EXPERIENCE WITH WOLSONG-1 PHASE-B PRE-SIMULATIONS USING WIMS/DRAGON/RFSP-IST CODE SUITE

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Abstract

The Wolsong-1 Phase-B pre-simulations have been carried out with the exclusive use of the code suite WIMS/DRAGON/RFSP-IST in replacement of the previous PPV/MULTICELL/RFSP code system in preparation of tests to be conducted as scheduled in December 2010 after the refurbishment. A comprehensive simulation package has been undertaken starting from the approach to first criticality to the flux measurements and scan. In order to secure the validity of the results, the simulations are performed using both the Uniform and SCM fuel tables. An elaborating contribution has been invested into the work in view of the inexperience of using WIMS/SCM fuel tables as well as incremental cross sections generated by using DRAGON-IST. The overall assessment of simulation results indicates that the newly adopted WIMS/DRAGON/RFSP-IST code suite could be used in replacement of PPV/MULTICELL/RFSP for the verification against the Phase-B test results.

1. Introduction

The Wolsong NPP Unit 1 (Wolsong-1) is under a major refurbishment project which includes replacement of the pressure tube. In order to prepare the licensing submission for the restart of the reactor, the relevant safety analysis works have almost been completed, and the rest of the work required for the restart, such as, Phase-B pre-simulations are being currently wrapped up.

For Wolsong-1 reactor physics analyses, the simulations are performed using the newly adopted code suite WIMS/DRAGON/RFSP-IST (Refs. 1,2,3) in replacement of the previous PPV/MULTICELL/RFSP (Refs. 4-5) code system. Locally, the WIMS code was in use in the past as a stand-alone standard lattice code for PHWR related design and safety analysis studies. Thus, the use of WIMS/DRAGON/RFSP-IST for the entire lattice and core physics simulations in support of licensing, which includes the preparation of Physics Design Manual and LOCA transient simulations as well as physics test validations, could be considered as a new experience.

Although the use of WIMS/DRAGON/RFSP-IST is at the present time purposed for the licensing support, it is further intended to be used on routine production basis at site to support reactor operations, such as, fuel management and regular tests which include SDS1/2 power rundowns. In other words, the experience gained through the comprehensive pre-simulations of Phase-B tests and the interpretation of results so obtained will be beneficial to strengthen the safe and economic operation of Wolsong-1.

In the following, the summary of preliminary validation of the code suite against Wolsong-2 reactor operations will be briefly presented followed by the Phase-B pre-simulation results along with the

comparisons against the measurement data, wherever the data are available. Finally, the experience gained through the exercise of performing the pre-simulations will be summarized with some suggestions and conclusions.

2. Wolsong-1 Refurbished Fresh Core Model

The reactor physics model of Wolsong-1 refurbished core is set up using WIMS/DRAGON/RFSP-IST code suite. The WIMS-IST code produces the base data of lattice physics parameters that are further used to generate relevant reactor physics data, such as, the macroscopic fuel properties (Ref. 6), which are required by RFSP-IST to produce global flux and power distribution in the core. The presence and effects of various reactivity devices in the core are represented by the incremental cross sections that are calculated by using the WIMS-IST/T16MAC/DRAGON-IST code system (Ref. 7). All the incremental cross sections are calculated for the reference cold state that is defined in Section 3. As usual, 160 depleted uranium fuel bundles are loaded in the central 80 channels of the core, with 2 bundles at position 8 and 9 in each channel, respectively. For the modelling of adjuster rods the depletion of stainless steel compositions are accounted for.

3. Extent of Phase-B Pre-Simulations and Core Model

The pre-simulations consist of a) Approach to First Criticality, b) Calibration of Liquid Zone Control System (LZC), Adjuster Rods (ADJ), Mechanical Control Absorbers (MCA) and Shut-Off Rods (SOR), c) Shutdown System 1 and 2 Power Rundown Tests (SDS1/2 PR), d) Coolant and Moderator Temperature Reactivity Change Tests (CTRC/MTRC) and e) Flux Shape Measurements (FSM).

The base core model used has mesh intervals of 44x36x24. But, for SDS1 power rundown tests the mesh intervals of 44x36x34 are used with the additional mesh spacings in z-direction so that the shut-off rod boundaries can be exactly coincident with mesh lines when SORs are inserted into the core. Note that there was no need for the additional mesh spacings in x- and y-directions to accommodate the location of shut-off rod boundaries because x-direction mesh lines with 44 mesh spacings are already coincident with SOR boundaries in that direction and y-direction boundaries are travelling with time during rod drop.

The reactor power is assumed to be 10^{-4} FP for all cases except SDS1/2 power rundown and flux shape measurement simulations, for which 10^{-3} FP is applied. The relevant WIMS/RFSP-IST input parameters for the reference cold state are;

Power = 33.4902×10^{-4} W/g of Initial HE, Coolant Temp = 30°C, Fuel Temp = 30 °C, Moderator Temp = 35 °C, Fuel Density = 10.4919 g/cm^3, Avg. Fuel Wt. = 19.135 (kg U)/BND, Coolant Purity = 99.000 at%, Moderator Purity = 99.833 at%.

The critical boron and gadolinium concentrations are found to be 8.650 and 2.440 ppm, respectively.

4. Liquid Zone Controller

The liquid zone controller (LZC) reactivity worth is calculated for the reference cold condition. The LZC reactivity change with average zone level is determined with 5% fill increment, and the results

are fitted linearly and also using third order polynomial for the entire range between 0-100% fill as follows;

ρ (mk) = -0.0644x - 0.2332 : x=% fill

ρ (mk) = $2.4112x^3 - 1.5058x^2 - 7.1431x - 0.0021$: x=fractional fill

The reactivity change from empty to 100% fill is -6.272 and -6.267 mk for Uniform and SCM fuel tables, respectively. The Uniform fuel table is the one (Ref. 6) generated in conventional format that has been in use since even before the SCM methodology was introduced. The prediction of both fuel tables agree within a difference of 0.015 mk, and using the third order polynomial fit the LZC reactivity worth can be approximated within a relative accuracy of 0.02 mk for the entire range of LZC levels. It is to note that the LZC incremental cross sections are generated by replacing HE_2 with O_2 because HE_2 is not present in WIMS-IST nuclear data library (Ref. 8).

5. Boron and Gadolinium Reactivity Worth

The core boron reactivity worths are calculated at the reference cold condition for the concentration range between 7.0-10.0 ppm and are approximately found to be 7.73 mk/ppm with the loading of both depleted and undepleted ADJs. For the concentration range between 2.0-3.0 ppm, the gadolinium core reactivity worth is also calculated and its value is approximately 27.28 mk/ppm. The ratio of gadolinium to boron reactivity worth is ~3.53, and both reactivity worths change linearly for the given ranges, which are relevant for Phase-B test conditions.

It is to note that the boron reactivity worth is relatively lower compared to PPV calculated worths which were 8.31 and 8.29 mk/ppm for Wolsong-2 and Wolsong-3 Phase-B conditions, respectively. The difference between PPV and WIMS-IST based poison reactivity worth is to attribute to the different core conditions due to the loading of reactivity devices with different incremental cross section sets. Only boron is used as poison in the moderator for the entire simulations.

6. Model Verification

As mentioned already, the core simulation results using SCM fuel tables as well as DRAGON-IST generated incremental cross sections are briefly validated against the Wolsong-2 operating data of about one year period for the equilibrium core state. The ADJ incremental cross sections used are for the undepleted compositions. The flux modes used to synthesize fluxes and subsequently generate power map based upon the 102 vanadium detector readings are the currently in Wolsong-2 production RFSP Direct Access File stored PPV time-average simulation based one and half group matrices. The full two group mode matrices that are compatible with WIMS-IST full two group formalism based SCM fuel tables are not yet available. Thus, the PPV fuel table based one and half group mode matrices are simply transposed in two group format into RFSP-IST DAF with SCM fuel tables. This procedure can be expected to not accumulate unacceptable errors in prediction of power distribution compared to PPV/RFSP calculations due to the other source of flux/power mapping errors associated with the procedures, such as, the uncertainty of sensitivity factors of individual detectors, which might eventually overshadow the beneficial aspects of flux mapping methodology.

The results of the core tracking simulations are summarized in Table 1.

Table 1 Core Tracking Simulation Results of Wolsong-2
(Total Number of Flux States = 116)

Peak Max CP (MW)		Peak Max BP (kW)		Peak Max CPPF	
PPV RFSP	SCM RFSP-IST	PPV RFSP	SCM RFSP-IST	PPV RFSP	SCM RFSP-IST
6.967(G15)	6.981(Q12)	850.2(H06/6)	864.8(H06/6)	1.113(G05)	1.127(G05)
Avg Max CP (MW)		Avg Max BP (kW)		Avg Max CPPF	
6.840	6.867	822.0	834.5	1.077	1.083

The peak maximum channel and bundle powers as well as CPPF show 0.2%, 1.7% and 1.3% larger values, respectively, for SCM/RFSP-IST predictions compared to PPV/RFSP results. The PPV and SCM peak maximum CPs occur at the different flux states of about 10 FPD interval. From the results shown in Table 1, it can be judged that the difference between PPV/RFSP and SCM/RFSP-IST models is within an acceptable range.

7. Reactivity Device Worths

The result of simulations carried out to predict the reactivity worths of individual and bank ADJs as well as MCAs and individual SORs are presented here (see Table 2).

The comparisons are made by using the average worth of rods, absorbers and banks, both for measurements and predictions. The measured data are taken from Wolsong-2 Phase-B tests that were conducted in February, 1997. The pre-simulation results of both the Wolsong-2 old PPV/MULTICELL/RFSP model and the present Wolsong-1 WIMS/DRAGON/RFSP-IST model are used for the comparisons against the measurements. Note that the Wolsong-1 core model is loaded with only the undepleted ADJs for comparison purposes. The W-1 pre-simulations are carried out by using both Uniform and SCM fuel tables, and it turned out that both fuel tables produce very close results. The SCM comparison results are summarized in Table 2.

The comparisons are made by converting the reactivity worth (mk) into the equivalent amount of boron concentration. Note that, as mentioned earlier in Section 5, the present W-1 and old W-2 core models yield different boron worth. The LZC reactivity worths between 20-60% fills, where the relationship between worth and fill overwhelms linearity, are very close for both models. The overall assessment can be described such that both models show the same tendency of predictions except for the case of ADJs with withdrawal of individual rods where the old W-2 model overpredicts and vice versa for the W-1 model. It is interesting to note that the W-1 model calculated boron ppm is consistently less than the amount resulting from the old W-2 pre-simulations, and the maximum difference is 0.17 ppm for SOR case. The maximum discrepancy between the differences of the old W-2 and the present W-1 predictions occurs for the case of ADJ rods (individually withdrawn), and the W-1 model underpredicts by -6.02% compared to W-2 model. The average discrepancies between the differences resulting from the old W-2 and present W-1 pre-simulations are [-3.68-2.34+3.80-9.33]/2=-5.78% and [-7.00-(-5.10)-12.21-(-10.16)-5.7-(-2.85)]/3=-2.27% for ADJ and MCA/SOR, respectively. This implies that the superiority in accuracy attainable from the underlying physics models of MULTICELL and DRAGON-IST methodology appears to be more clearly eminent for black absorbers than grey ones, and in fact this can be easily

envisaged by representing the neutronic phenomena with the ratio of scattering and absorption in the vicinity of device material boundaries.

Table 2 Wolsong-2 Phase-B Measurements and Pre-Simulations using The Old W-2[@] Model and The Present W-1[+] Model

	W-2 Measurements		W-2 Pre-Simulations			W-1 Pre-Simulations		
Boron Worth (mk/ppm)			8.31			7.73		
LZC Worth (mk/[% fill])*			0.071			0.072		
Device	Worth (mk)	Equiv. Boron (ppm)	Worth (mk)	Equiv. Boron (ppm)	Diff. (%)[#]	Worth (mk)	Equiv. Boron (ppm)	Diff.[~] (%)[#]
ADJ ^ Individual	10.88	1.31	11.26	1.36	-3.68	9.92	1.28	2.34
ADJ [&] Bank	13.65	1.64	13.12	1.58	3.80	11.58	1.50	9.33
MCA ^ Individual	-7.71	-0.93	-8.29	-1.00	-7.00	-7.55	-0.98	-5.10
MCA [&] Bank	-9.58	-1.15	-10.87	-1.31	-12.21	-9.93	-1.28	-10.16
SOR^ Individual	-45.37	-5.46	-48.14	-5.79	-5.70	-43.40	-5.62	-2.85
				Avg. Diff.	**-4.96**		**Avg. Diff.**	**-1.29**

@ PPV/MULTICELL/RFSP - PPV fuel table simulations
+ WIMS/DRAGON/RFSP-IST - SCM fuel table simulations
* Estimated by linear fitting between 20-60 % fills.
# Difference (%) = (Measurement-Simulation)/Simulation*100
^ The worth of individual rods is measured and simulated one rod by one rod.
& The worth of banks is measured and simulated one bank by one bank.
~ The differences are calculated by using equivalent boron (ppm) instead of worth (mk).

The average value of the differences for the devices considered here between the two models are -4.96% and -1.29% for the W-2 model and the W-1 model, respectively, and it could be conclusively judged that the underlying mathematics and physics modelling methodology based upon more rigorous treatment of neutron transport equations using collision probability copes with the given neutronic phenomena more realistically in comparison to the methodology that uses reaction rate averaging approximations to solve neutron balance equations for the purpose of generating the incremental cross sections.

The decrease in reactivity worth of ADJs from undepleted to depleted ones is -11.3% and -13.5% for the rods and banks, respectively.

The computer system used is X86-Based PC with the processor x86 Family 6 Model 15 Stepping 11 GenuineIntel ~2405Mhz. The system is operating under OS Microsoft Windows XP Professional Version 5.1.2600 Service Pack 3. The computing time used to generate the incremental cross sections of a single rod by using DRAGON-IST is approximately 1.25 and 20.50 hours for ADJ and SOR/MCA, respectively.

8. Coolant and Moderator Temperature Reactivity Change (CTRC & MTRC)

The behaviour of reactivity change with coolant and moderator temperature is considered between 35-260 ℃ and 35-70 ℃, respectively, and this temperature range would cover the range between cold state for Phase-B and normal operating conditions. The comparisons between the

measurements and present pre-simulations for CTRC and MTRC are given in Table 3 and 4, respectively. The differences (%) between the measurements and predictions are again calculated by using the equivalent boron concentration (ppm) instead of worth (mk).

It is generally understood that the SCM methodology is primarily designed to account for the local parameter effects of each fuel bundle in the core that could accumulate in time in context of core-tracking simulations. The local parameters that would be relevant for normal operating conditions are usually the coolant and fuel temperatures and also the occasional inclusion of poison in the moderator system as well as small changes in D_2O purity. For the extended application of SCM to perform safety analysis, the coolant density and fuel temperature are the relevant parameters that experience significant changes during a LOCA.

Table 3 Wolsong-2,3,4 Phase-B Measurements and Pre-Simulations using W-1[+] Model - CTRC

	W-2,3,4 Measurements (Averaged)		W-1 Pre-Simulations		
Boron Worth (mk/ppm)	8.30		7.73		
Coolant and Fuel Temperature [^oC]	Change (mk)	Equiv. Boron (ppm)	Change (mk)	Equiv. Boron (ppm)	Diff. (%)[#]
35	0	0	0	0	0
50	-0.908	-0.109	-0.810	-0.105	3.81
65	-1.611	-0.194	-1.565	-0.202	-3.96
80	-2.339	-0.282	-2.283	-0.295	-4.41
95	-3.073	-0.370	-2.967	-0.384	-3.65
110	-3.701	-0.446	-3.613	-0.467	-4.50
125	-4.361	-0.525	-4.218	-0.546	-3.85
140	-4.954	-0.597	-4.788	-0.619	-3.55
155	-5.563	-0.670	-5.312	-0.687	-2.47
170	-6.125	-0.738	-5.874	-0.760	-2.89
185	-6.634	-0.799	-6.616	-0.856	-6.66
200	-7.059	-0.850	-7.004	-0.906	-6.18
215	-7.513	-0.905	-7.341	-0.950	-4.74
230	-7.825	-0.943	-7.215	-0.933	1.07
245	-8.088	-0.974	-7.431	-0.961	1.35
260	-8.285	-0.998	-7.572	-0.980	1.84
				Average	**-2.59**

+ WIMS/DRAGON/RFSP-IST - SCM fuel table simulations
# Difference (%) = (Measurement-Simulation)/Simulation*100

Base upon the above-mentioned considerations, for the study of CTRC one single SCM fuel table is used for the entire coolant temperature variation range by specifying the minimum and maximum interpolation points of coolant temperature sufficiently wide enough to cover the entire coolant temperature range in the WIMS Utilities input.

However, this concept could not be equally applied to the case of moderator temperature changes because in a CANDU lattice about 95% of thermal neutron populations reside in the moderator region with majority in thermal equilibrium with the surrounding moderator isotopes. Thus, any perturbation that might lead to the breach of thermal equilibrium and consequently resulting in the spectral shift of thermal neutron flux distribution from Maxwellian to a new non-equilibrium state would be more significantly susceptible to the assumptions and simplifications adopted in the mathematics and physics modelling background of SCM methodology compared to the case of coolant temperature perturbations. This in-depth scrutinizing has led to a suggestion that as a

precautionary measure for the study of moderator temperature reactivity change, the SCM fuel tables should be generated by confining the range between the minimum and maximum interpolation points closely to around a moderator temperature reference value.

The results reported here are produced by using several SCM fuel tables which have been generated with 10 ℃ interval that covers any changes in moderator temperature around a given reference temperature point. The results obtained based upon this approach have been thoroughly compared to the predictions generated by using the straightforward Uniform fuel tables, and both results agree within the sufficient accuracy that would reliably support any practical applications.

Table 4 Wolsong-3 Phase-B Measurements and Pre-Simulations using W-1^{+} Model - MTRC

	W-3 Measurements		W-1 Pre-Simulations		
LZC Worth (mk/[% fill])*	0.071		0.072		
Moderator Temperature (^{o}C)	Change (mk)	Observed LZC Level (% fill)	Change (mk)	Observe LZC Level Change(% fill)	Diff. (%)#
35	0	0	0	0	0
45	0.286	4.03	0.328	4.56	-11.62
50	0.472	6.65	0.473	6.57	1.22
55	0.627	8.83	0.606	8.42	4.87
60	0.767	10.80	0.721	10.01	7.89
65	0.886	12.48	0.826	11.47	8.81
70	0.996	14.03	0.916	12.72	10.30
				Average	**3.58**

+ WIMS/DRAGON/RFSP-IST - SCM fuel table simulations
* Estimated by linear fitting between 20-60 % fills.
# Difference (%) = (Measurement-Simulation)/Simulation*100

In Table 3 the coolant temperature reactivity changes are shown. The measured values are the averaged ones out of Wolsong-2,3,4 Phase-B tests.

As in the case of reactivity devices discussed in Section 7, the comparisons are made by converting the reactivity change (mk) into the equivalent amount of boron concentration. Note that the predicted change of boron concentration is underestimated below 50 ℃ and above 230 ℃, and between these temperatures the simulation overpredicts. The maximum and minimum differences occur at 185 ℃and 230 ℃, respectively. It can be claimed that the differences reveal a well scattered pattern within a clearly limited band, and this phenomena could be attributed to the fact that the fuel temperature is also increased in unison with the coolant temperature so that the neutronic phenomena in the clustered fuel region including coolant are predominantly governed by the temperature dependent effects of fertile and fissile isotopes, such as, Doppler broadening and resonance absorption, energy self-shielding and fission rates. Simply speaking, the effects of change in coolant temperature effect accompanied by density change are well undermined due to the fuel temperature effects while the moderator temperature remains unchanged, and the results display the negative fuel temperature reactivity coefficients for fresh core.

The average value of 15 differences between 35-260 ℃is turned out to be -2.56%.

Similar comparisons as the above-discussed coolant temperature reactivity change are shown in Table 4 for the moderator temperature reactivity change.

The comparisons are here made, in contrast to the cases of device reactivity worth and CTRC, by converting the reactivity change (mk) into the equivalent amount of LZC level change (% fill). As a matter of fact, MTRC is measured by observing the response of LZC levels because for the temperature range of interest the reactivity change would be so small, say about ~1 mk, that the tests could be more clearly conducted by observing the LZC level changes at constant boron concentration in the moderator.

The result in Table 4 gives the test results starting from the moderator temperature point where the increase of LZC level would have reached about, say, ~5% fill. This practice could be considered as fairly acceptable to make the comparisons between the observations and predictions with more clear judgements because for the initial small change in moderator temperature the fast fluctuating LZC levels due to RRS responses might be disturbing to clearly separate the net increase in LZC levels.

Note that the predicted LZC level change is underestimated except at 45 ^{o}C, where the maximum difference occurs. The differences increase gradually with temperature and tend to level off as shown in Figure 1.

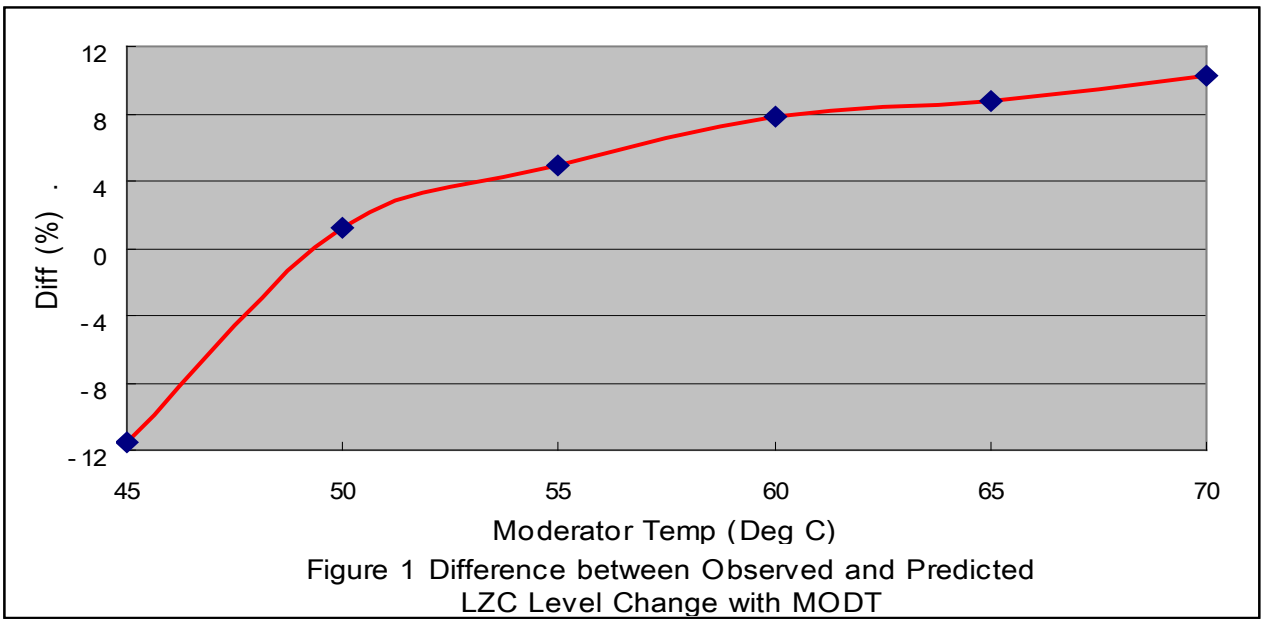

Figure 1 Difference between Observed and Predicted LZC Level Change with MODT

The average value of 6 differences between 35-70 ℃is turned out to be 3.58%. Note that MTRC is in average underpredicted compared to the case of CTRC, which is in opposite(see Table 3).

The incremental cross sections used for CTRC as well as MTRC simulations are the ones generated at the Phase-B reference cold conditions with boron concentration of 8.50 ppm in the moderator.

9. SDS1 Trip Test

The CERBERUS module, a space-time dependent kinetics code based upon IQS method, of RFSP-IST is used to simulate SDS1 power rundown test along with SCM fuel table. All the relevant parameters required to perform the simulations including the SOR drop curve are the consistent ones that are used for Wolsong-1 safety analysis, such as, LOCA. The SOR incremental cross sections are generated for the Phase-B reference cold conditions, and the most effective two SORs, namely, #4 and #8, are assumed unavailable. The initial power level is set to 0.1% FP and the

simulations are carried out with 40% average uniform LZC levels until 26 SORs are fully inserted into the core. The transient lasted 1.593 s including the trip delay time counted from the manual activation of SDS1 until to the actuation of SOR drops.

The power, amplitude and dynamic reactivity relative to time=0 s are given below at the end of transient along with the relative flux calculated by using the INTREP module at the vertical fission chamber location of view port #2. The initial values of power, amplitude and flux are set to 1.0.

Time	Rel. Power	Amplitude	Reactivity	Rel. Flux at VFC (View Port #2)
1.5930 s	0.1552	0.0802	-66.1000 mk	0.0767

The W-1 pre-simulation results are compared with the W-3 post-simulations obtained by using PPV/MULTICELL/RFSP along with the W-3 Phase-B tests and are graphically shown in Figure 2. Both simulation results of W-1 and W-3 are in good agreements and it can be observed that the W-1 flux drop curve is slightly shifted to the right compared to the W-3 flux drop curve. In other words, the W-1 pre-simulation of SDS1 trip tests offers a slightly enhanced conservatism in context of safety analysis.

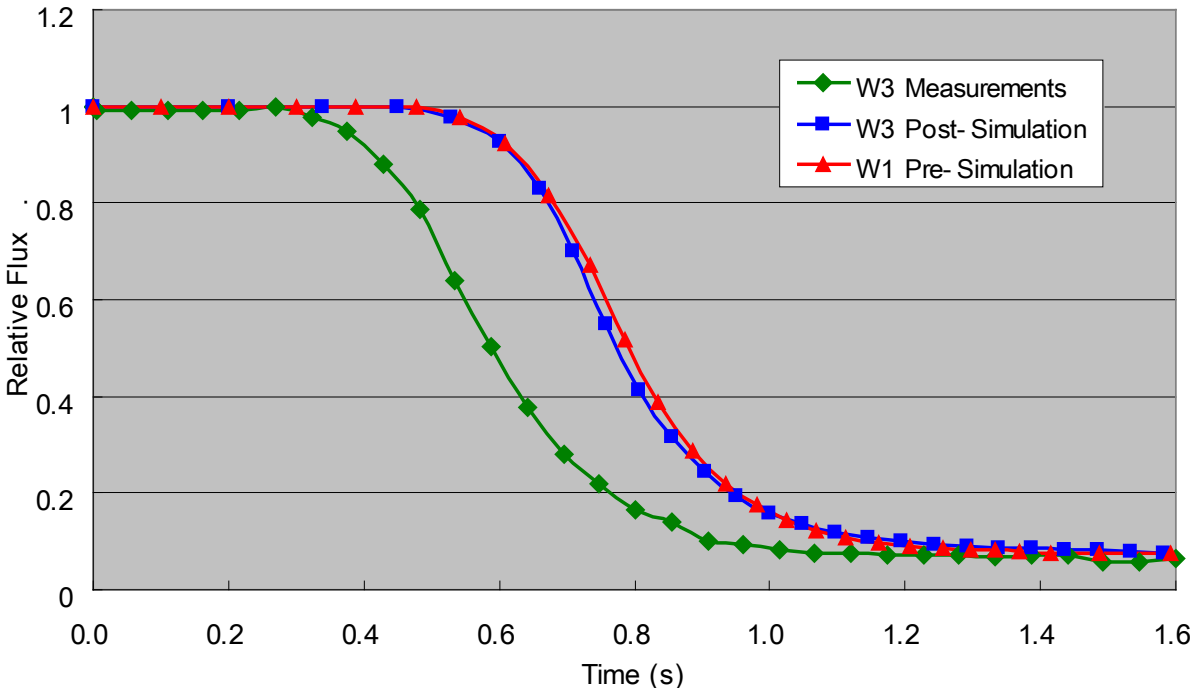

Figure 2 SDS1 Trip Test (VFC Response)

10. Flux Measurements

For the pre-simulations that are required for flux measurements and scans during Phase-B tests, five reactor configurations are considered consisting of the following cases;

Case A : Nominal Configuration
Case B : 50% Insertion of MCA Bank #1, All ADJs In

Case C : All MCAs In, All ADJs In
Case D : All MCAs Out, ADJ Banks #1,2,3,4 Out
Case E : All MCAs Out, All ADJ Banks #1~7 Out

The fluxes are interpolated using the INTREP module at the sites of vanadium detectors, vertical and horizontal flux detectors, SDS1 vertical ROP detectors and SDS2 horizontal ROP detectors for Cases A-E. The W-1 pre-simulation results show closely similar flux distributions compared to the PPV/MULTICELL/RFSP W-4 post-simulation results. The comparisons against the W-4 Phase-B measurements show that the RMS errors for the various cases observed are well within the limit of 10% which is normally judged as 'good'.

Table 5 Wolsong-4 Phase-B Measurements and Post-Simulations
using The Old W-4[@] Model and Pre-Simulations using The Present W-1[+] Model

DET	W-4 Meas	W-4 Post-Simul	W-1 Pre-Simul	W-4 Diff(%)[#]	W-1 Diff(%)[#]
5G	1.291	1.246	1.230	3.64	4.97
6G	1.256	1.236	1.215	1.62	3.39
1G	1.066	1.036	1.051	2.88	1.41
2G	1.057	1.037	1.052	1.95	0.51
3G	0.730	0.770	0.781	-5.15	-6.52
4G	0.760	0.768	0.779	-1.12	-2.44
7G	0.876	0.857	0.838	2.22	4.47
8G	0.860	0.850	0.836	1.18	2.96
3H	1.103	1.118	1.113	-1.41	-0.93
1H	1.113	1.068	1.101	4.16	1.10
4H	1.278	1.314	1.303	-2.72	-1.86
6H	1.355	1.245	1.224	8.87	10.68
8H	0.804	0.772	0.788	4.05	1.94
5H	0.665	0.697	0.715	-4.61	-7.02
7H	0.872	0.874	0.857	-0.27	1.74
2H	0.909	0.911	0.901	-0.23	0.83
1J	1.069	1.064	1.096	0.45	-2.50
4J	1.298	1.303	1.306	-0.33	-0.60
5J	1.115	1.237	1.220	-9.82	-8.57
6J	1.288	1.316	1.305	-2.09	-1.28
3J	0.656	0.698	0.717	-6.03	-8.52
7J	0.760	0.779	0.795	-2.53	-4.42
2J	0.951	0.924	0.910	2.98	4.48
8J	0.869	0.880	0.867	-1.31	0.17
			Average	**-0.15**	**-0.25**
			RMS(%)	**4.19**	**4.58**

@ PPV/MULTICELL/RFSP - PPV fuel table simulations
+ WIMS/DRAGON/RFSP-IST - SCM fuel table simulations
# Difference (%) = (Measurement-Simulation)/Simulation*100

The vanadium detector flux predictions reveal the best RMS errors around about ~3%, and the other RMS errors are within a range between 4~6%. The SDS2 horizontal ROP detector flux values show relatively larger RMS errors compared to the other detector flux estimates. In Table 5 the fluxes at 24 SDS2 ROP horizontal detector sites, which are normalized to sum up to 24, are compared against the W-4 measurements for Case D. Note that the difference values (%) given in the last two columns in Table 5 are calculated from the non-truncated values of the measurements and pre-simulation results. The comparisons are also graphically displayed in Figure 3.

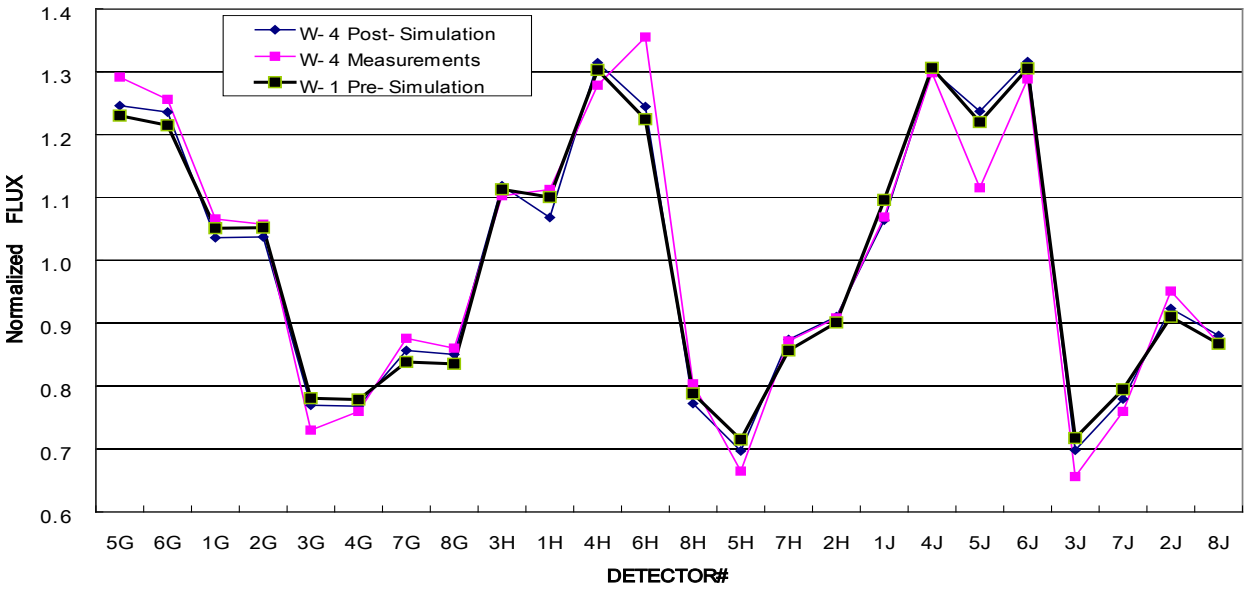

Figure 3 SDS2 Horizontal ROP Detector Fluxes with All MCAs and ADJ Banks #1,2,3,4 Out

11. Conclusions

It can be concluded that the newly adopted code suite WIMS/DRAGON/RFSP-IST could be justified for the use to carry out the core physics analyses in support of Wolsong-1 operations based upon the comparison results using the Wolsong-1 Phase-B pre-simulations against the past Wolsong-2,3,4 Phase-B measurements. The comparison results reveal some overall improvements in accuracy. It is to mention here that further extended use of the code suite should be made easier for users by alleviating the efforts required to generate WIMS/SCM fuel tables as well as DRAGON incremental cross sections.

12. Acknowledgement

The author, Dai-Hai Chung, wishes to express his appreciation to J.V. Donnelly, NSS-AMEC, for the valuable discussions held with respect to the SCM fuel table applications.

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