PRE-SIMULATIONS OF REACTIVITY DEVICE MANOEUVRES AT DARLINGTON WITH RFSP AND RRS EMULATOR

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Abstract

Reactivity device manoeuvres were completed at 30%FP reactor power, on May 18th 2012, during startup after a 2012 long outage. The main objective of these tests was to confirm that the new SDS1 and SDS2 NOP detectors were positioned at the correct locations in the reactor. Reactor physics pre-simulations were executed using a combination of the stand-alone RFSP code and the coupled RFSP/RRS Emulator code suite. The intent of these simulations was to calculate the response of the NOP detectors signals and predict the impact of the reactivity device manoeuvres on operational metrics, such as flux tilt, in order to ensure that these metrics are within acceptable operational limits. Good agreement was found between measurements and the pre-simulations.

1. Introduction

An important factor affecting the accuracy of predicting the impact of reactivity device manoeuvres on in-core detector signals and on operational parameters is the dynamic response of the Reactor Regulating System (RRS). In the reactor physics pre-simulations (completed in advance of the device manoeuvres), the dynamic RRS response was implemented in the model using the RFSP [1] and RRS Emulator (RRS_Em) codes, with the coupling between the two codes facilitated using the PhysicsShell software [2]. The pre-simulations also accounted for the fission-product transient during the unit startup, which was modelled using stand-alone RFSP simulations.

The results of the pre-simulations were used in support of the review of the operational procedure for the manoeuvres to ensure that the operational parameters, such as flux tilt, would be within the acceptable operational limits during the manoeuvres.

2. Methodology Used in Pre-simulations

2.1 Description of computer programs

RFSP is a computer program used in simulations of reactor physics phenomena in safety analysis and operational support of CANDU reactors. Its main function is to calculate neutron-flux and power distributions using two-group, three-dimensional neutron diffusion theory.

RRS Emulator (RRS_Em) is a computer code for the simulation of RRS response. The RRS_Em uses RFSP predictions of the RRS detector signals and channel powers to perform the bulk and spatial control functions of the RRS, as well as the thermal power calibration. The input of the RRS_Em is configurable to simulate the station-specific response of the reactor power setpoint routine, bulk and differential Liquid Zone Controller (LZC) control valve lift calculations, and power calibration. The dynamic response of the RRS detector signals and channel powers is calculated using the *CERBERUS, *INTREP, and *DISPLAY modules of RFSP. The RRS response computed by the RRS_Em is reflected as a change in the reactivity device configuration in the next simulation time step. The RFSP and RRS_Em were run in a coupled configuration using the PhysicsShell software.

2.2 Manoeuvres performed

During the test, the following adjusters (AA) and LZCs were manoeuvred in sequence:

- AA #10
- AA #12
- AA #15
- AA #22
- LZC #1
- LZC #2
- LZC #3
- LZC #7
- LZC #12
- LZC #14

The adjuster manoeuvres were performed by withdrawing single rods from the fully-inserted to fully-withdrawn position at the maximum design speed, holding the rods in the fully withdrawn position for several minutes prior to reinsertion.

The LZC manoeuvres were performed by placing the LZC control valves of single LZCs on manual control. The valve lift relative to the valve lift bias was set to a small positive or negative value to respectively fill or drain the LZC, with manoeuvre consisting of the following steps:

- initial fill to a high level (87% in the simulations)
- hold at the high level for several minutes (5 minutes in the simulations)
- drain to a low level (13% in the simulations)
- hold at the low level for several minutes (5 minutes in the simulations)
- return the LZC to the automatic valve lift control, which results in a graduate return near the pre-manoeuvre level.

2.3 Fission-product transient

The fission-product transient following the reactor startup was simulated using the *SIMULATE module of RFSP. The simulation included a shutdown for 45 days, followed by the startup with critical gadolinium concentration in the core. The startup transient included the anticipated interim power holds represented in the model by maintaining power at 3% FP for 12 hours and at 15% FP for 4 hours before raising it to 30% FP. Bulk control was enabled in all simulation steps and spatial control was enabled at powers of 15% FP and above.

To account for the potential variations in the fission-product concentrations during the tests, the manoeuvres listed in Section 2.2 were simulated sequentially, starting at 4 hours and 8 hours after reaching 30% FP, with bulk and spatial control enabled in all simulation steps. To compensate for the buildup of xenon and the change in the concentration of other fission products, moderator gadolinium concentration was adjusted so as to ensure an Average Zone Level (AZL) of 40% prior to each manoeuvre. During this stage of the simulations, initial states were prepared for the RFSP/RRS_Em Emulator (RRS_Em) simulations of each manoeuvre.

2.4 Dynamic RFSP/RRS_Em simulations

The dynamic RFSP/RRS_Em simulations assumed the fission-product conditions and moderator gadolinium concentrations determined for each manoeuvre in the stand-alone RFSP simulations discussed in Section 2.3. The neutronic calculations were performed using the *CERBERUS module of RFSP, with the LZC levels computed by the RRS_Em using predictions of the RRS detector signals as input. The simulation time step was 0.5 second, consistent with the RRS Fast Cycle. The dynamic response of the RRS and NOP detectors, accounting for the delayed response components of the in-core detectors, amplifier time constants, and fixed delays, was modelled using the *INTREP module of RFSP. The RRS_Em also simulated the effects of thermal power calibration on the RRS detector signals, using RFSP predictions of Fully-Instrumented Channel (FINCH) powers output using the *DISPLAY module of RFSP.

Because *CERBERUS in the RFSP versions currently qualified for operational and safety analysis does not simulate transient changes in the fission product concentrations, the fission product levels were assumed constant for the duration of each device manoeuvre and equal to the fission product concentrations at the beginning of the manoeuvre as calculated by *SIMULATE (Section 2.3).

3. Measurements

The reactivity device manoeuvres were completed at 30%FP reactor power, on May 18th 2012, during startup after the 2012 long outage. The objective of the manoeuvres was to confirm that the 14 newly installed SDS1 and SDS2 NOP detectors responded as expected and were positioned at the correct locations in the reactor. This was in addition to the SDS1 rundown test at low power, performed to confirm the dynamic behaviour of new detectors.

As mentioned above, two sets of pre-simulations had been completed, assuming 4 hours and 8 hours at 30% FP before the test. In practice, the test commenced 10 hours after raising power to 30% FP, i.e. the actual fission-product concentrations during the test were slightly different than simulated. Given that the differences between the simulation results assuming 4 and 8 hours of operation at 30% FP were small, the impact of the discrepancy in the assumed timing of the test on the differences between the simulations and the measurements is also small.

The zone level distribution prior to the first manoeuvre is presented in Figure 1. Note that small level tilts existed in steady state.

4. Comparisons Between Measurement and Simulation

4.1 Adjuster Rod Manoeuvres

Sample measured values are presented in Figure 2 (new zone level distribution with AA10 out of core) and Figure 3 (response of the new detector VFD12-RE2E). Figure 4 presents the simulated and the measured flux tilt for the same rod manoeuvre. Compared to the pre-simulations, the measurements show a small non-zero flux tilt. Note that pre-simulations were not performed for adjuster rod re-insertion and that all simulated detector signals were multiplied by the Channel Power Peaking Factor (CPPF) in effect at that time.

Detector position was confirmed through sufficient response to the movement of a device in its proximity. Furthermore, in all cases the detector responses "followed" the expected profiles determined through simulation. Figure 5 and Figure 6 provide two other detector responses to a different rod withdrawal – AA 12. The latter figure illustrates the effect of the RRS response on the detector signal, where some detector signals temporarily *decrease* following the adjuster withdrawal as the LZC levels change in response. Both figures show close agreement in both the direction and the timing of the change in the detector signal between the measurements and the pre-simulations, with the observed detector response being slightly lower than simulated.

4.2 Zone Level Manoeuvres

Detector response to the entire zone 3 manoeuvre is presented in **Figure 7** and the zone level distribution when Zone 3 was drained is presented in Figure 8. Again, detector position was confirmed through sufficient response to zone level changes. Furthermore, the detector responses "followed" the expected profiles determined through simulation and the changes in detector signals matched simulated values.

The flux tilts increased to higher values during zone manoeuvres than during AA manoeuvres, but it was well below the values considered safe to continue. Figure 9 and Figure 10 present the pre-simulated and measured flux tilts for the entire Zone 3 level manoeuvre. When the pre-existing flux tilt is considered, it appears that the prediction was very close to measured flux tilts, since the increase in the maximum tilt above the pre-existing baseline is very similar between the measurements and the simulations.

5. Conclusion

Taking into account the dynamic RRS response in pre-simulation of reactivity device manoeuvres, the transient response of the flux detectors signals can be modelled. The predictions can be used effectively to ensure that the operational metrics remain within acceptable operational limits during the manoeuvres. The dynamic RFSP/RRS_Em simulations of the reactivity device manoeuvres that took place on May 18th, 2012 show good agreement between the simulations and the station measurements, also demonstrating the capability of RRS_Em for operational analysis.

6. 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] J. Szymandera, L. Blake, B.G. Phan, O. Nainer, "PhysicsShell: A Solution to Multi-Code Linking", Proceedings of the 23rd CNS Nuclear Simulation Symposium, Ottawa, Ontario, Canada, 2008 November 2-4.

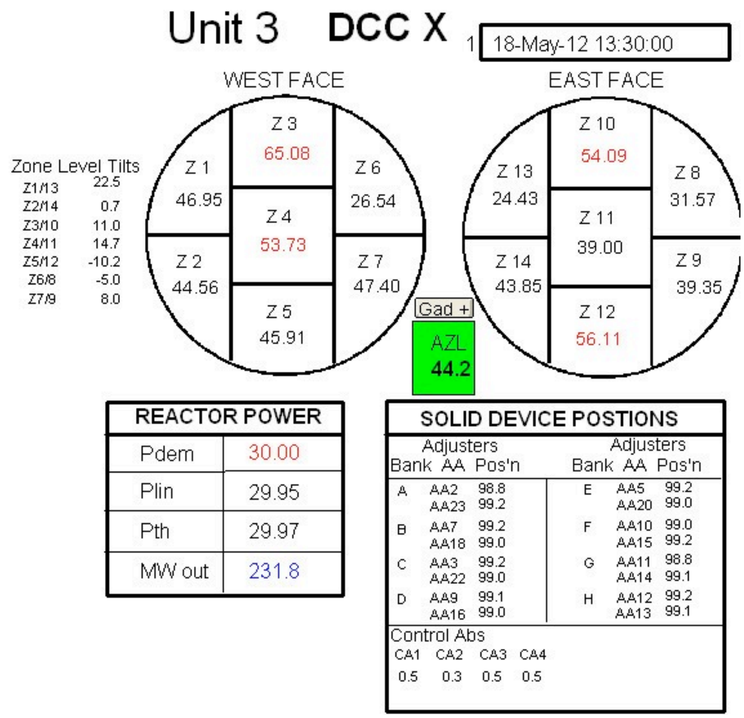

Figure 1 Zone levels before the device manoeuvres

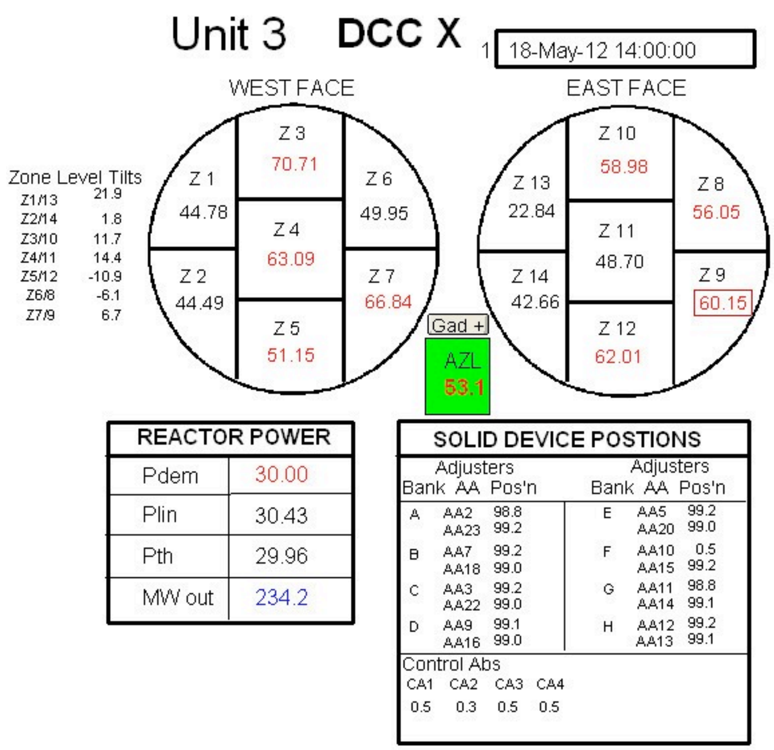

Figure 2 Zone levels with AA# 10 out

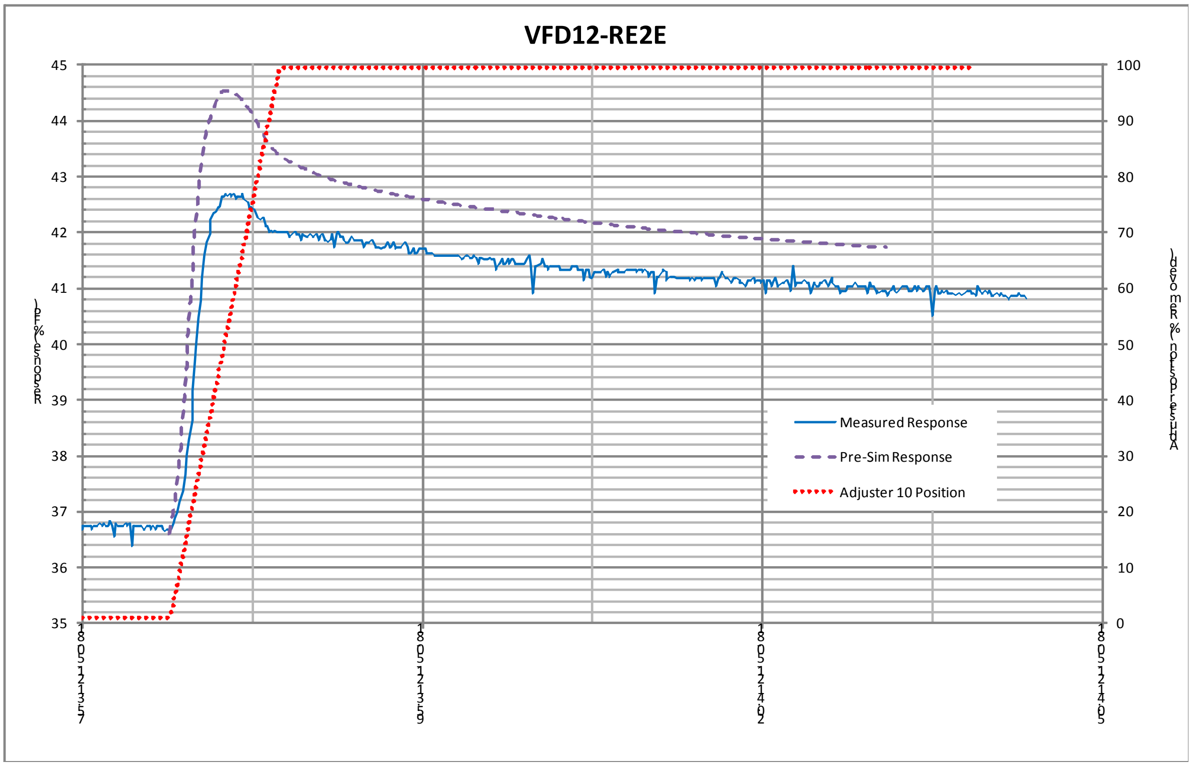

Figure 3 Response of detector VFD12-RE2E to withdrawal of AA10

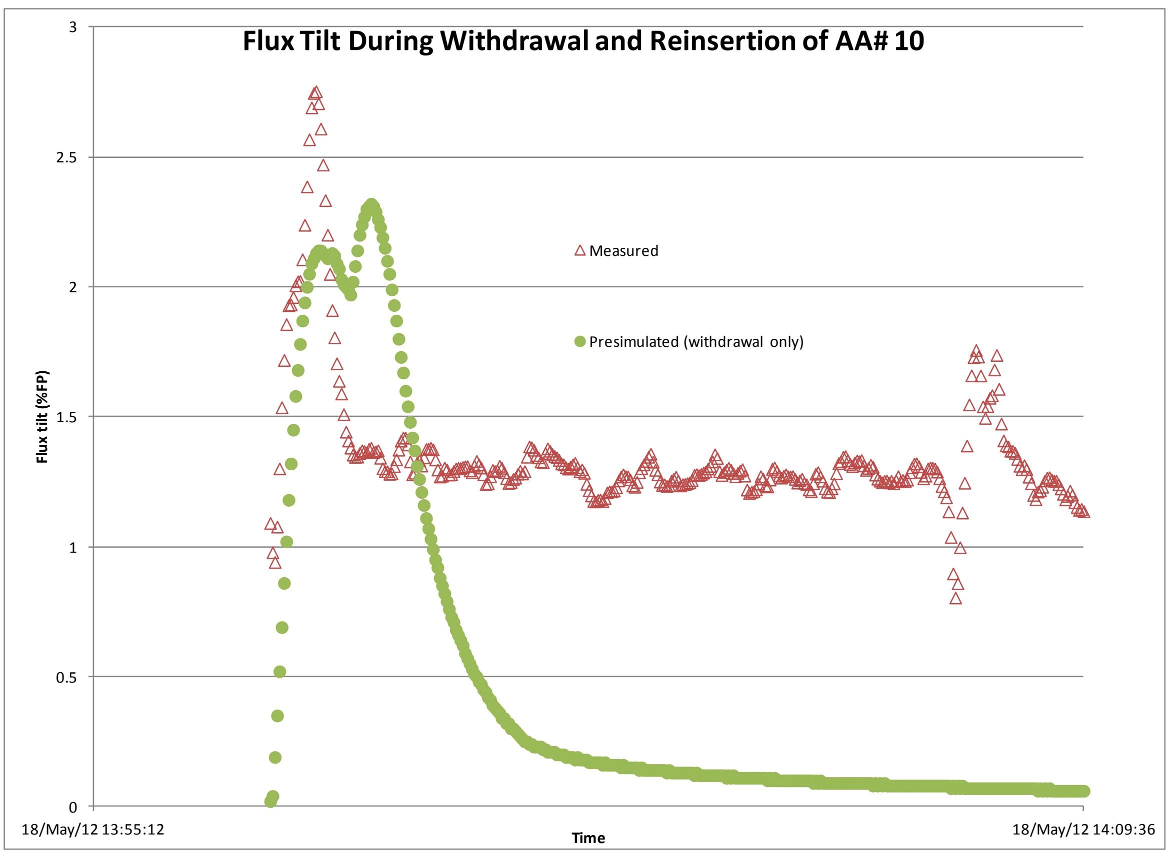

Figure 4 Flux tilt during the AA10 manoeuvre

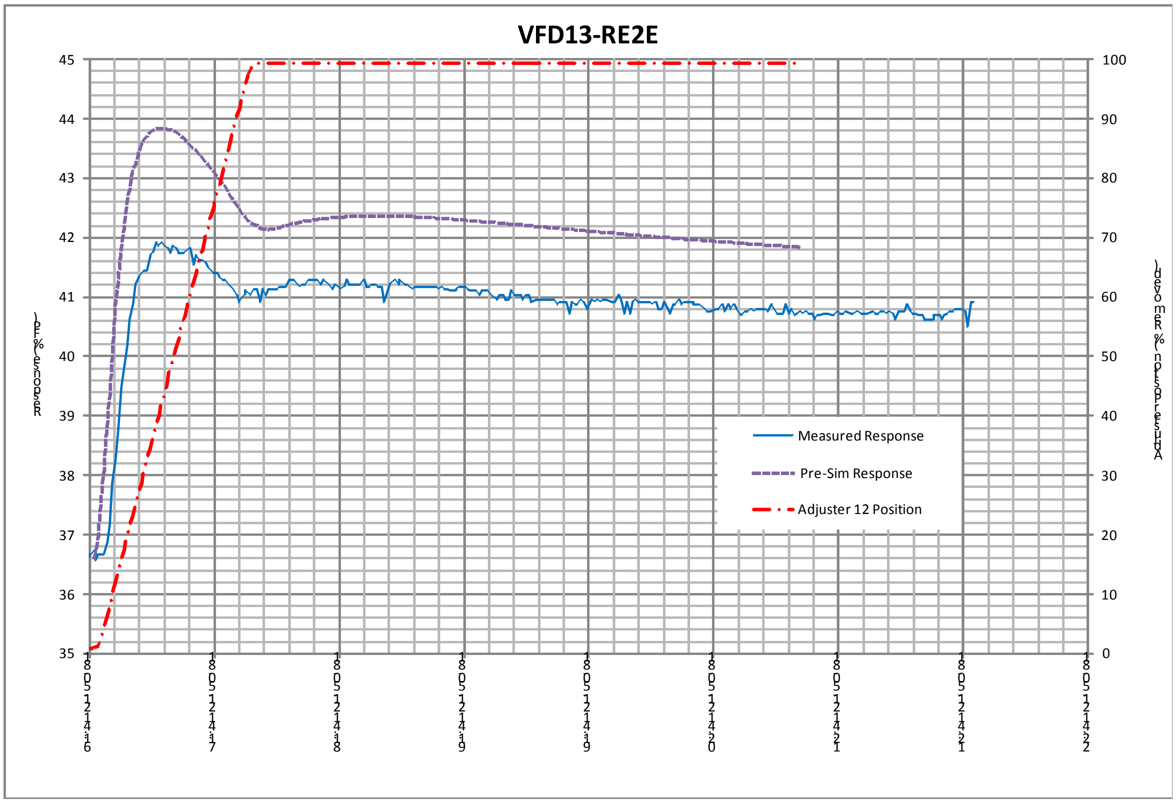

Figure 5 Response of detector VFD13-RE2E to withdrawal of AA12

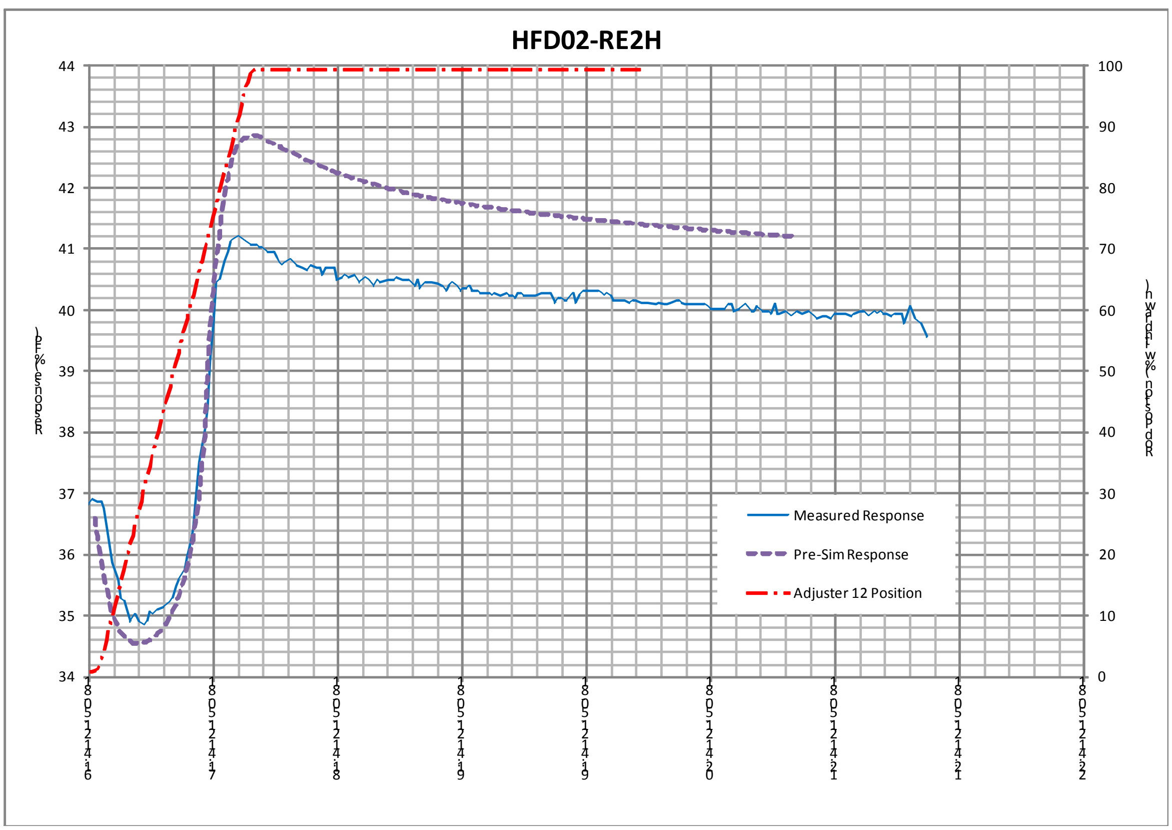

Figure 6 Response of detector HFD02-RE2H to withdrawal of AA12

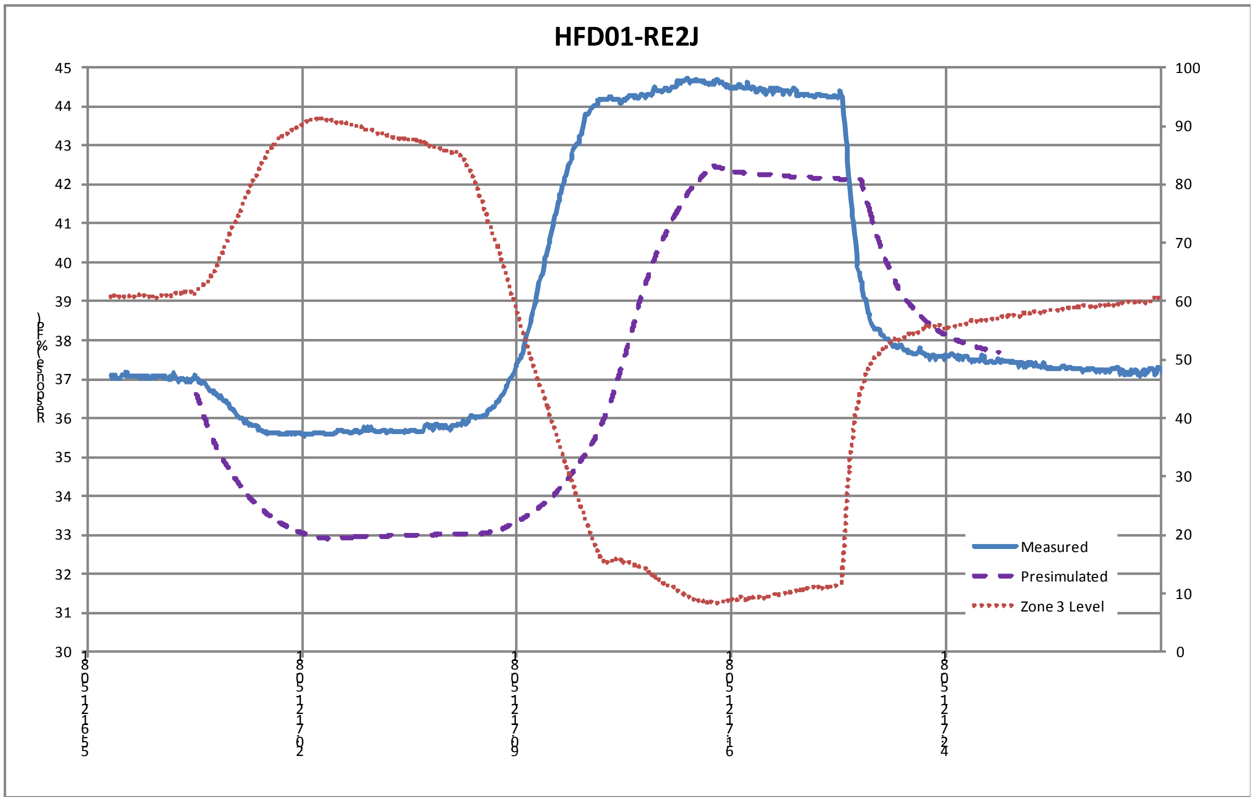

Figure 7 Detector response to Zone 3 drain from 90% to 10%

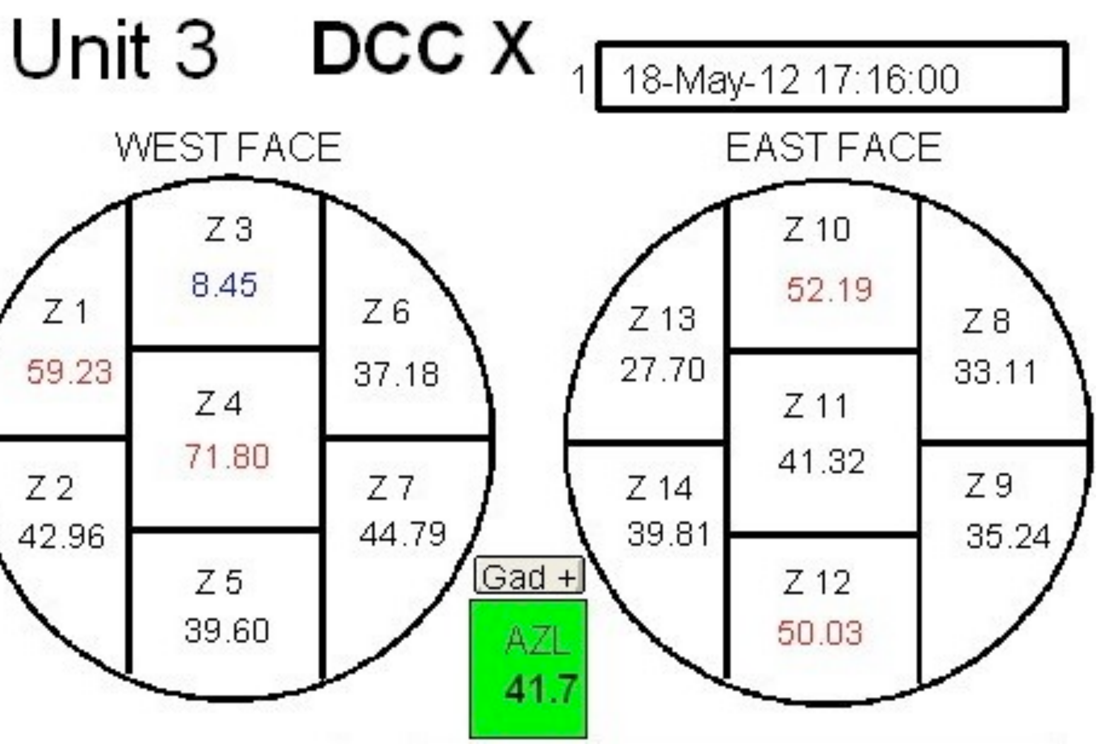

Figure 8 Zone levels with Zone 3 drained

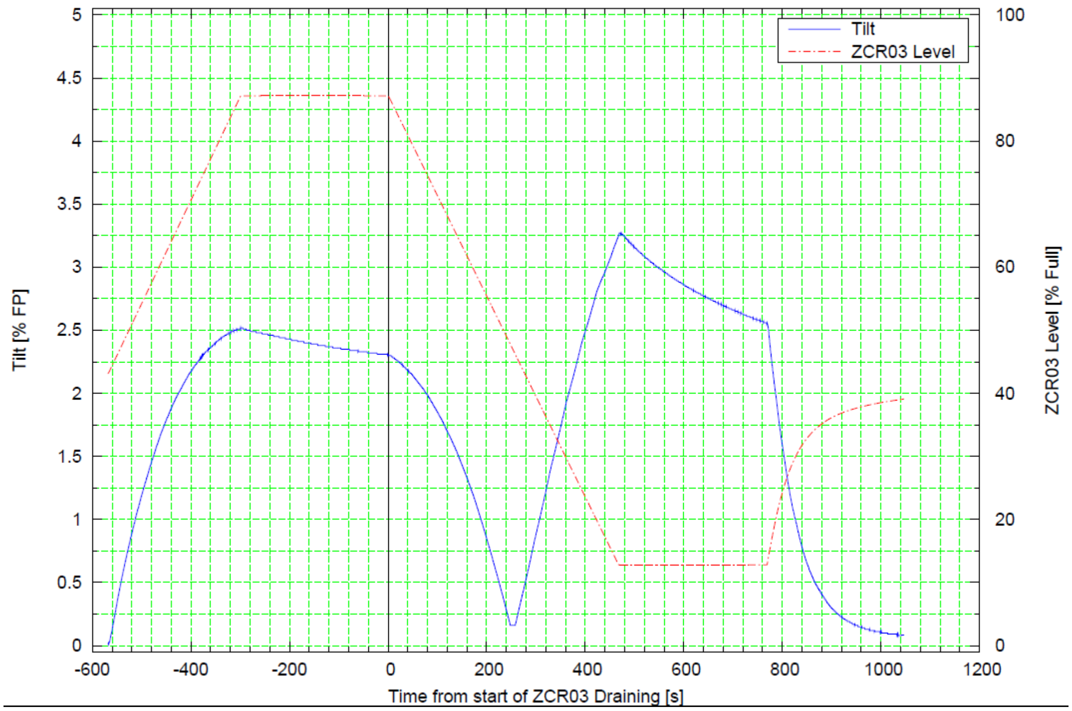

Figure 9 Pre-simulated flux tilt during Zone 3 level manoeuvre

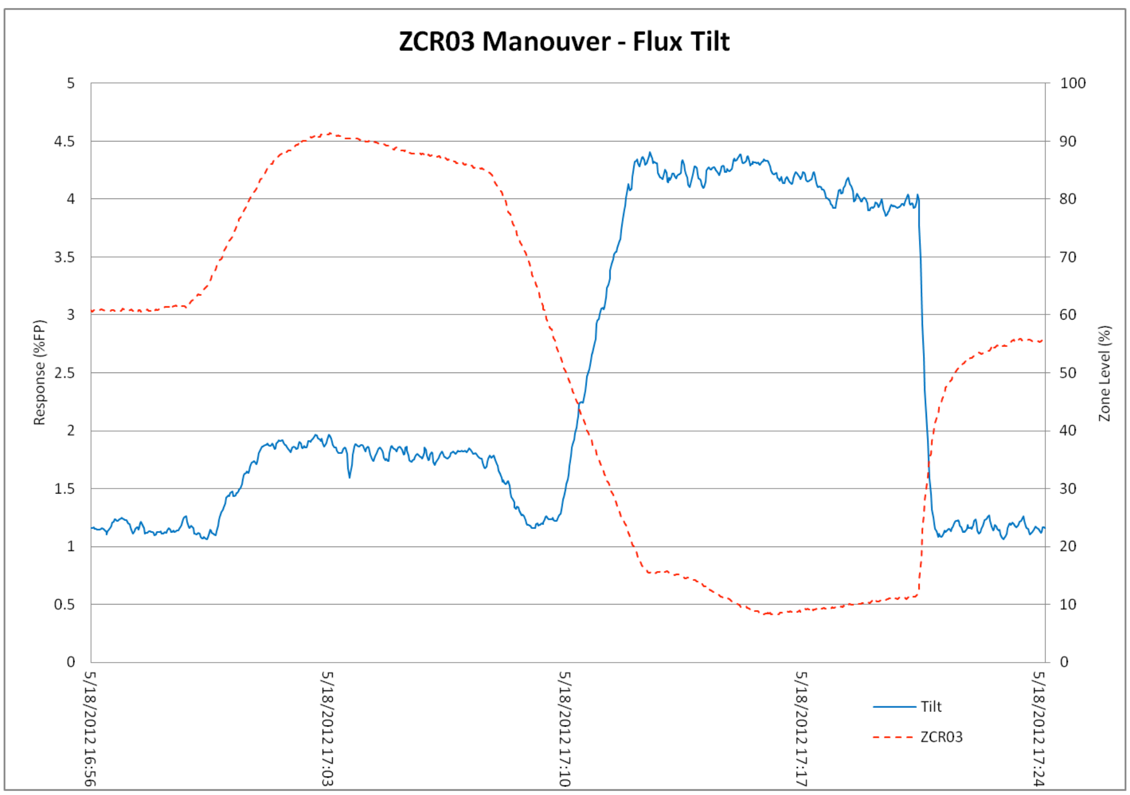

Figure 10 Measured flux tilt during zone 3 level manoeuvre