group RFSP POWDERPUFS (PPV) model in effect at Point Lepreau in 1992 and 1994. In the RFSP-PPV model used at Point Lepreau up to 1995, there were 6 MULTICELL incremental macroscopic cross-sections specified for each device (i.e., fast transport, slow transport, fast absorption, slow absorption, moderation, and production). The SORO model ΔA incremental cross-section parameter was calculated by using only the incremental macroscopic thermal absorption cross-section ($\Delta\Sigma_{a2}$) and the incremental macroscopic

[1] The abbreviation "SORO" stands for "Simulation Of Reactor Operation".

production cross-section ($\Delta\upsilon\Sigma_f$) stored in RFSP. Incremental cross-sections were converted for use with SORO and no empirical tuning was performed[2].

The RFSP model device locations were converted into the corresponding SORO model coordinates. All of the RFSP Point Lepreau model devices were included in the corresponding SORO model.

2.2 SORO-WIMS Fuel Tables

The SORO-WIMS fuel tables for the Point Lepreau reactor were created by converting the RFSP-PPV input parameters into the corresponding WIMS input values. The same type of conversion had previously been used for the OPG and Bruce Power SORO fuel tables. SORO fuel tables for the Point Lepreau reactor were created for the different fuel bundle manufacturers with natural and depleted fuel types for the 37-element fuel bundles. Different sets of fuel tables were required for the TFD scans and the core-follow simulations, since the bundle uranium masses were slightly different for the various manufacturers during each time period.

For the core-follow simulations, changes in moderator temperature, moderator isotopic, and heat transport isotopic were not taken into account in the SORO fuel tables, since the magnitude of the changes was small. However, the actual moderator poison concentration values (in ppm of boron) were taken into account for each flux state calculation.

2.3 SORO Starting State and Core-Follow History

The SORO starting state for the Point Lepreau reactor simulation of the TFD scans was created by using the bundle fuel types and burn-ups from a 1992 RFSP-PPV state in the RFSP Direct Access File (DAF), and storing this information in the SORO Master File (SMF). Similarly, the SMF with the starting state for the core-follow simulations was created by loading the fuel types and burn-ups from a 1994 RFSP-PPV state.

It is important to note that the SORO starting state for the TFD scans was based on a single RFSP state and no previous core-tracking was carried out with SORO to create this starting state. This is likely the cause of some localized differences in the SORO simulation of TFD scans.

The RFSP input files for the core-follow simulations were translated into the corresponding SORO input file format. The burn step, channel fuelling, zone controller levels, and the reactor power were also extracted from RFSP inputs and used as input to the SORO simulations.

The correct channel fuelling direction and channel flow direction for the Point Lepreau reactor were stored in the SORO "maps" file, used for fuelling operations.

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[2] SORO uses $\Delta A = \dfrac{\Sigma_{a2} - \nu\Sigma_f}{D_t C_v}$ where D_t is core thermal diffusion coefficient and C_v is the correction factor for the volume that the cross-section is smeared over.

2.4 SORO Version

The "production" SORO version was used as a starting point for the simulations of the Point Lepreau reactor. Although several SORO subroutines had slight modifications, e.g. to accommodate the Point Lepreau 37-element fuel bundles in a reactor with 380 channels, the SORO flux calculation subroutine (including the bundle power and channel power calculations) was maintained identical to that compiled in the production SORO version in use by OPG and BP.

This SORO version (also referred to as SORO-WIMS) 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
- Explicit treatment of 7 saturating fission product absorbers (Rh105, Cd113, Xe135, Sm149, Sm151, Eu155, and Gd157)
- Coarse mesh

3. Results

3.1 TFD Scan Results

The SORO simulation of the Point Lepreau TFD scans was carried out for one flux state at 100%FP with an equilibrium core.

The SORO calculated fluxes along each of the Vertical Flux Detector (VFD) assembly locations were extracted and compared to the corresponding measured TFD fluxes. The flux scans are shown in Figures 1 and 2, and the SORO calculated fluxes are in good agreement with the measured fluxes.

In Figures 1 and 2, the data points denoted as "Meas" are the approximate "cell-averaged" measured values, which were obtained from the average of the data points bracketing each minimum. The SORO and measured fluxes were each normalized to the maximum value for that scan. The "cell-averaged" values were then compared to the corresponding SORO cell flux.

The percent error in the SORO calculated flux is defined as $\left(\frac{SORO\ \ flux}{Measured\ \ flux}-1\right)*100$.

All of the Root Mean Squared (RMS) errors were less than 8% and the largest RMS errors occurred in VFD 13 and 14, which are located in the center of the core. This suggests that the SORO adjuster incremental cross-section ΔA for the Point Lepreau reactor may need to be reduced (tuned) in order to increase the flux in that area.

The SORO predicted location of the Maximum Bundle Power (MBP) for the TFD simulation was channel P17 bundle 7, and the closest VFD to this bundle position is VFD 16. As shown in Figure 2, the SORO calculated flux in VFD 16 row P is in very good agreement with the measured flux.

Although this model has not been optimized for use with SORO, the SORO calculated fluxes are in good agreement with the measured fluxes, which provides confidence that the SORO model and fuel tables for the Point Lepreau reactor are appropriate. Since the SORO fluxes are used in the calculation of bundle powers, the flux scan comparisons provide some measure of the SORO accuracy for predicting the bundle powers and maximum bundle powers.

3.2 Core-Follow Results

The Point Lepreau core-follow history for one year of operation between March 1994 and April 1995 was simulated with the SORO program. The SORO-WIMS results were compared to the RFSP-WIMS results, in which comparisons were made between the RFSP-WIMS 1.5-group and 2-group models with the same Point Lepreau core-follow history as used in this study. The SORO and RFSP comparisons were carried out in order to help validate the SORO model and fuel tables for the Point Lepreau reactor. It should be noted that the RFSP-WIMS diffusion calculations are not directly used for compliance monitoring generally.

Overall, the SORO results were in good agreement with the RFSP-WIMS results. The SORO-WIMS Maximum Channel Power (MCP) and MBP results were on average 1.3% and 0.3% higher respectively than the RFSP-WIMS results, and the SORO reactivity trended well with the RFSP-WIMS simulations. The locations of the SORO MCP and MBP channels were very similar to those obtained from the RFSP-WIMS simulations. The time-averaged SORO-WIMS channel powers were compared to those from RFSP-WIMS and the differences are shown in Figure 3. There was very good agreement between the SORO and RFSP time-averaged channel powers, except at the boundary channels, which is probably due to the difference in the SORO and RFSP methods used in modelling the reflector and the extrapolation length at the boundary cells.

The SORO calculated zone controller worth was found to be 0.077 mk/%AVZL over the range of 20% to 80% Average Zone Level (AVZL), and the SORO reactivity difference between the “all adjusters out of core” and the “all adjusters in core” cases was 15.7 mk. The SORO zone controller worth appears to be larger than the previously calculated. The SORO model ΔA cross-sections for the zone controllers and adjusters were not adjusted (i.e., tuned) for this study, since a complete set of adjuster worth measurements was not available.

The SORO calculated fluxes at the 102 vanadium (flux mapping) detector locations were compared to the measured detector signals over the 1-year time period. The SORO thermal fluxes at the vanadium detector sites were obtained from the volume-weighted average of the fluxes in the mesh cells spanned by the detector. The mean difference between the SORO and measured fluxes for all of the detectors at each state is shown in Figure 4, and the corresponding standard deviation is shown in Figure 5. The standard deviations shown in Figure 5 range from 2.9% to 3.4% and are in reasonable agreement with those calculated with RFSP-WIMS.

Also investigated were the relative differences on an individual detector basis, and the mean difference between the SORO and measured detector fluxes (i.e., SORO flux error) for each detector ranges from -5.6% to 5.7%, and the standard deviation ranges from 0.4% to 1.0%, depending on the location in the core.

Analysis of spatial locations of the detector mean errors showed that SORO is over predicting at the top and bottom of the core and under predicting near the horizontal centerline. This suggests that the SORO adjuster ΔA cross-sections may need to be reduced to increase the flux in that central region. This is consistent with the flux scan comparison results presented in Section 3.1.

The SORO flux error at the detectors was also examined along several channels near the center of the core in order to assess the axial profile of the errors. The mean SORO flux error indicates SORO over predicts the flux in bundle positions 3 and 10 and under predicts the flux in the centre of the core for a few particular channels. The corresponding standard deviation of the SORO flux error is essentially constant along the axial positions for most of the channels.

The errors were also examined for the detector closest to the SORO MBP location (some of the channels did not have a flux mapping detector nearby). The corresponding mean SORO flux error ranges from 0% to 5.5%, and the average of the error values was 2.6%.

The SORO detector flux and the measured flux were also examined with respect to the top-to-bottom, north-to-south, and east-to-west tilts. The SORO tilts were similar to those obtained from the RFSP-WIMS simulations, and also were in reasonable agreement with the measured values.

Overall, the SORO calculated fluxes at the vanadium detector sites were in good agreement with the measured detector fluxes over the 1-year of core-follow history, and this provides additional evidence of the accuracy of the SORO calculated MBP results.

4. Conclusions

A SORO model was created for the Point Lepreau reactor, and simulations were carried out in order to compare the SORO fluxes to the measured fluxes from the TFD scans and from the vanadium detectors for one year of operating history.

The SORO calculated flux along each of the VFD assembly locations were in good agreement with the measured TFD flux. Similarly, the SORO calculated fluxes at the 102 vanadium flux mapping detector locations were also in good agreement with the measured detector fluxes over the 1-year of core-follow history for the Point Lepreau reactor.

The relative difference between the SORO and measured fluxes for all of the detectors at each state in the core-follow history had a standard deviation in the range of 2.9% to 3.4%. Also investigated were the relative differences on an individual detector basis, and the mean error for each detector ranged from -5.6% to 5.7%, and the standard deviation ranged from 0.4% to 1.0%, depending on the location in the core. The SORO fluxes at the MBP locations were in good agreement with the measured flux values from both the TFD scans and the vanadium detectors for the core-follow history.

The results from this study provide additional confidence that SORO accurately calculates the bundle fluxes used in the calculation of bundle powers. The flux scan comparisons and the core-follow detector flux comparisons provide a separate and independent source of evidence with respect to the accuracy of the SORO MCP and MBP predictions. The results of the SORO simulations reported here compared well to those from previous RFSP - WIMS simulations of Point Lepreau core follow, performed as part of validation of physics toolset against actual operating history.

Figure 1. Comparison of SORO Cell Fluxes with TFD Measurement for VFD assemblies 1 through 14

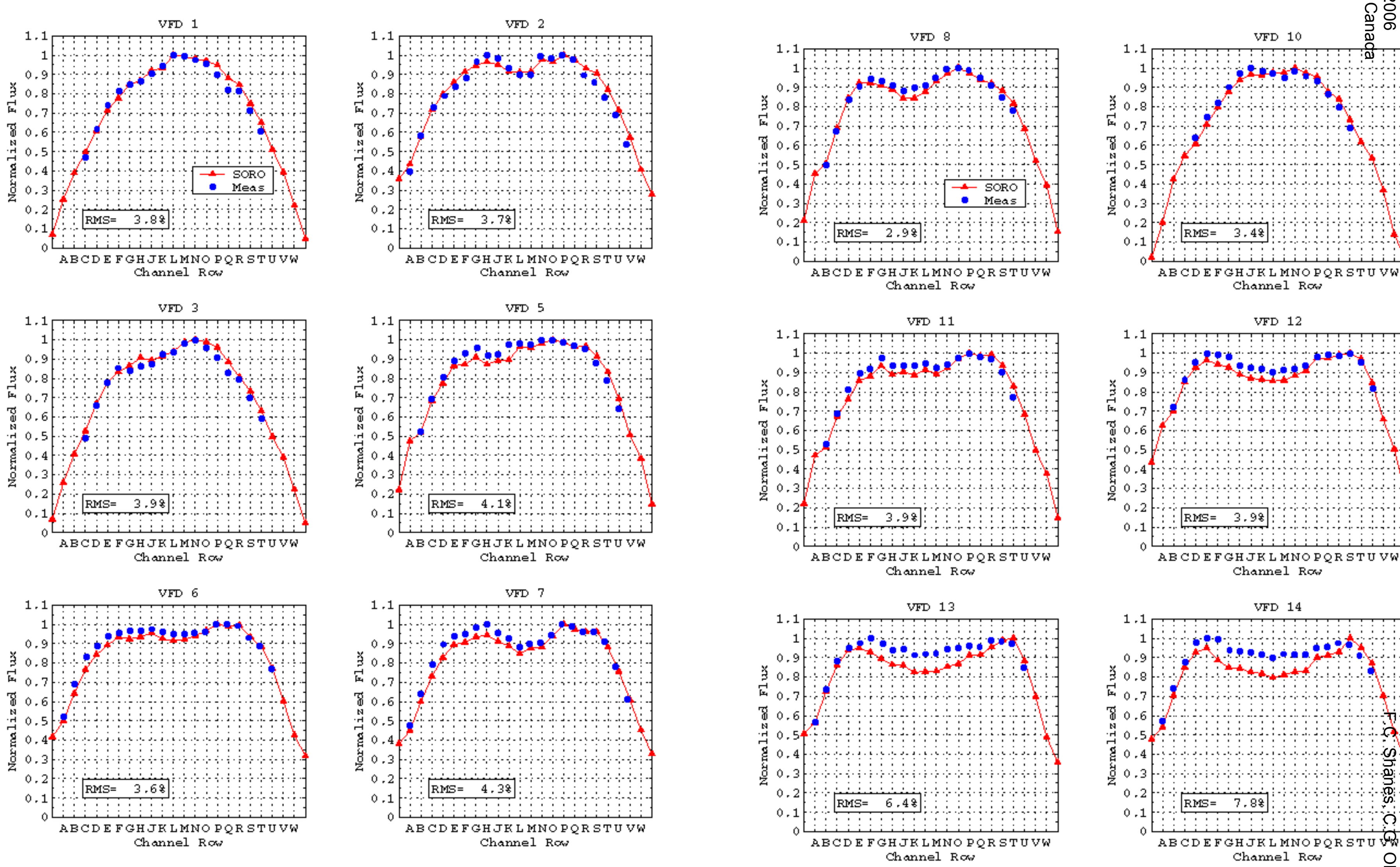

Figure 2. Comparison of SORO Cell Fluxes with TFD Measurement for VFD assemblies 15 through 26

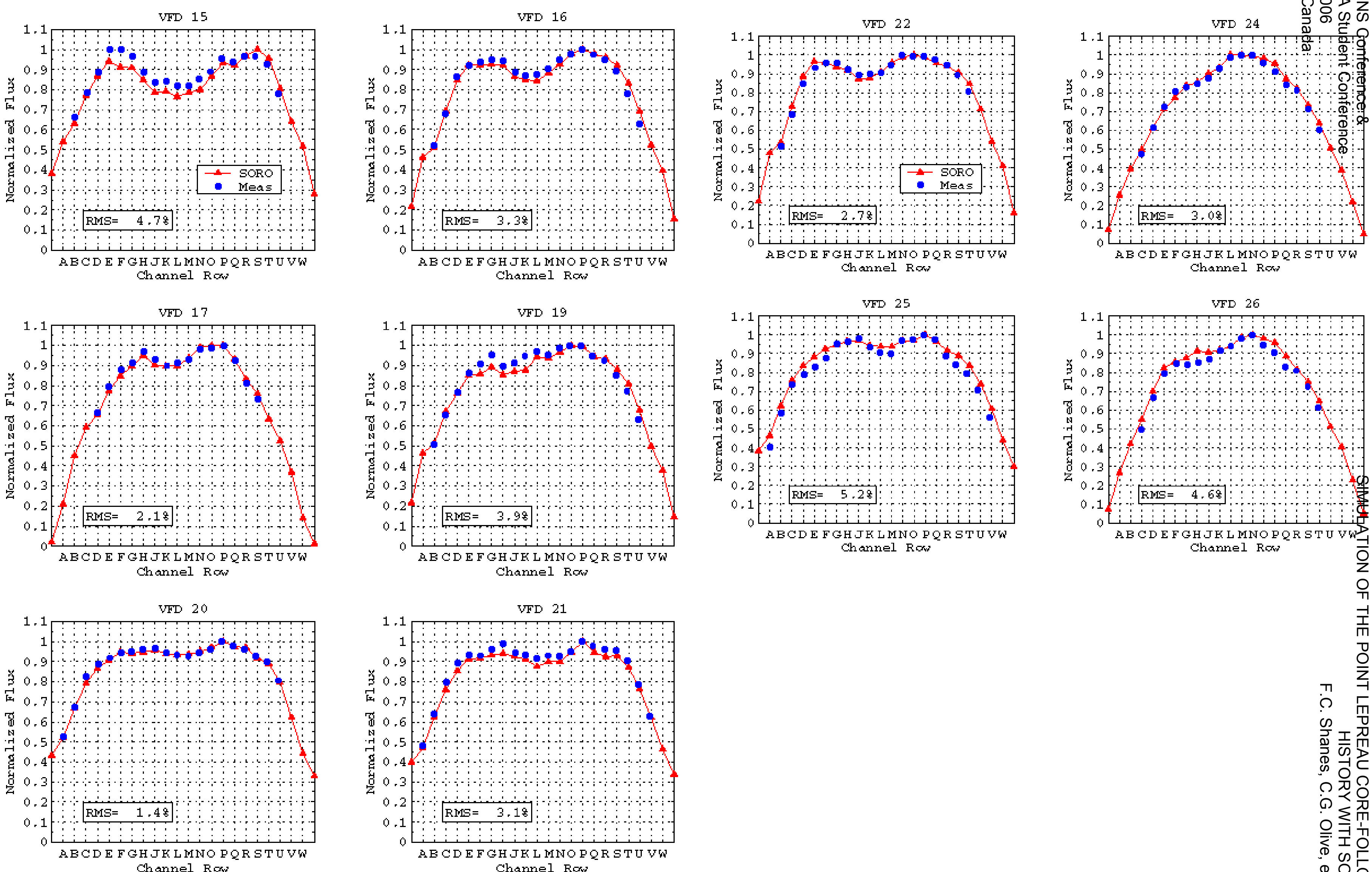

Figure 3. Time-Averaged Channel Power Difference Defined as 100(SORO/RFSP_WIMS – 1).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A									-4.4	-3.1	-2.9	-3.3	-3.0	-4.4								
B						-3.7	-1.7	-1.0	-1.2	-0.8	-1.1	-1.4	-0.9	-1.3	-1.5	-1.5	-3.7					
C					-2.1	-1.1	-0.4	-0.4	-0.3	-0.4	-0.9	-1.1	-0.4	-0.5	-0.5	-0.5	-0.9	-2.0				
D				-1.7	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2	-0.9	-1.0	-0.2	-0.3	-0.2	-0.1	-0.1	-0.7	-2.1			
E			-1.9	-0.4	0.7	0.5	0.6	0.4	0.3	0.3	-0.4	-0.3	0.2	0.3	0.5	0.6	0.6	0.6	-0.5	-2.0		
F			-1.0	-0.4	0.3	0.0	0.4	0.3	0.2	0.0	-0.4	-0.5	0.0	0.0	0.4	0.3	0.1	0.1	-0.6	-1.6		
G		-1.9	-0.5	-0.2	0.1	-0.1	0.3	0.3	0.2	0.3	0.2	0.3	0.2	0.0	0.4	0.3	-0.2	0.0	-0.4	-0.8	-2.0	
H		-1.2	-0.4	-0.3	0.1	-0.2	0.4	0.2	0.2	0.2	0.3	0.3	0.4	0.0	0.4	0.4	-0.4	-0.1	-0.3	-0.8	-1.5	
J	-2.6	-0.7	-0.2	0.0	0.0	-0.2	0.2	0.3	0.2	0.3	0.4	0.4	0.3	0.1	0.2	0.3	-0.8	-0.1	-0.3	-0.4	-0.8	-2.9
K	-2.1	-0.6	-0.3	-0.1	0.0	-0.1	0.4	0.4	0.2	0.3	0.1	0.0	0.3	0.3	0.3	0.5	-0.3	0.1	-0.2	-0.5	-0.9	-2.3
L	-2.0	-0.5	-0.2	0.0	0.9	0.7	0.4	0.5	0.3	0.4	-0.2	-0.2	0.4	0.3	0.4	0.5	0.6	0.7	-0.2	-0.5	-0.9	-2.3
M	-2.0	-0.5	-0.1	0.0	1.0	0.7	0.4	0.4	0.4	0.4	-0.3	-0.3	0.4	0.3	0.4	0.4	0.6	0.8	-0.2	-0.4	-0.8	-2.4
N	-1.7	-0.4	0.0	0.3	1.2	0.7	0.5	0.5	0.3	0.4	-0.3	-0.3	0.4	0.2	0.3	0.4	0.7	0.8	0.0	-0.2	-0.9	-2.4
O	-2.4	-0.7	-0.2	0.0	0.7	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.4	0.3	0.3	0.3	0.3	0.5	-0.1	-0.4	-0.9	-2.8
P		-1.2	-0.2	0.1	0.5	0.2	0.5	0.5	0.4	0.3	0.7	0.8	0.4	0.3	0.4	0.4	0.0	0.1	-0.1	-0.4	-1.5	
Q		-1.7	-0.4	0.1	0.5	0.1	0.5	0.6	0.4	0.4	0.6	0.6	0.5	0.3	0.4	0.5	-0.2	0.1	0.0	-0.5	-2.1	
R			-0.7	0.2	0.7	0.3	0.8	0.7	0.6	0.6	0.3	0.3	0.5	0.5	0.6	0.8	0.1	0.4	0.2	-0.8		
S			-1.1	0.3	0.7	0.2	0.9	0.6	0.5	0.3	-0.1	-0.3	0.5	0.4	0.6	0.6	0.0	0.4	0.0	-1.0		
T				0.4	1.1	1.3	1.1	0.9	0.7	0.5	-0.2	-0.2	0.6	0.6	0.7	0.8	1.1	0.8	-0.1			
U					1.4	1.8	1.4	1.3	0.9	0.8	-0.1	0.0	0.7	1.0	0.7	1.4	1.1	0.7				
V						0.8	1.6	1.3	1.0	0.7	0.5	0.6	0.7	1.0	0.9	1.4	0.6					
W									-1.0	-0.5	-1.2	-1.0	-0.7	-0.7								

Figure 4. Mean difference between SORO simulated and Measured Vanadium detector signals

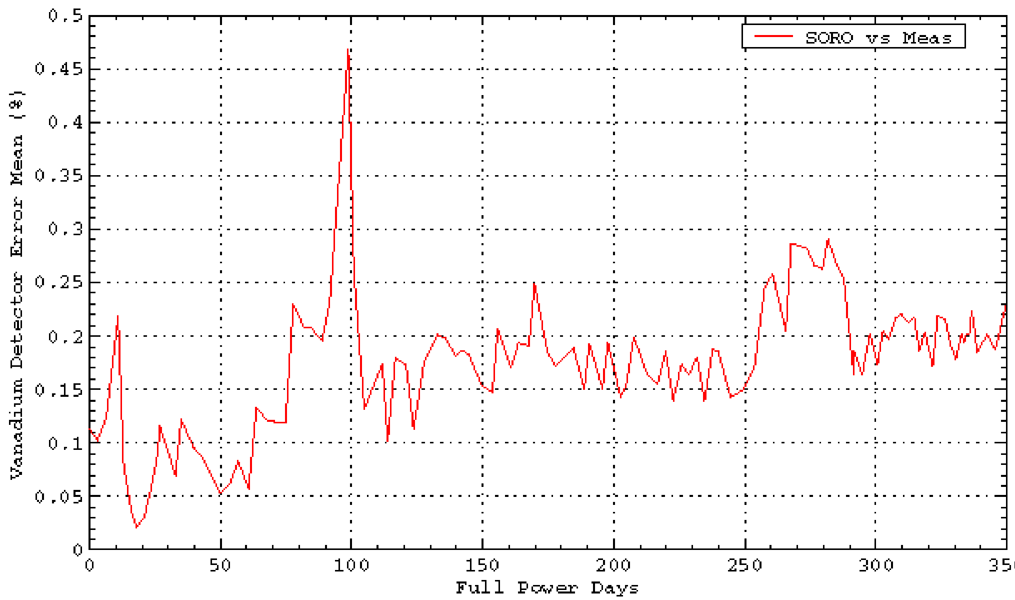

Figure 5. Standard deviation of the difference between SORO simulated and Measured Vanadium detector signals