Reactor Physics Analysis and Generation of Flux Shapes by Enhanced ROP Methodology for Wolsong 2

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1. Introduction

KHNP is performing a project to complete the Regional Overpower Protection (ROP) analysis of Wolsong Unit 2. Wolsong Unit 2 is approaching a critical stage in the operational life of the reactor related to the Heat Transport System (HTS). In this case, aging factors such as pressure tube diametral creep (PTDC) pose significant challenges to the maintenance of a large operational margin.

An enhanced ROP methodology was developed to demonstrate margins in the current ROP Trip Setpoints (TSPs) and mitigate the downward pressure on the ROP Trip Setpoints due to regulatory concerns such as HTS aging. With the enhanced methodology, the ROP trip setpoint problem is computed based on the Extreme Value Statistics (EVS) methodology and the Frequency of Initial Core States (FICS) method for the probabilistic consideration of flux shapes arising from slow Loss of Regulation (LOR) accidents.

The impact of HTS aging is incorporated in the physics analysis through the uniform application of a core-wide average PTDC in the lattice physics calculations with WIMS. A value of average PTDC is typical of Wolsong Unit 2 at 6500 Effective Full Power Days (EFPD).

2. Methodology and Assumptions

The flux shapes in the ROP analysis are generated using the physics toolset comprised of DRAGON, WIMS, and RFSP **[Ref 1]**. The geometry of the Wolsong CANDU reactor core is relatively complex, with 37-element fuel bundles in 380 fuel channels, reactivity devices, guide tubes, and other structural components. The detailed spatial distributions of the neutron flux are calculated by WIMS using multigroup neutron-transport theory.

Consistent with Figure 1, the main output factors of the flux shape generation phase of the ROP analysis are as follows:

i) Channel overpower ratios - these are used as explicit input to the SIMBRASS code to compute the TSPs;

ii) ROP detector ratios - these are used as explicit input to the SIMBRASS code to compute the TSPs;

iii) Bundle powers - these are used as explicit input to the NUCIRC code to compute the critical channel powers (CCPs)

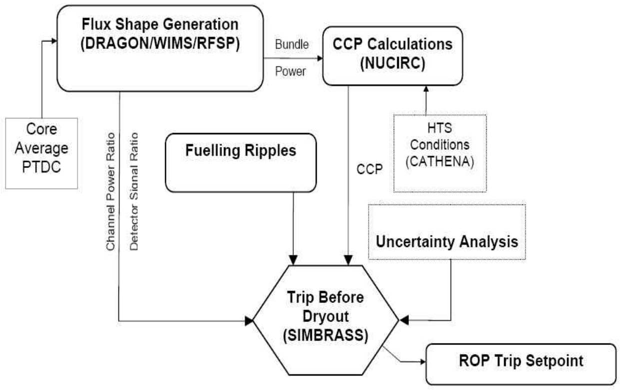

Figure 1. ROP Analysis Simplified Framework

There are two types of WIMS lattice-cell tables: uniform parameter tables suitable for use with the TIMEAVER and SIMULATE modules of the RFSP, and Simple Cell Method (SCM) tables for use with SIMULATE with the SCM option. Additionally, both types of WIMS tables can be broken down further into fuel tables and reflector tables. The WIMS uniform parameter tables are generated with fixed lattice-cell properties, as presented in Table 1.

Parameter	Value
Fuel Material	UO_2
Effective Fuel Density (g/cm^3)	10.4919
Fuel Temperature (°C)	687.0
Moderator Temperature (°C)	69.0
Moderator Purity (atom %)	99.833
Moderator Density (g/cm^3)	1.08517
Moderator Boron Concentration (ppm)	0.0
Coolant Temperature (°C)	288.0
Coolant Purity (atom %)	99.0
Coolant Density (g/cm^3)	0.81164

Table 1. Lattice-Cell Properties for WIMS Uniform Parameter Tables

2.1 Rationality Checks

The rationality checks for the incremental cross-section involve computing the reactivity worth of all components using the RFSP code to ensure that they are within the expected range based on experience and judgment **[Ref 2]**.

The items that are checked included the mesh selection, material specifications, end region treatment, appropriate region selection in the SCM, and the burnup step size.

2.2 WIMS-Based Fuel and Reflector Properties

The generation of fuel and reflector tables for use in RFSP is done using WIMS with the WIMS specific library. This WIMS library is based on the international Evaluation Nuclear Data File B-Ⅵ (ENDF/B-Ⅵ) library.

The generation of fuel and reflector tables is managed by WIMS Utilities **[Ref 3]**. The two main programs of WIMS Utilities are PROCS16 and GEN_WIMS.

2.3 Generation of Flux Shapes using RFSP

The process of modeling an equilibrium core in RFSP requires knowledge of the target power distribution. The target power distribution used in this ROP analysis was reproduced as Figure 2. This power distribution was computed with an un-aged WIMS-based RFSP model with powers in the seven irradiation zones closely matching the design values.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A									3188	3328	3409	3409	3328	3188								
B						2953	3539	4026	4253	4423	4475	4475	4423	4253	4026	3539	2952					
C					3330	3905	4497	4943	5230	5371	5371	5370	5371	5229	4943	4496	3903	3329				
D				3466	4132	4800	5354	5731	5945	6016	5934	5934	6016	5945	5730	5353	4798	4130	3463			
E			3344	4141	4886	5496	5951	6224	6329	6333	6217	6217	6332	6328	6223	5950	5494	4883	4138	3340		
F			4007	4785	5449	5950	6266	6423	6358	6321	6249	6249	6320	6358	6422	6265	5948	5447	4782	4002		
G		3641	4506	5287	5805	6188	6394	6475	6387	6347	6341	6340	6347	6386	6474	6393	6187	5804	5285	4503	3638	
H		4083	4964	5666	6021	6292	6450	6500	6417	6389	6407	6407	6389	6416	6500	6449	6291	6020	5664	4962	4082	
J	3311	4380	5315	5936	6161	6297	6413	6460	6421	6402	6412	6412	6402	6421	6460	6413	6297	6161	5936	5315	4382	3307
K	3501	4626	5558	6130	6261	6326	6411	6437	6402	6369	6349	6349	6369	6402	6437	6411	6326	6261	6131	5559	4630	3498
L	3639	4770	5702	6273	6416	6445	6459	6448	6391	6325	6241	6241	6325	6391	6448	6460	6446	6417	6275	5704	4774	3637
M	3636	4781	5732	6333	6516	6543	6517	6475	6398	6310	6189	6189	6311	6398	6475	6517	6544	6517	6335	5735	4787	3636
N	3498	4655	5632	6284	6539	6600	6558	6505	6423	6343	6246	6246	6343	6423	6505	6559	6600	6541	6286	5635	4661	3499
O	3307	4404	5387	6102	6484	6616	6577	6536	6451	6399	6377	6377	6400	6451	6536	6578	6616	6485	6104	5390	4409	3307
P		4081	4987	5744	6201	6473	6538	6543	6445	6419	6446	6446	6419	6445	6544	6539	6474	6202	5745	4989	4084	
Q		3598	4450	5216	5707	6101	6347	6456	6397	6399	6442	6442	6399	6397	6456	6348	6101	5707	5216	4451	3598	
R			3874	4585	5146	5665	6104	6340	6340	6372	6394	6394	6372	6340	6340	6104	5665	5146	4585	3874		
S			3170	3875	4523	5158	5736	6100	6275	6342	6287	6287	6342	6275	6100	5736	5158	4523	3875	3170		
T				3154	3801	4495	5121	5570	5844	5953	5879	5879	5953	5844	5570	5121	4495	3801	3154			
U					3007	3643	4289	4796	5133	5298	5273	5273	5298	5133	4796	4289	3643	3007				
V						2553	3209	3746	4040	4245	4310	4310	4246	4040	3746	3209	2553					
W									2764	2972	3084	3084	2972	2764								

Figure 2. Target Power Distribution in kW for ROP Analysis

The key assumptions pertaining to simulations of the flux shapes are itemized below.

1. The reactor is initially in a steady state, with reference thermal-hydraulic conditions, for all perturbation cases. The reactor is operating at 100 percent full power, unless otherwise stated, with all reactivity devices in the nominal position.
2. Each fuel channel contains twelve fuel bundles, and each channel is fuelled using an eight-bundle shift-fuelling scheme.
3. The individual zone controller operating range is 5% to 90% full for normal reactor regulation system operation.
4. All of the adjusters are made of stainless steel. The long adjuster rods are types A, B and C, and the short adjuster types are type D **[Ref 4]**.

3. Descriptions of the Flux Shape Categories

3.1 Steady State Cases

This category (SS) includes ten cases for average liquid zone controller (LZCR) levels of 20%, 40%, 50%, 60% and 80% full, with and without bulk and spatial control. All of the devices are in the nominal position in these cases.

3.2 Zone Controller Drains and Controller Fills

The flux shapes in these categories include single, axial zone, and zone assembly drains and fills. Additionally, each flux shape is simulated with and without bulk and spatial control.

3.3 Mechanical Control Absorber Insertion

There are three flux shape categories involving mechanical control absorber (MCA) insertion from the nominal flux shape.

4. Conclusions

Currently, KHNP is performing a project for the implementation of enhanced ROP methodology for Wolsong Unit 2. The Wolsong Unit 2 reactor is approaching a critical stage in its operational life, as HTS aging factors (e.g., pressure tube diametral creep, etc.) will have a significant impact on the degradation of the HTS system and operational margin.

The objective of the reactor physics phase of the ROP analysis is to perform rationality checks of the physics models and to generate input files for downstream NUCIRC and SIMBRASS codes.

Simulation of the flux shapes was completed using RFSP version REL_3-04-04PC.

Bundle power files were prepared for a critical channel power analysis using NUCIRC, and the channel overpowers and detector ratios results are ready for trip setpoint analysis using the SIMBRASS code.

REFERENCES

[1] P. Schwanke, “RFSP-IST Version REL_3-04: Users’ Manual”, SQAD-06-5054/153117360-UM-02, September 2006.

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