Simulation of Adjuster Withdrawal in Darlington Unit 4

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Abstract

Physics simulations in safety analyses are generally performed using a bundle irradiation distribution that is consistent with an approximate time-average configuration. In this paper, three assessments of a spurious adjuster withdrawal event at Darlington are performed with RFSP. The simulations are performed using a time-average irradiation distribution and the SORO predicted irradiation distribution just prior to the actual event. In all three of the assessments it is shown that the results are quite insensitive to the assumed irradiation distribution. This supports the approach of assuming a time-average irradiation distribution in safety analyses.

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1.0 Introduction

Physics simulations supporting safety analyses are generally performed using a bundle irradiation distribution that is consistent with an approximate time-average configuration. In this paper, three assessments of a spurious withdrawal of one of the adjuster absorbers at Darlington are performed with the physics neutron diffusion code RFSP [1]. The simulations are performed using two distinct irradiation distributions: a time-average approximation, typical of safety analyses, and the SORO predicted irradiation distribution just prior to the actual event. One of the simulations includes prediction of the Unit response in the absence of a forced shutdown, consisting of the associated xenon transient and RRS response. The second simulation consists of the withdrawal of AA18 and not crediting RRS response, leading to a Neutron Overpower (NOP) trip. The last assessment involves simulation of NOP type flux shapes of AA18 withdrawal and the resulting NOP trip setpoints.

In all three of the assessments documented in this paper, it is shown that the results are quite insensitive to the assumed starting irradiation distribution. This supports the approach of assuming a time-average irradiation distribution in safety analyses.

2.0 Adjusters in Darlington

The Darlington Nuclear Generating Station Units have 16 adjusters absorbers (AAs) normally fully inserted and under manual control; automatic control by the reactor regulating system (RRS) is permitted following power reduction or turbine trip. The layout of the adjusters is depicted in Figure 1. The total reactivity worth of the 16 AAs is approximately 12.5 mk.

3.0 Description of Event

On April 21 19:08, 2010 adjuster AA18 spuriously withdrew from Darlington Unit 4 while the reactor was at full power. Adjuster 18 is a shorter adjuster, located in the south-east quadrant of the core. The sudden unintended movement of the AA18 initiated a slow reactivity and power transient anomaly which was quickly compensated for by the reactor regulating system. The RRS filled the water level in the neighbouring zone controller units (ZCUs). The operators attempted to reinsert AA18, but the adjuster did not respond and remained out-of-core. The operator followed procedures and moved to manually shutdown the reactor so that the fault with AA18 could be diagnosed and corrected. The Unit was shut down approximately seven minutes after the start of withdrawal of AA18.

4.0 RFSP Model

The physics simulations are performed using the RFSP code. The three main modules in RFSP that are used to compute neutron flux are *TIME-AVER, *SIMULATE, and *CERBERUS. The latter two are used explicitly and the first is used only to establish a time-average power distribution. The major difference between *SIMULATE and *CERBERUS is that the former assumes a quasi-steady-state at each step in the simulation but the latter models the neutron kinetics in detail. Common to both is the starting bundle irradiation distribution. As discussed in Section 5.0, the simulations are performed using a bundle irradiation distribution based on a time-average representation and one that corresponds to the SORO state immediately prior to withdrawal of AA18.

4.1 Reactivity Devices

Apart from AA18 withdrawal, the reactivity devices are in their nominal positions. The mechanical control absorbers and shutoff rods are out of core and the remaining 15 adjusters are in core.

4.2 Time-Average Representation

In the RFSP model, the bundle irradiation distribution can be set such that the power distribution matches a target power map. This is accomplished via an iterative process that tunes channel exit irradiations in the *TIME-AVER model, followed by the *TAVEQUIV module to establish individual bundle irradiations and channel power computation using *SIMULATE. This process is repeated until the channel powers predicted by *SIMULATE match the target channel powers – the NOP reference. The other relevant parameters of the time-average model are shown in Table 1.

4.3 SORO Based Irradiation Distribution

The SORO burnup[1] data extracted for the production state just prior to the AA18 event corresponds to production state number 13651, recorded April 21, 2010 at 05:16 EST. This burnup is converted for use in RFSP and the core parameters consistent with the predictive SORO simulation at 19:08 hours, Table 1, are implemented in the RFSP simulation. Collectively, this is the starting RFSP state for simulations involving SORO based irradiations.

4.4 Neutron Detector Modelling

4.4.1 In Core Detectors

The 54 SDS1 vertical in-core detectors in Darlington are Inconel and over-prompt. However, in the model, they are assumed to be under-prompt by 5% (i.e., a prompt fraction of 0.95). Consistent with Darlington design, the SDS1 detectors are not dynamically compensated.

The 51 SDS2 horizontal in-core detectors in Darlington are Platinum-clad Inconel and are under-prompt. In the RFSP model, they are modeled with a prompt fraction of 0.80 (i.e., they are under-prompt by 20%). These detectors are dynamically compensated so that their signal more closely tracks power to fuel under transient conditions.

4.4.2 Ion Chambers

RFSP is not able to model the out-of-core behaviour of the neutronic flux due to the assumption of zero neutron flux at a specified distance from the inner shell of the calandria. As a result, the out-of-core detectors cannot be modeled in their correct physical locations. To account for the behaviour of the out-of-core detectors, they are assumed to be within the reflector region. The three ion chambers of SDS2 are assumed to be located in the south end of the reactor – closest end to AA18, and the SDS1 ion chambers on the north end.

5.0 RFSP Time-Average and SORO Irradiations

The phenomenon of nuclide transmutation due to neutron flux can be expressed in units of MWh/kgU, commonly referred to as burnup, or in units of n/kb (neutrons per kilo-barn), commonly referred to as irradiation. The SORO code uses the former and the RFSP code uses the latter. Thus, prior to using the SORO burnup distribution in RFSP, it must first be converted to compatible units.

In the RFSP code, the user has the option utilizing an irradiation distribution that mimics time-average core properties or a user defined distribution that is imported via an external file. The time-average core is setup via the *TIME-AVER module. This module calculates core burnup, power and flux distributions while taking into account a specific fuelling scheme. The results of these calculations are considered representative of a core operating in steady state over a very long period of time. However, since *TIME-AVER is not used explicitly in the simulations presented in this paper, it is necessary to create a time-average equivalent model using the *TIMEQUIV module of RFSP. Thus, using the results of *TIME-AVER, the bundle specific irradiations compatible with the *SIMULATE and *CERBERUS modules are obtained using the *TIMEQUIV module.

SORO (Simulation of Reactor Operation) is used at all OPG nuclear stations to monitor and plan fuelling operations. This includes license compliance (maximum bundle and channel powers), calculation of shut down system NOP calibration factors, channel gap management, and fuel string location reactivity calculations. To support these objectives, SORO tracks the irradiation of every bundle in the core. This information is considered the most accurate representation of actual bundle irradiations.

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[1] The burnup distribution in SORO production state 13651 does not include the fuelling of channels K13, Q23, and T02 which occurred between the time of the SORO computation at 05:16 and the withdrawal of AA18 at 19:08 later that day.

6.0 Simulations

The assessments in this paper were performed using the physics neutron diffusion code RFSP (version 3-01-00P04). The lattice parameters were prepared using the transport codes WIMS-AECL 2.5d, for fuel and reflector properties, and DRAGON 3.04L for reactivity devices.

Three distinct simulations involving the withdrawal of AA18 are discussed in this paper: i) crediting RRS, ii) RRS not credited, iii) channel power ratios of before and after AA18 withdrawal with NOP trip setpoint calculations.

6.1 Crediting RRS

The Unit response in the absence of operator action (forced shutdown) is calculated through the simulation of the AA18 withdrawal and associated xenon transient and RRS response. The simulation is performed using the *SIMULATE module of RFSP and is terminated when one of the following criterion are met: i) Setback, ii) Stepback, iii) NOP Trip, or iv) a new steady-state is reached as indicated by a stabilization of the levels in the liquid zone controllers.

The RFSP simulations are performed with two sets of in-core irradiation distributions: i) computed by the RFSP module *TAVEQUIV, and ii) extracted from the SORO state immediately preceding withdrawal of AA18. The simulation uses the RRS functionality that is available in RFSP for the *SIMULATE module.

6.2 RRS is not Credited

The core transient resulting from withdrawal of AA18 and not crediting RRS is simulated using the *CERBERUS module of RFSP. The level in the 14 liquid zone controllers is assumed to be frozen at the station observed values just before withdrawal of AA18. The reactivity transient is tracked until the NOP trip setpoint is reached on the second of the two Shutdown Systems (SDSs) in all three logic channels (i.e., 3 out of 3 trip logic).

The RFSP simulations are performed with two sets of in-core irradiation distributions: i) computed by the RFSP module *TAVEQUIV, and ii) extracted from the SORO state immediately preceding withdrawal of AA18.

6.3 Channel Power Ratios

A set of flux distributions are generated as listed in Table 2. The flux shape types are simulated with two sets of in-core irradiations: i) computed with the RFSP module *TAVEQUIV, representing the standard NOP analysis methodology, and ii) extracted from the SORO state immediately preceding the withdrawal of AA18. The levels of the liquid zone controllers observed at the station just after AA18 withdrawal, as used in Case 1, are shown in Table 3. Flux shapes with time-average properties are based on the methodology that is used in NOP analyses.

For the time-average irradiation based flux shapes, the reference flux shape used in the computation of the channel overpowers and detector ratios, is the time-average shape with all zone controllers set at 42% full. For the SORO irradiation based flux shapes, the reference flux shape is calculated with the SORO irradiations and the zone levels set to 42%.

While not discussed in detail in this paper, the channel overpowers and detector ratios are used to compute the NOP trip setpoints. Included in this computation are the critical channel powers specific to the RFSP results of the two irradiation distributions.

7.0 Results

The discussions of the results of the three assessments are presented in the following sub-sections.

7.1 Simulation With RRS Credited

Figure 2 to Figure 4 show the transient simulation results with bulk and spatial control functional without operator action for the case with RFSP time averaged irradiations; Figure 5 through Figure 7 show the same results for the SORO snapshot irradiation.

The predicted zone controller levels are in-line with the scenario being simulated. Adjuster 18 is located in zones 8 and 9 and the liquid controllers in these two zones are predicted to increase significantly in response to the withdrawal of AA18. A near saturation of these zone controllers was also observed at the station. The general trend of the liquid controllers in the remaining zones also compare favourably to those observed at the station.

The reactor core response to the withdrawal of AA18 for both the time-average and SORO snap shot core representation transient are quite similar. Within both simulations, the setback condition is predicted on high flux tilt (greater than 10%) after approximately 2.5 hours. The progression of the tilt with time is also quite similar as can be seen in Figure 2 and Figure 5. Both representations indicate a rise in tilt of approximately 4% after the withdrawal and then a continued increase as a result of the ensuing xenon transient. It is important to note that the setback condition time is computed assuming an initial tilt of zero.

The behaviour of the normalized zone powers and zone controller units (zone levels) is also quite similar between the two core representations. These trends can be seen in Figure 3 and Figure 4 for the time-average, and Figure 6 and Figure 7 for the SORO irradiations for the zonal powers and zone levels, respectively. The zone controller levels predicted just after AA18 withdrawal are compared to the station measurements in Figure 8. Irrespective of the initial irradiation distribution, the predicted zone controller levels match the levels observed at the station very well.

Overall, the progression of the transient with RRS credited using the two core representations is very similar.

7.2 Simulation with RRS Not Credited

Simulations of the AA18 transient in the absence of bulk/spatial control and operator action are used to compute the NOP trip times. In these transient simulations, the NOP trip times for SDS1 and SDS2 for the time-average core representation are 12.88 s and 14.61 s. Similarly, for the SORO representation, the trip times are 12.52 s and 14.13 s, respectively for SDS1 and SDS2. The differences between the trip times computed in the time-average and SORO representations are within approximately 0.5 s. In this particular simulation, it is evident that the time-average representation is slightly conservative with respect to predicted trip time compared to the SORO irradiation.

7.3 Channel Power Ratios and NOP Trip Setpoints

The comparison of RFSP predictions with time-average and SORO irradiations, with differences in COPs expressed as percentages, for each of the four flux shapes listed in Table 2 are shown in Figure 9 to Figure 12. The differences in detector responses for these same flux shapes are given in Figure 13 to Figure 16.

Comparing the COPs of flux shapes with bulk and spatial control on, either when the functionality is predicted with RFSP (Case 2) or when it is simulated with actual zones (Case 1), to the COPs without spatial and bulk control (Cases 3 and 4), the former are substantially smaller. This indicates that RRS reduces the overall impact on the COPs; as expected.

The differences[2] in the predicted COPs for time-average and SORO based irradiation distributions are quite small over the four flux shapes and reach a maximum of less than ~2%. For most of the comparisons, the greatest discrepancy is observed in the vicinity of the zone compartments. As well, the smallest differences are present in the flux shape with bulk and spatial control on (Case 2). In this flux shape, the fill levels in the zone controllers respond to the consequential AA18 perturbation in the two core configurations (i.e., time-average and SORO irradiations) and generally limit the COPs. While for the other flux shapes, the zone controller levels are equal for the two representations and the COPs in the two representations differ by slightly larger amounts. Nevertheless, the results indicate that the time-average approximation is quite good and that the COPs used in the NOP trip setpoint computations are consistent with actual production states.

The differences in SDS1 and SDS2 detector ratios shown in Figure 13 to Figure 16 indicate that time-average and SORO based irradiation flux shape simulations result in detector ratio differences on the same order as differences in COPs. This is not unexpected due to the tight coupling of these two parameters.

The SDS1 and SDS2 NOP trip setpoints were calculated for each of the four flux shapes for both of the irradiation distributions. For each flux shape the CCPs are generated with time averaged core properties and SORO based core irradiations. It was found that the NOP trip setpoints differed by a maximum 1% relative (SDS2 trip setpoint for Case 1) between the SORO irradiation and time averaged generated NOP trip setpoints. The difference is less than 0.5% relative for the two flux shapes used in safety analysis.

8.0 Conclusions

From the simulation of the core response in the absence of operator action, it was shown that the setback condition on high flux tilt (greater than 10%) was reached after approximately 2.5 hours. The simulations indicate a rise in tilt of approximately 4% after the withdrawal of AA18 and then a continued increase as a result of the ensuing xenon transient.

In addition to simulations predicting core response in the absence of shutdown, a number of transients are simulated assuming failure of RRS. In these cases, the predicted time of SDS1 and SDS2 NOP trips are approximately 12.88 s and 14.61 s for the time-average representation, and 12.52 s and 14.13 s for the SORO representation. A high log rate trip was not predicted to occur.

A broad set of flux shapes relating to AA18 withdrawal have been simulated with RFSP. The flux shapes were simulated using time-average and SORO based irradiations. The differences in the predicted COPs for time-average and SORO based irradiation distributions were found to be quite small over the four flux shapes and reach a maximum of less than ~2%.

The NOP trip setpoint for each of the flux shapes were computed. It was found that the difference between the NOP trip setpoint results using a time averaged core or SORO irradiations is insignificant for the examined flux shapes. A maximum 1% relative difference is calculated between the SORO irradiation and time averaged generated NOP trip setpoints.

In all three of the assessments documented in this paper, it is shown that the results are quite insensitive to the assumed starting irradiation distribution. This supports the approach of assuming a time-average irradiation distribution in safety analyses.

9.0 References

[1] B. Rouben, "RFSP-IST, The Industry Standard Tool Computer Program for CANDU Reactor Core Design and Analysis", Proceedings of the 13th Pacific Basin Nuclear Conference, Shenzhen, China, 2002 October 21-25.

[2] These differences are computed as 100*(SORO-RFSP); where SORO are the COPs with SORO based irradiations and RFSP are the COPs with time-average irradiations.

Parameter	Time-Average Model	SORO Based Model
Moderator Temperature (^oC)	66.0	66.0
Coolant Temperature (^oC)	288.50	292.00
Moderator Purity (at.%)	99.97	99.98
Coolant Purity (at.%)	99.11	98.88
Moderator Poison (ppm)	0.0	0.60 (Boron)
Coolant Density (g/cc)	0.8179	0.8068
ZCR01	42%	35%
ZCR02	42%	49%
ZCR03	42%	55%
ZCR04	42%	52%
ZCR05	42%	26%
ZCR06	42%	45%
ZCR07	42%	41%
ZCR08	42%	39%
ZCR09	42%	50%
ZCR10	42%	57%
ZCR11	42%	56%
ZCR12	42%	41%
ZCR13	42%	38%
ZCR14	42%	51%

Table 1: Core Parameters for Time-Average and SORO Based Models

Case	Flux Shape Description
1	AA18 Fully Out, RFSP Bulk and Spatial Control off, zone levels observed in station before and after AA18 withdrawal
2	AA18 Fully Out, RFSP Bulk and Spatial Control on, start with 42% average zone level
3	AA18 Fully Out, RFSP Bulk and Spatial Control off, start with 42% AVZL
4	AA18 Fully Out, RFSP Bulk and Spatial Control off, zone levels frozen at those observed in station before AA18 withdrawal

Table 2: Description of Flux Shapes

Zone Controller	Fill Level
ZCR01	33%
ZCR02	50%
ZCR03	54%
ZCR04	61%
ZCR05	28%
ZCR06	60%
ZCR07	55%
ZCR08	81%
ZCR09	84%
ZCR10	61%
ZCR11	79%
ZCR12	53%
ZCR13	37%
ZCR14	52%

Table 3: Zone Controller Levels at Darlington just after AA18 Withdrawal

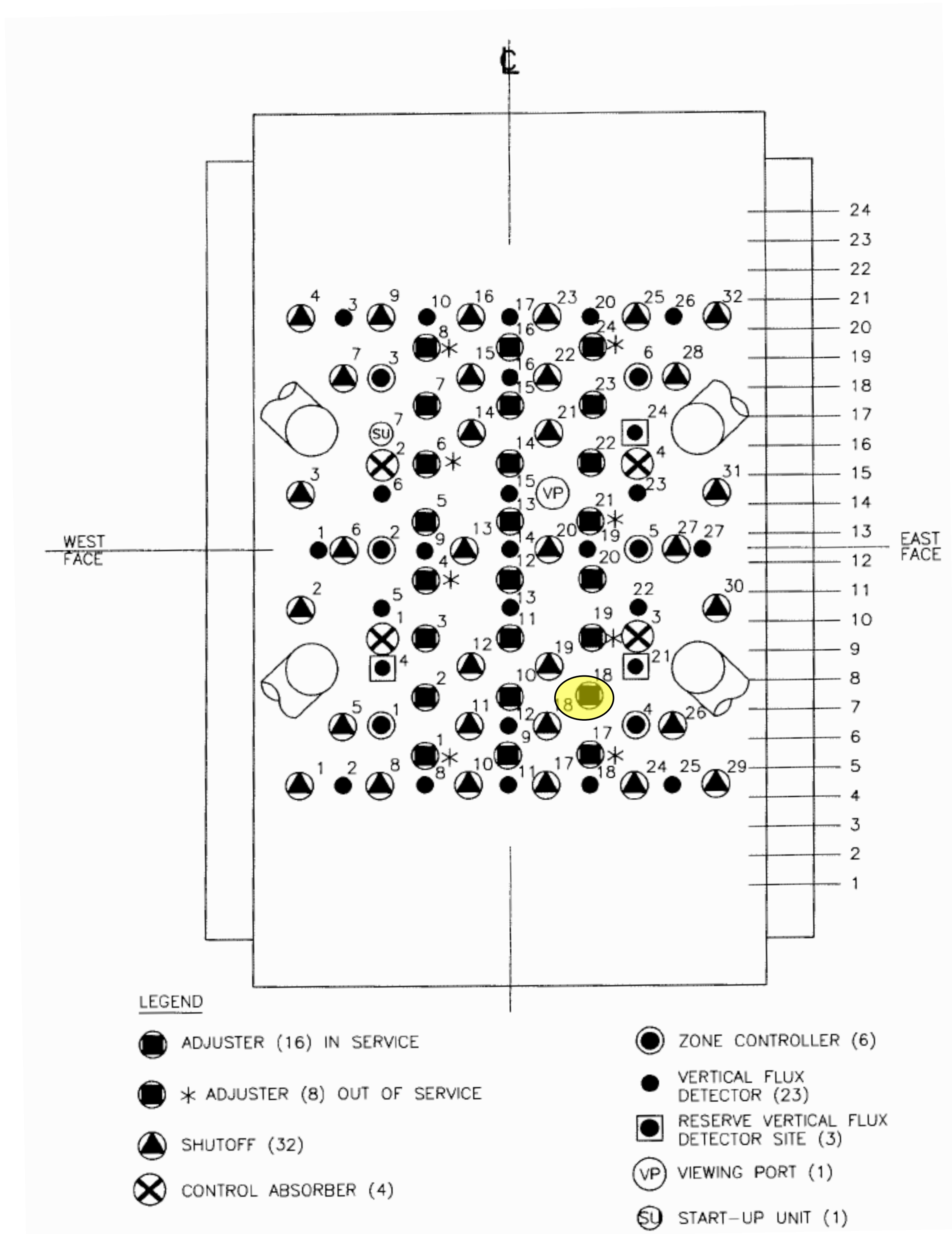

Figure 1 – Darlington Nuclear Generating Station Reactivity Control Unit Locations

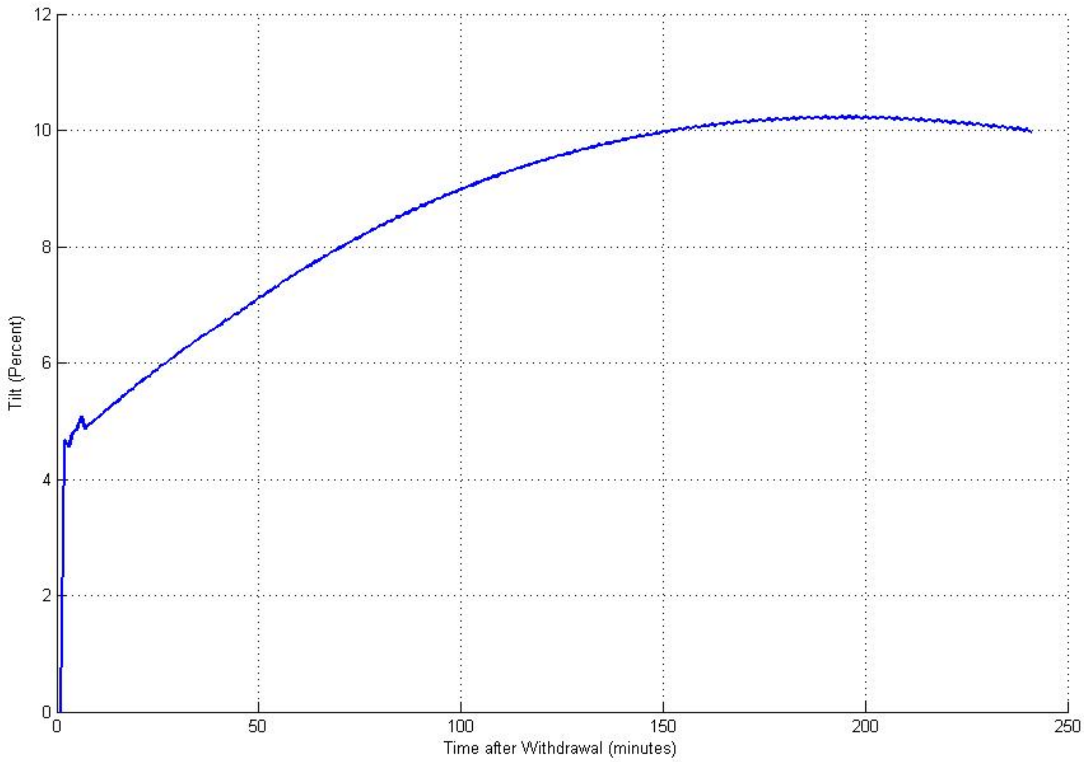

Figure 2 – Tilt vs. Time after Withdrawal of AA18 (Time-Average Irradiations)

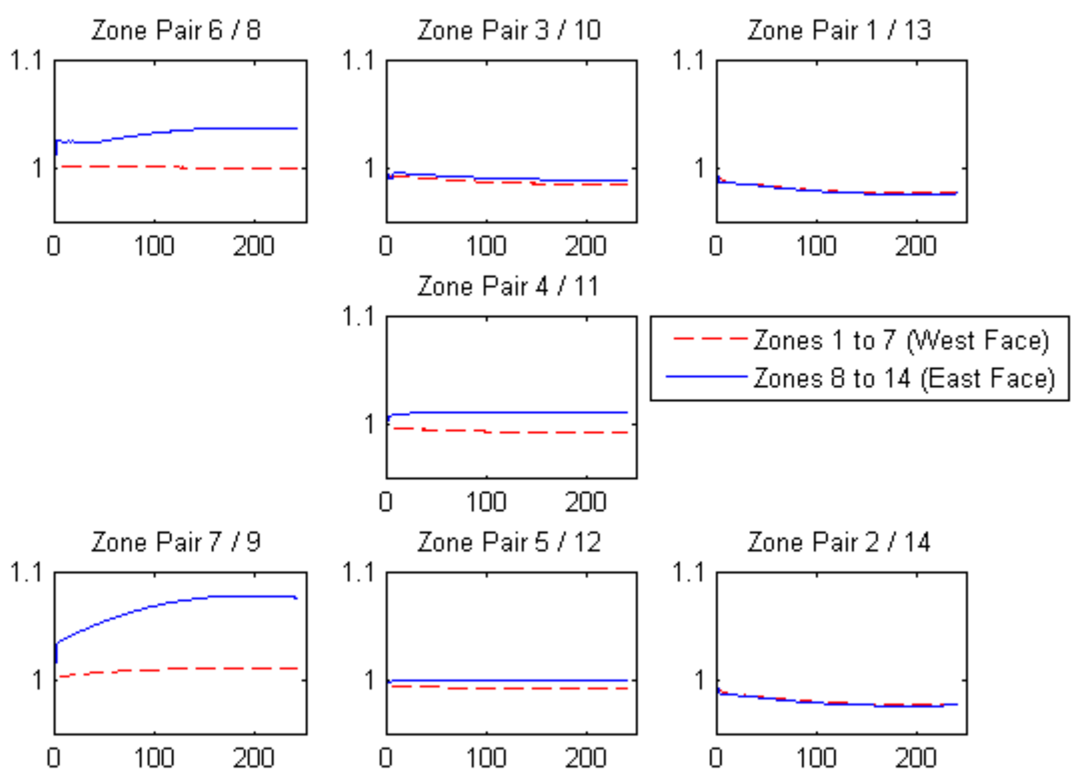

Figure 3 – Normalized Zone Power vs. Time after Withdrawal of AA18 (minutes) (Time-Average Irradiations)

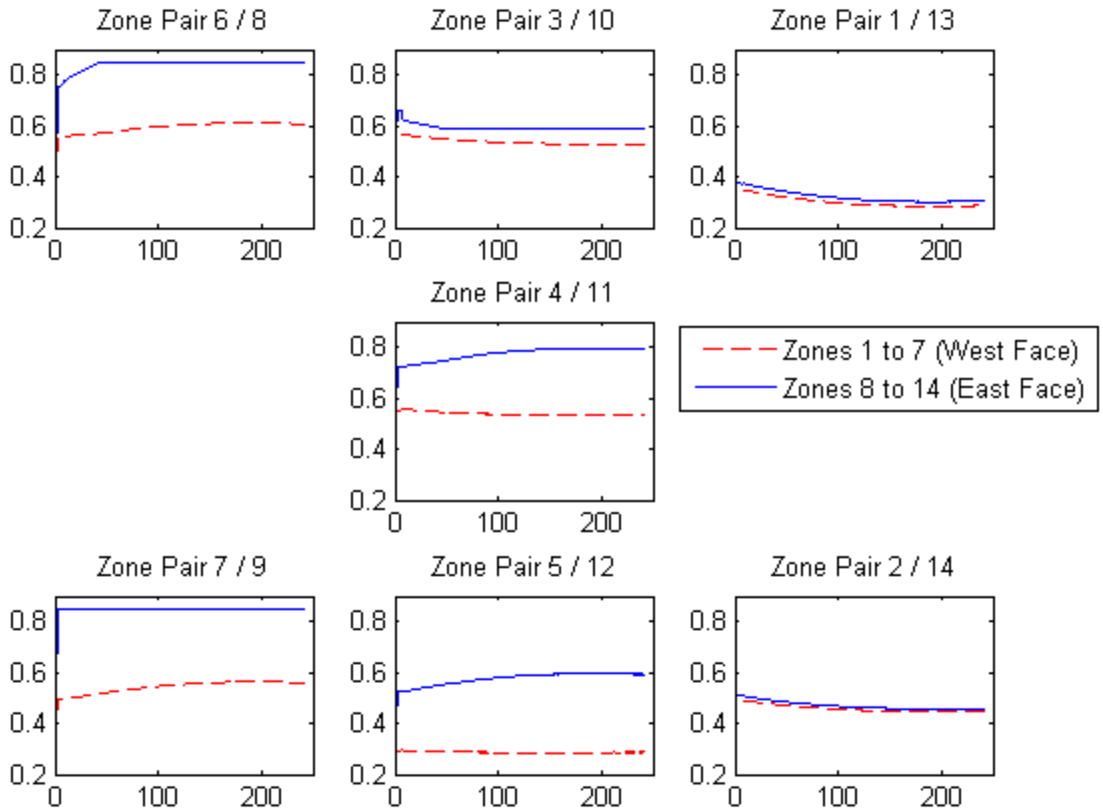

*Figure 4 – Zone Level vs. Time after Withdrawal of AA18 (minutes) (Time-Average Irradiations – RFSP module *TAVEQUIV)*

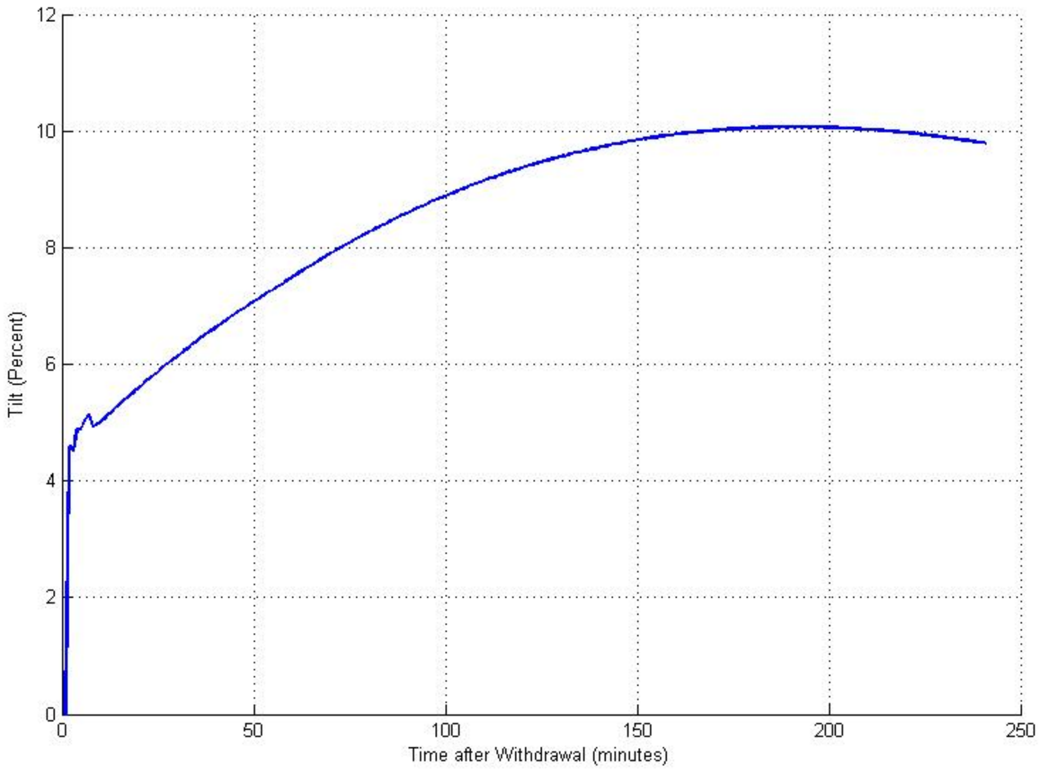

Figure 5 – Tilt vs. Time after Withdrawal of AA18 (SORO Irradiations)

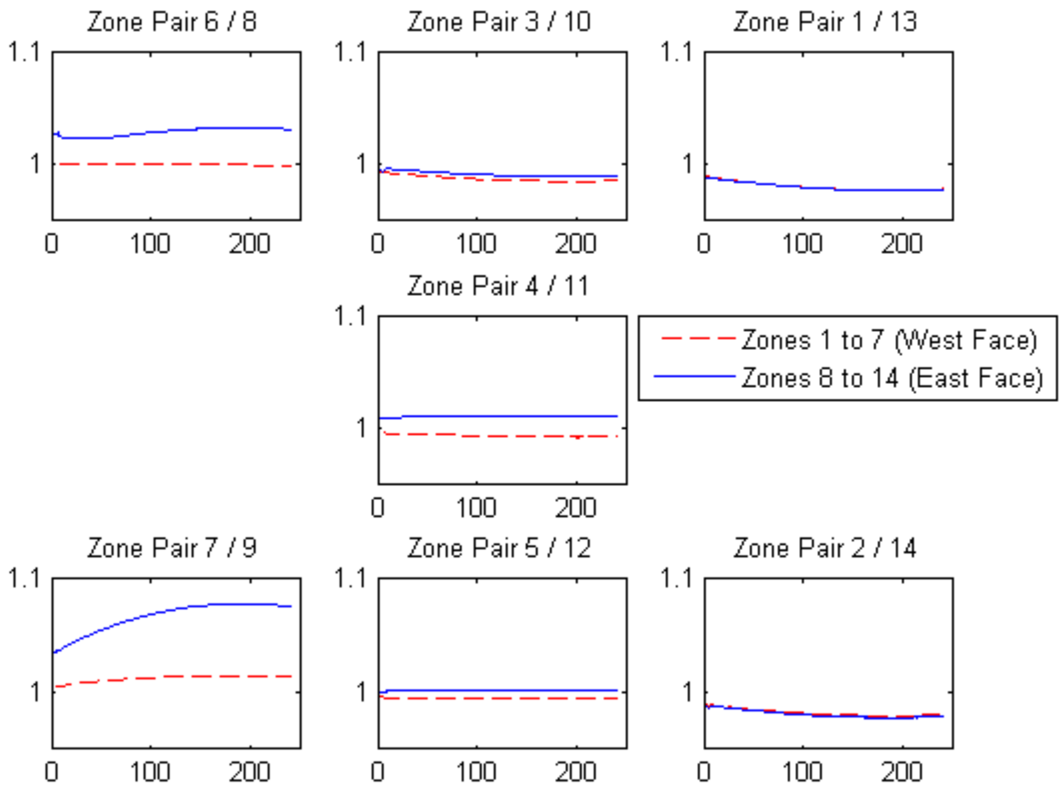

Figure 6 – Normalized Zone Power vs. Time after Withdrawal of AA18 (minutes) (SORO Irradiations)

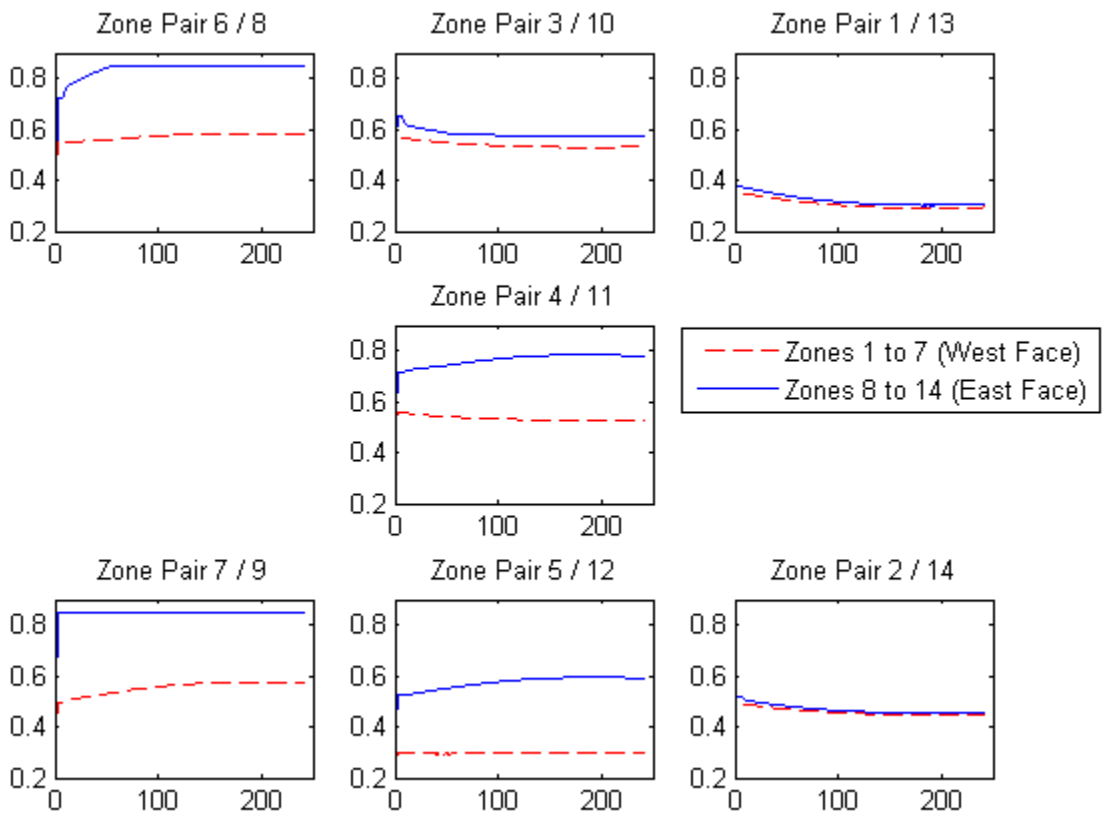

*Figure 7 – Zone Level vs. Time after Withdrawal of AA18 (minutes) (SORO Irradiations – RFSP module *SIMULATE)*

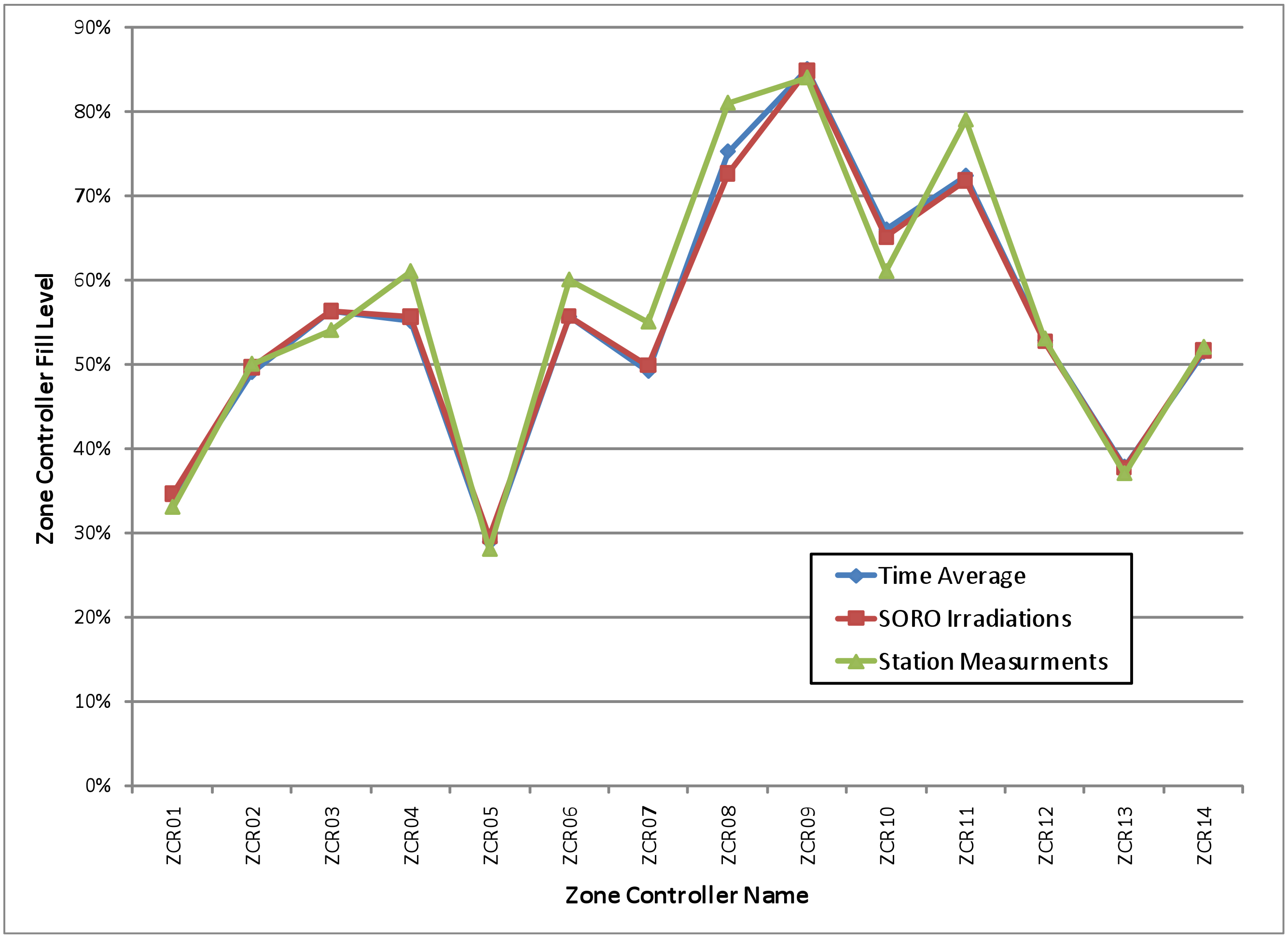

Figure 8 - Comparison of Predicted and Measured Zone Controller Levels just after AA18 Withdrawal

Minimum: -0.60, Maximum: 0.50

	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								-0.30	-0.30	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.10	-0.10							
B						-0.30	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20	-0.10	-0.10	-0.10	-0.10					
C					-0.20	-0.20	-0.20	-0.20	-0.30	-0.30	-0.20	-0.10	-0.10	-0.10	-0.20	-0.20	-0.10	-0.10	0.00	0.00				
D				-0.20	-0.30	-0.30	-0.20	-0.20	-0.30	-0.20	-0.20	-0.20	-0.10	-0.10	-0.10	-0.20	-0.10	0.00	0.00	0.00	0.00			
E			-0.30	-0.30	-0.20	-0.20	-0.30	-0.30	-0.30	-0.30	-0.20	-0.20	-0.10	-0.20	-0.20	-0.10	-0.10	0.00	0.00	0.00	0.00	0.00		
F		-0.30	-0.30	-0.20	-0.30	-0.30	-0.30	-0.40	-0.30	-0.30	-0.30	-0.20	-0.10	-0.10	-0.10	-0.10	-0.10	0.00	0.10	0.10	0.10	0.10	0.00	
G		-0.20	-0.20	-0.30	-0.30	-0.30	-0.30	-0.40	-0.40	-0.30	-0.30	-0.20	-0.20	-0.10	-0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.10	0.20	
H		-0.20	-0.20	-0.30	-0.30	-0.40	-0.50	-0.50	-0.40	-0.30	-0.30	-0.20	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.20	0.20	0.10	0.10	
J	-0.20	-0.20	-0.20	-0.30	-0.30	-0.50	-0.50	-0.60	-0.40	-0.30	-0.20	-0.10	-0.10	0.00	0.00	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20	0.20
K	-0.20	-0.20	-0.20	-0.20	-0.30	-0.40	-0.60	-0.50	-0.60	-0.30	-0.10	0.00	0.00	0.00	0.10	0.10	0.20	0.20	0.30	0.20	0.20	0.20	0.30	0.20
L	-0.10	-0.10	-0.20	-0.20	-0.30	-0.40	-0.30	-0.40	-0.30	-0.20	-0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.30	0.20	0.30	0.30	0.30	0.20	0.30
M	-0.10	-0.10	-0.20	-0.20	-0.20	-0.20	-0.30	-0.30	-0.20	-0.10	0.00	0.20	0.20	0.20	0.20	0.20	0.10	0.20	0.30	0.30	0.30	0.30	0.30	0.20
N	-0.10	-0.10	-0.10	-0.20	-0.10	-0.10	-0.10	-0.10	-0.10	0.00	0.10	0.10	0.20	0.30	0.20	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
O	0.00	0.00	-0.10	0.00	0.00	0.00	-0.10	0.10	0.10	0.10	0.20	0.10	0.20	0.30	0.20	0.20	0.20	0.30	0.40	0.30	0.30	0.30	0.30	0.30
P	-0.10	-0.10	0.00	0.00	0.00	0.10	0.00	0.20	0.20	0.20	0.20	0.10	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.40	0.30	0.30	0.30	0.30
Q	0.00	0.00	0.00	0.10	0.20	0.20	0.20	0.40	0.20	0.20	0.20	0.10	0.20	0.20	0.30	0.30	0.40	0.30	0.30	0.30	0.30	0.30	0.20	0.30
R		0.10	0.10	0.10	0.20	0.30	0.40	0.30	0.30	0.20	0.20	0.10	0.20	0.10	0.10	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	
S		0.10	0.10	0.20	0.20	0.30	0.40	0.50	0.30	0.20	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.20	0.20	
T		0.10	0.20	0.30	0.30	0.40	0.40	0.40	0.30	0.20	0.20	0.00	-0.20	0.10	0.10	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
U			0.20	0.30	0.30	0.30	0.40	0.30	0.20	0.30	0.20	0.10	-0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20		
V				0.30	0.30	0.40	0.30	0.30	0.20	0.20	0.10	0.10	0.00	0.10	0.00	0.10	0.10	0.10	0.10	0.20	0.20			
W					0.30	0.30	0.30	0.20	0.20	0.20	0.10	0.00	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.10				
X						0.30	0.40	0.30	0.20	0.20	0.20	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.10					
Y								0.20	0.20	0.20	0.20	0.20	0.10	0.20	0.10	0.20	0.10							

Figure 9 – Difference in COP Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control off Zone levels as before and after AA18 Withdrawal (Case #1)

Minimum: -0.40, Maximum: 0.50

	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								0.10	0.10	0.20	0.10	0.00	0.00	0.10	0.00	0.00	0.00							
B						0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	-0.10					
C					0.20	0.30	0.30	0.20	0.20	0.20	0.10	0.20	0.20	0.10	0.00	0.00	0.00	-0.10	0.00	0.00				
D				0.20	0.30	0.30	0.30	0.20	0.20	0.10	0.20	0.20	0.20	0.20	0.10	0.00	0.10	0.00	0.00	0.00	0.00			
E			0.10	0.20	0.30	0.50	0.40	0.20	0.10	0.20	0.20	0.40	0.40	0.10	0.00	0.10	0.00	0.00	0.00	0.00	-0.10	0.00		
F		0.00	0.10	0.20	0.30	0.40	0.50	0.20	0.10	0.10	0.10	0.20	0.20	0.10	0.10	0.00	0.10	0.00	0.00	0.00	-0.10	-0.10	-0.10	
G		0.00	0.10	0.00	0.10	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.00	0.00	-0.10	-0.10	
H		0.00	0.00	0.00	0.10	0.10	0.00	-0.20	-0.20	-0.10	-0.10	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.20	0.10	0.00	-0.10	-0.10	
J	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.20	-0.30	-0.30	-0.20	-0.20	0.00	-0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	-0.10	-0.10	-0.20
K	-0.10	-0.10	-0.10	-0.20	-0.20	-0.30	-0.40	-0.40	-0.40	-0.20	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	-0.10	-0.10	-0.10	-0.10
L	-0.20	-0.20	-0.20	-0.20	-0.30	-0.20	-0.30	-0.30	-0.20	-0.20	-0.10	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.10	-0.20	-0.10
M	-0.20	-0.20	-0.20	-0.10	-0.20	-0.10	-0.10	-0.20	-0.20	-0.10	0.00	0.20	0.20	0.10	0.00	0.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.20	-0.20	-0.10
N	-0.20	-0.20	-0.20	-0.10	0.00	0.00	0.00	0.00	-0.10	0.00	0.10	0.10	0.20	0.10	0.00	0.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.20	-0.20	-0.10
O	-0.20	-0.10	-0.10	-0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.10	-0.10	-0.20	-0.20	-0.10
P	-0.20	-0.20	-0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.10	-0.20	-0.10
Q	-0.20	-0.20	-0.10	0.00	0.00	0.00	0.10	0.20	0.20	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	-0.10	-0.10	-0.20	-0.10
R		-0.10	-0.10	-0.10	0.10	0.10	0.10	0.20	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	-0.10	-0.10	-0.20	
S		-0.10	0.00	-0.10	0.00	0.10	0.20	0.20	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.10	0.00	-0.10	-0.10	-0.20	
T		-0.10	-0.10	0.00	0.00	0.10	0.20	0.20	0.10	0.00	0.10	0.00	0.10	0.10	0.00	0.00	-0.10	0.00	0.00	-0.10	-0.10	-0.10	-0.20	
U			0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00	-0.10	0.00	-0.10	-0.10	-0.20		
V				0.00	0.10	0.10	0.00	0.10	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.20	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10			
W					0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.20	-0.20				
X						0.00	0.00	0.00	-0.10	0.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.20	-0.10	-0.10	-0.20					
Y								0.00	0.00	0.00	-0.10	-0.10	-0.20	-0.20	-0.10	-0.20	-0.20							

Figure 10 – Difference in COP Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control on Zones start at 42% (Case #2)

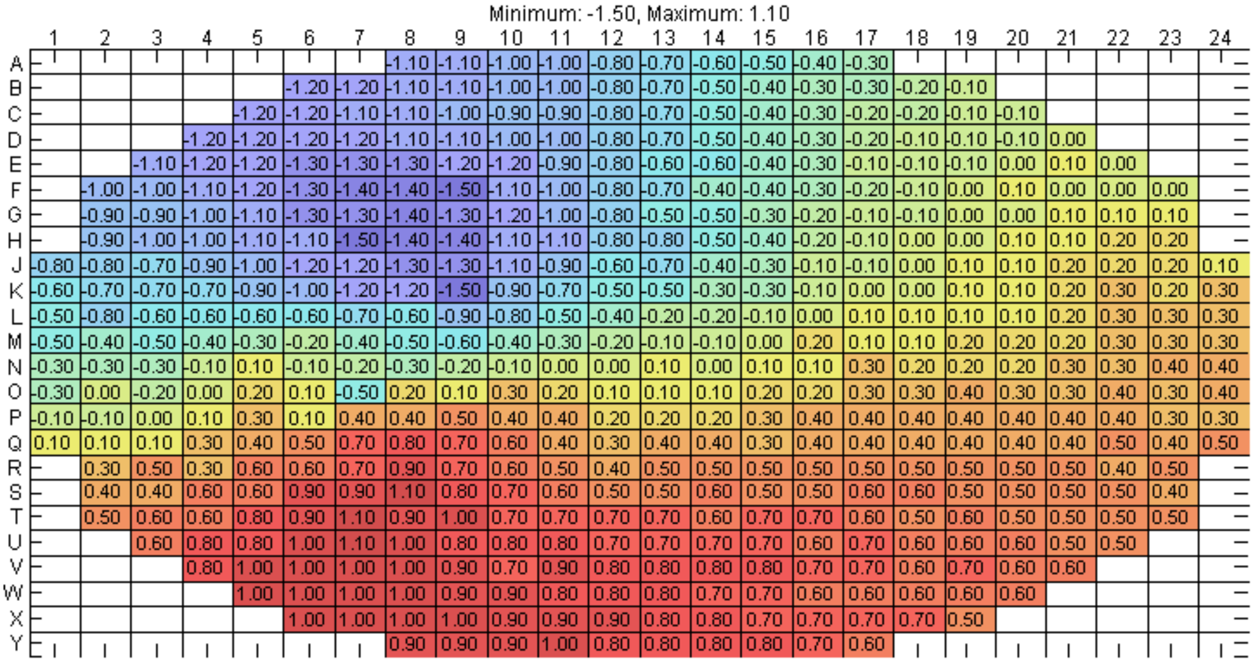

Figure 11 – Difference in COP Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control off Zones 42% (Case #3)

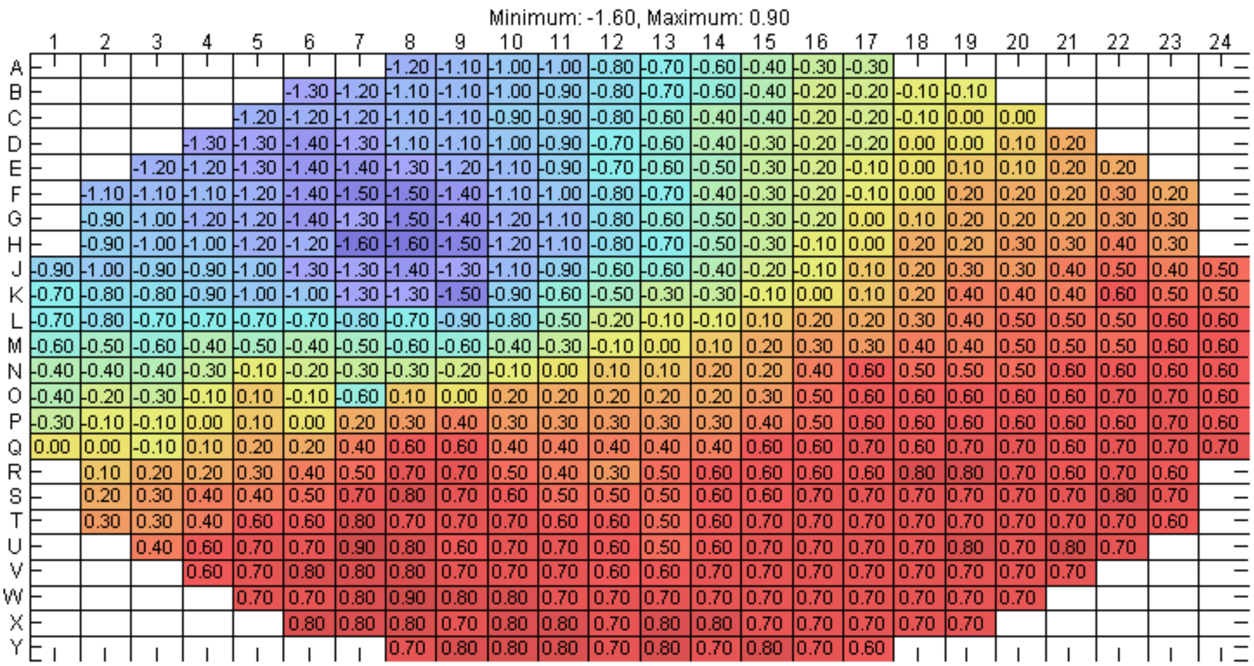

Figure 12 – Difference in COP Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) Bulk and Spatial Control off Zones at pre event levels (Case #4)

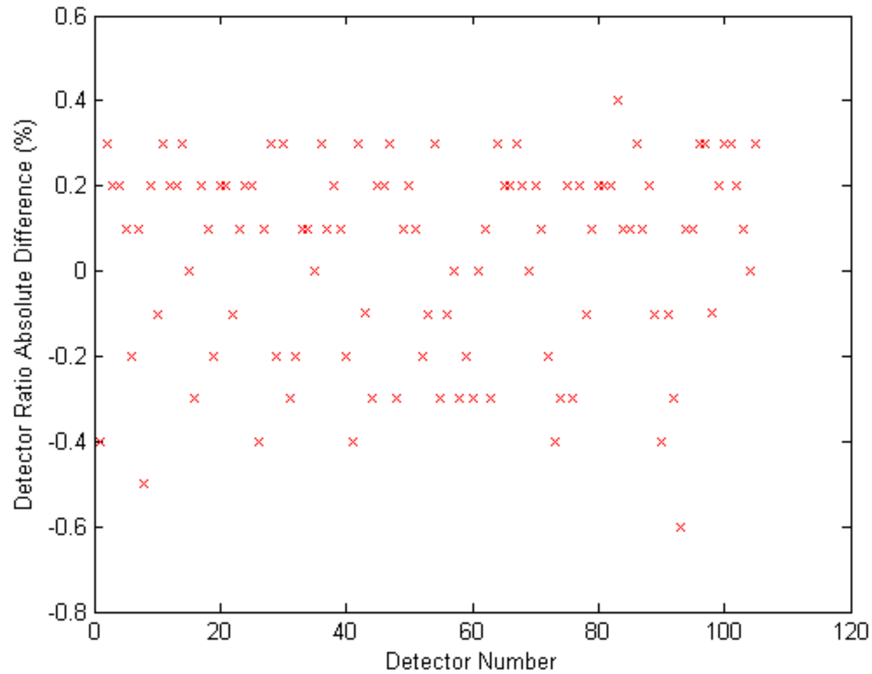

Figure 13 – Difference in Detector Ratios Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control off Zone levels as before and after AA18 Withdrawal (Case #1)

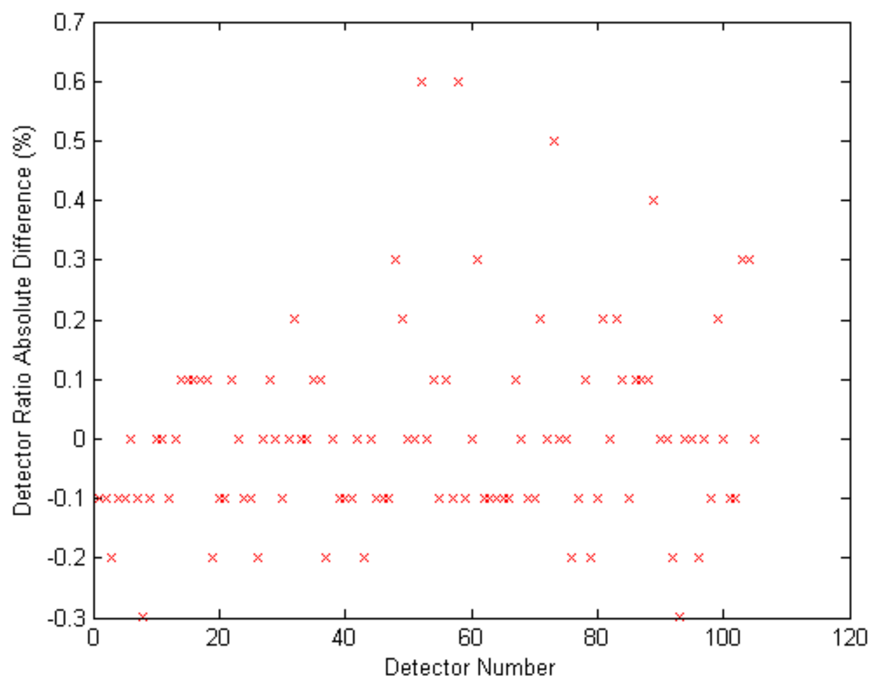

Figure 14 – Difference in Detector Ratios Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control on Zones start at 42% (Case #2)

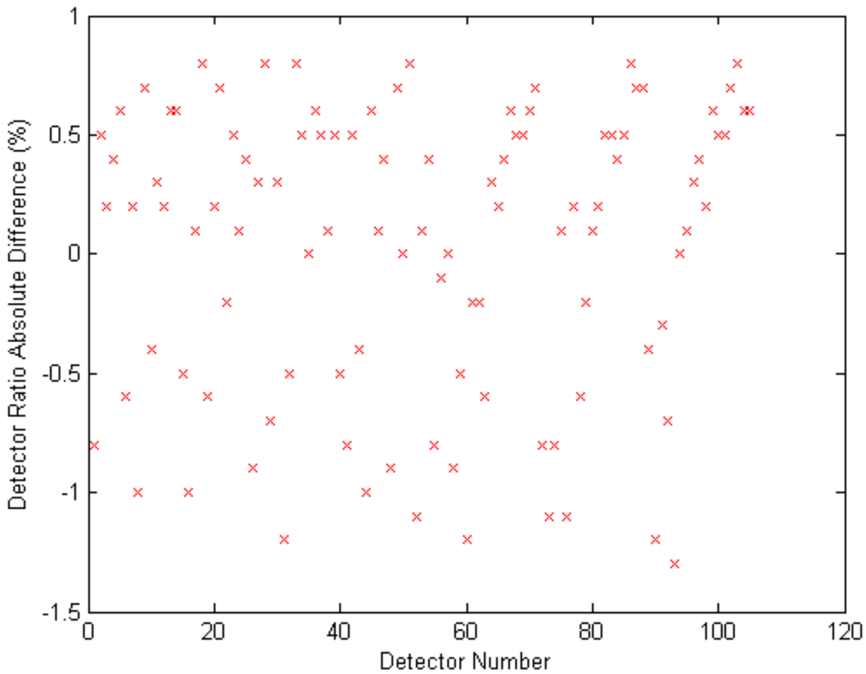

Figure 15 – Difference in Detector Ratios Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control off Zones 42% (Case #3)

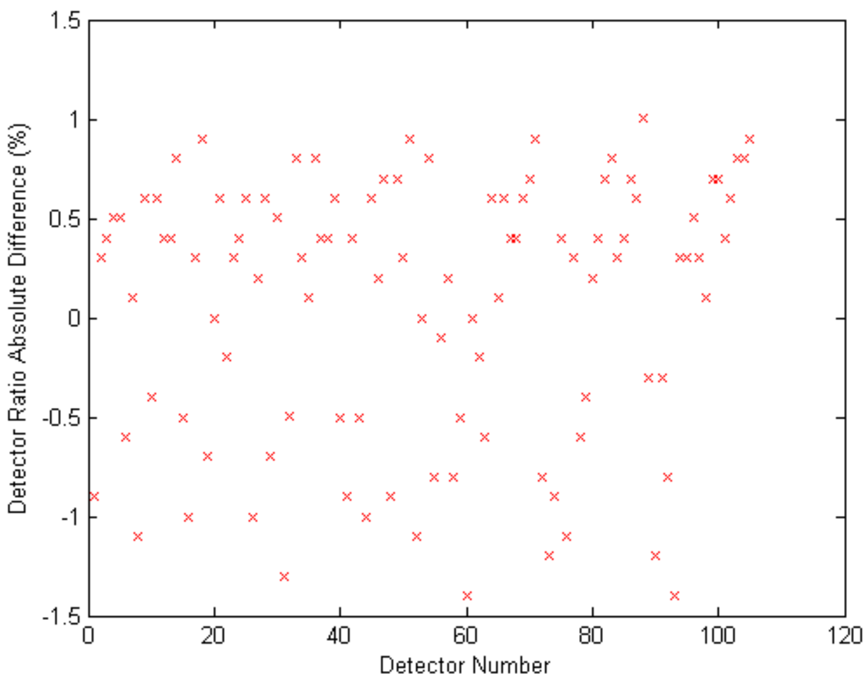

Figure 16 – Difference in Detector Ratios Expressed as Percent (SORO Irradiations minus Time-Average Irradiations) – Bulk and Spatial Control off Zones at pre event levels (Case #4)