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ROP Analysis of a CANDU 6 Reactor with DUPIC Fuel

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ABSTRACT

The regional overpower protection (ROP) system was assessed for a CANDU 6 reactor with the DUPIC fuel, including the validation of the WIMS/RFSP/ROVER-F code system used for the estimation of ROP trip setpoint. For the standard natural uranium core, the ROP trip setpoint was estimated to be 122.9%, while it was 121.8% when estimated by the current design code. The validation calculation has shown that it is appropriate to use the WIMS/RFSP/ROVER-F code system for ROP system analysis of the CANDU 6 core. For the DUPIC core, the ROP trip setpoint was estimated to be 123.4%, which is almost the same as that of the standard natural uranium core. This study has shown that the DUPIC fuel does not hurt the current ROP trip setpoint margin designed for natural uranium CANDU 6 reactors.

1. INTRODUCTION

In CANDU reactors, the Regional Overpower Protection Trip (ROPT) systems protect the reactor against overpowers in the core, whether due to a localized peaking within the core or a general increase in core power levels. The general design requirements for the ROPT systems are summarized in Ref. 1. There are two ROPT systems - one for each of the two fast-acting shutdown systems (SDS's). Each ROPT system consists of a number of fast-responding self-powered flux detectors, suitably distributed throughout the core within vertical or horizontal assemblies. The SDS1 ROPT detectors are located in some of the 26 vertical assemblies, which are shared with other flux detectors used for reactivity control and flux mapping. The

SDS2 ROPT detectors are located in seven horizontal assemblies. Each ROPT detector has a pre-set trip setpoint and each SDS is connected to three logic channels. The reactor trip occurs when two channels out of three are tripped (see Figs. 1 and 2).

Previous study [2] has shown that the ROP trip setpoint of DUPIC core is comparable to that of natural uranium core. In this study, the calculation cases are extended to 232 cases, which are the whole design-base cases for Wolsong-1 ROP analysis. The cross-sections were produced by WIMS-AECL [Ref. 3] and POWDERPUFS-V (PPV) [Ref. 4] for DUPIC and natural uranium fuel, respectively. The flux shape and detector response were generated by RFSP [Ref. 5] and the critical channel powers (CCPs) were calculated by NUCIRC [Ref. 6]. Finally ROVER-F [Ref. 7] was used for ROP trip setpoint calculation.

In Section 2, data generation procedures are described. The validation calculation of the WIMS/RFSP/ROVER system is performed in Sec.3. The trip setpoint for the DUPIC fuel core is calculated in Sec. 4. Finally summary and conclusion are given in Sec. 5.

2. DATA GENERATION PROCEDURE

2.1 RFSP Physics Calculations

The RFSP physics calculations are performed to obtain flux shapes and channel powers. Then, the bundle powers are used in CCP calculations. The physics calculations are performed for 232 design-base cases [8] except for four cases of startup after long shutdown and ten cases of harmonic top-to-bottom and side-to-side tilt. The detailed design-base case is described in Ref. 8. The thermal neutron flux calculated for each case is processed to obtain the ROP detector response at each detector location. This processing is performed by INTREP module in the RFSP code.

2.2 CCP Calculations

The design criterion for the ROPT system is to prevent damage to the channel - specifically, the onset of intermittent dryout (OID). The CCP is calculated for each of the design-base cases. The detailed methodology and calculation procedures are described in Ref. 9.

2.3 Ripple Data Generation

The probabilistic assessment uses a set of rippled power distributions, representative of the ripples expected in the operating reactor. The ripples used in this assessment were obtained from 600-FPD refueling simulation. A total 121 ripples were obtained, at 5-day interval.

3. VALIDATION OF WIMS/RFSP/ROVER SYSTEM

For ROP analysis of the DUPIC core, a code system WIMS/RFSP/ROVER-F should be used instead of PPV/RFSP/ROVER-F, which is used for standard 37-element fuel core. Therefore, it is necessary to assess the WIMS/RFSP/ROVER-F code system for ROP analysis of CANDU reactors. The validation calculation was performed for the standard 37-element natural uranium core. For this study, 26 limiting cases, shown in Table 1, were chosen based on the ROP analysis results of Wolsong-1 plant [Ref. 6]. Table 2 shows the uncertainty data used for the ROP calculations.

The trip setpoint estimated by WIMS/RFSP/ROVWER-F system is 122.9%, while the setpoint estimated by PPV/RFSP/ROVER-F is 121.8%. The difference between two code systems is around 1%, which indicates that the WIMS/RFSP/ROVER-F system has validity to be used for ROP trip setpoint analysis of the CANDU 6 core.

4. ROP CALCULATION FOR DUPIC CORE

4.1 Trip Setpoint

The trip setpoint was calculated for the DUPIC fuel core based on a 98% 2-out of-2 trip probability over 232 design-base cases. The trip setpoint of the DUPIC fuel core was estimated to be 123.4%, which is slightly higher than the current ROP setpoint of the 37-element natural uranium core in Wolsong-1 (121.8%). Therefore, it is expected that the loading of the DUPIC fuel in the CANDU6 reactor does not hurt the ROP trip setpoint adversely.

4.2 Single Detector Failure

The trip setpoint was evaluated for the case of a single detector failure, which may change the trip setpoint. Table 2 shows the trip setpoint change for the single detector failure case. It can be seen that the trip setpoint does not change in case of SDS1 detector failure, but the maximum decrease in the trip setpoint is around 11% in case of SDS2 detector failures.

4.3 REFORM Calculation

REFORM is a process that attempts to improve ROP margin by changing the reference power shape of the core. The REFORM process follows several steps. First the excess margin (the amount by which the margin to dryout exceeds the margin to trip) is determined for each channel in the core. The channel power in each fuel channel is then adjusted, in small increments, to minimize this excess margin. Since overall reactor power is to be conserved, the revised power shape is normalized. This has an effect of adding powers to the channels with excess margin and the removing powers from channels with small excess margins. The result is that, in the most limiting channels, the channel power is decreased, leading to a larger margin to dryout and increased permissible ROP setpoints.

In order to investigate the possibility of increasing the trip setpoint in the DUPIC fuel core, REFORM calculation has been performed. The calculation result shows that the trip setpoint increases to 125.7%, which is 3% higher than the normal trip setpoint. However, this is a theoretical improvement, which needs to be checked against operational considerations. The trip margin improvement indicated by the ROVER-F code is not currently required.

5. SUMMARY

For the DUPIC fuel core, ROP system has been assessed using the ROVER-F input data produced by WIMS/RFSP system, CCP data by NUCIRC, and the ripple data by 600-FPD refueling simulations.

The results have shown that the ROP trip setpoint of the DUPIC core is almost the same as that of the standard natural uranium core. When necessary, the trip setpoint could be increased by 3% through the REFORM process of the channel power distribution of the DUPIC core.

Consequently, it is expected that the loading of the DUPIC fuel in a CANDU 6 reactor does not show any adverse effects on ROP trip setpoint.

ACKNOWLEDGEMENT

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Table 1 Case Set for Natural Uranium Core Analysis

Case	Description
1	SSSC50 STEASTATE WITH S.C.*
37	D14C50 ZONE DRAIN 14 FROM 50%
39	D02C80 ZONE DRAIN 02 FROM 80%
42	D05C80 ZONE DRAIN 05 FROM 80%
44	D07C80 ZONE DRAIN 07 FROM 80%
46	D09C80 ZONE DRAIN 09 FROM 80%
49	D12C80 ZONE DRAIN 12 FROM 80%
51	D14C80 ZONE DRAIN 14 FROM 80%
53	D02N50 ZONE DRAIN 02 FROM 50%
58	D07N50 ZONE DRAIN 07 FROM 50%
60	D09N50 ZONE DRAIN 09 FROM 50%
65	D14N50 ZONE DRAIN 14 FROM 50%
114	MCAN2H MCA 1ST FI & 2ND HI
122	ZTSFSE 1ST AZIMUTHAL SIDE/SIDE
123	ZTSESF 1ST AZIMUTHAL SIDE/SIDE
130	ZT2A01 2ND AZIMUTHAL 135,315 HI
131	T2A02 2ND AZIMUTHAL 045,225 HI
152	SSSD03 BANK 7 FULL-IN/NO TIMESTEP
171	SA4403 BANK 7 FULL-IN
173	SA4405 BANK 6 FULL-IN
174	SA4406 BANK 6 FULL-IN/Xe @ 4.3 MIN
177	SA4409 BANK 4 FULL-IN
178	SA4410 BANK 4 FULL-IN/Xe @ 3.9 MIN
195	SBCK05 BANK 2 OUT/Xe @ 18.3 MIN
196	SBCK06 BANK 3 OUT
197	SBCK07 BANK 3 OUT/Xe @ 28.5 MIN
222	ABHO01 STARTUP BANK 7 HALF-IN

* Reference Case

Table 2 Uncertainty Data for Natural Uranium Core Analysis

Uncertainty	Value (%)
Detector Random	±2.60
Channel Random	±1.49
Common Random	±4.18
Bias	+0.14

Table 3 ROP Calculation Results of PPV/RFSP/ROVER System

Case		Description	Trip Probability	
			SDS1	SDS2
42	D05C80	ZONE DRAIN 05 FROM 80%	.9929	.9559
173	SA4405	BANK 6 FULL-IN	.9615	.9605
49	D12C80	ZONE DRAIN 12 FROM 80%	.9967	.9642
114	MCAN2H	MCA 1ST FI & 2ND HI	.9918	.9647
152	SSSD03	BANK 7 FULL-IN/NO TIMESTEP	.9976	.9734
178	SA4410	BANK 4 FULL-IN/Xe @ 3.9 MIN	.9959	.9748
44	D07C80	ZONE DRAIN 07 FROM 80%	.9953	.9782
51	D14C80	ZONE DRAIN 14 FROM 80%	.9929	.9859
122	ZTSFSE	1ST AZIMUTHAL SIDE/SIDE	.9937	.9909
39	D02C80	ZONE DRAIN 02 FROM 80%	.9994	.9916
171	SA4403	BANK 7 FULL-IN	.9992	.9917
196	SBCK06	BANK 3 OUT	.9991	.9918
123	ZTSESF	1ST AZIMUTHAL SIDE/SIDE	.9968	.9933
46	D09C80	ZONE DRAIN 09 FROM 80%	.9973	.9936
197	SBCK07	BANK 3 OUT/Xe @ 28.5 MIN	.9990	.9940
131	ZT2A02	2ND AZIMUTHAL 045,225 HI	.9951	.9950
58	D07N50	ZONE DRAIN 07 FROM 50%	.9977	.9950
177	SA4409	BANK 4 FULL-IN	.9973	.9952
130	ZT2A01	2ND AZIMUTHAL 135,315 HI	.9985	.9958
65	D14N50	ZONE DRAIN 14 FROM 50%	.9968	.9960
53	D02N50	ZONE DRAIN 02 FROM 50%	.9993	.9967
60	D09N50	ZONE DRAIN 09 FROM 50%	.9987	.9972
37	D14C50	ZONE DRAIN 14 FROM 50%	.9984	.9975
222	ABHO01	STARTUP BANK 7 HALF-IN	1.0000	.9976
195	SBCK05	BANK 2 OUT/Xe @ 18.3 MIN	.9997	.9980

ROP Trip Setpoint = 121.77

Table 4 ROP Calculation Results of WIMS/RFSP/ROVER System

Case		Description	Trip Probability	
			SDS1	SDS2
44	D07C80	ZONE DRAIN 07 FROM 80%	.9942	.9701
51	D14C80	ZONE DRAIN 14 FROM 80%	.9893	.9800
39	D02C80	ZONE DRAIN 02 FROM 80%	.9987	.9802
152	SSSD03	BANK 7 FULL-IN/NO TIMESTEP	.9998	.9806
123	ZTSESF	1ST AZIMUTHAL SIDE/SIDE	.9897	.9812
171	SA4403	BANK 7 FULL-IN	.9997	.9832
122	ZTSFSE	1ST AZIMUTHAL SIDE/SIDE	.9893	.9841
46	D09C80	ZONE DRAIN 09 FROM 80%	.9925	.9874
130	ZT2A01	2ND AZIMUTHAL 135,315 HI	.9962	.9890
114	MCAN2H	MCA 1ST FI & 2ND HI	.9988	.9897
53	D02N50	ZONE DRAIN 02 FROM 50%	.9983	.9915
131	ZT2A02	2ND AZIMUTHAL 045,225 HI	.9916	.9917
58	D07N50	ZONE DRAIN 07 FROM 50%	.9967	.9919
60	D09N50	ZONE DRAIN 09 FROM 50%	.9964	.9923
65	D14N50	ZONE DRAIN 14 FROM 50%	.9955	.9942
222	ABHO01	STARTUP BANK 7 HALF-IN	1.0000	.9946
42	D05C80	ZONE DRAIN 05 FROM 80%	.9995	.9948
49	D12C80	ZONE DRAIN 12 FROM 80%	.9998	.9961
37	D14C50	ZONE DRAIN 14 FROM 50%	.9977	.9964
196	SBCK06	BANK 3 OUT	.9997	.9966
197	SBCK07	BANK 3 OUT/Xe @ 28.5 MIN	.9995	.9967
177	SA4409	BANK 4 FULL-IN	.9991	.9980
178	SA4410	BANK 4 FULL-IN/Xe @ 3.9 MIN	.9992	.9980
195	SBCK05	BANK 2 OUT/Xe @ 18.3 MIN	.9998	.9982
173	SA4405	BANK 6 FULL-IN	.9991	.9983

ROP Trip Setpoint = 122.90

Table 5 Uncertainty Data for DUPIC Core Analysis

Uncertainty	Value (%)
Detector Random	±2.60
Channel Random	±1.97
Common Random	±4.18
Bias	+0.14

Table 6 ROP Calculation Results of DUPIC Core

Case		Description	Trip Probability	
			SDS1	SDS2
49	D12C80	ZONE DRAIN 12 FROM 80%	.9984	.9749
42	D05C80	ZONE DRAIN 05 FROM 80%	.9966	.9751
112	MCAN1H	MCA 1ST BANK HALF-IN	.9993	.9785
44	D07C80	ZONE DRAIN 07 FROM 80%	.9982	.9859
39	D02C80	ZONE DRAIN 02 FROM 80%	.9996	.9900
108	MCAC1H	MCA 1ST BANK HALF-IN	.9993	.9908
46	D09C80	ZONE DRAIN 09 FROM 80%	.9968	.9918
51	D14C80	ZONE DRAIN 14 FROM 80%	.9965	.9919
114	MCAN2H	MCA 1ST FI & 2ND HI	.9951	.9944
123	ZTSESF	1ST AZIMUTHAL SIDE/SIDE	.9976	.9952
115	MCAN2F	MCA 1ST FI & 2ND FI	.9954	.9997
110	MCAC2H	MCA 1ST FI & 2ND HI	.9972	.9955
126	ZTT045	1ST AZIMUTHAL TOP AT 045	.9992	.9957
121	ZT1ABT	1ST AZIMUTHAL BOTTOM/TOP	.9957	.9993
129	ZTT315	1ST AZIMUTHAL TOP AT 315	.9959	.9986
122	ZTSFSE	1ST AZIMUTHAL SIDE/SIDE	.9974	.9962
120	ZT1ATB	1ST AZIMUTHAL TOB/BOTTOM	.9997	.9965
38	D01C80	ZONE DRAIN 01 FROM 80%	.9974	.9967
50	D13C80	ZONE DRAIN 13 FROM 80%	.9977	.9968
128	ZTT225	1ST AZIMUTHAL TOP AT 225	.9968	.9978
130	ZT2A01	2ND AZIMUTHAL 135,315 HI	.9990	.9969
53	D02N50	ZONE DRAIN 02 FROM 50%	.9995	.9972
60	D09N50	ZONE DRAIN 09 FROM 50%	.9988	.9972
45	D08C80	ZONE DRAIN 08 FROM 80%	.9974	.9986
127	ZTT135	1ST AZIMUTHAL TOP AT 135	.9990	.9975

ROP Trip Setpoint = 123.36

Table 7 Trip Setpoint for Single Detector Failure

SDS1 Detector		SDS2 Detector	
Detector	Setpoint	Detector	Setpoint
1D	1.2336	1G	1.2336
2D	1.2336	2G	1.2226
3D	1.2336	3G	1.2334
4D	1.2336	4G	1.2332
5D	1.2336	5G	1.2336
6D	1.2336	6G	1.2336
7D	1.2336	7G	1.2100
8D	1.2336	8G	1.2202
9D	1.2336		
10D	1.2336		
11D	1.2254		
12D	1.2336		
1E	1.2159	1H	1.2332
2E	1.2336	2H	1.2312
3E	1.2336	3H	1.2165
4E	1.2336	4H	1.2111
5E	1.2336	5H	1.2323
6E	1.2336	6H	1.2336
7E	1.2336	7H	1.1204
8E	1.2336	8H	1.2002
9E	1.2336		
10E	1.2336		
11E	1.2336		
1F	1.2336	1J	1.2333
2F	1.2336	2J	1.2326
3F	1.2336	3J	1.2215
4F	1.2336	4J	1.1689
5F	1.2336	5J	1.2336
6F	1.2336	6J	1.2336
7F	1.2336	7J	1.1947
8F	1.2336	8J	1.1960
9F	1.2336		
10F	1.2336		
11F	1.2336		

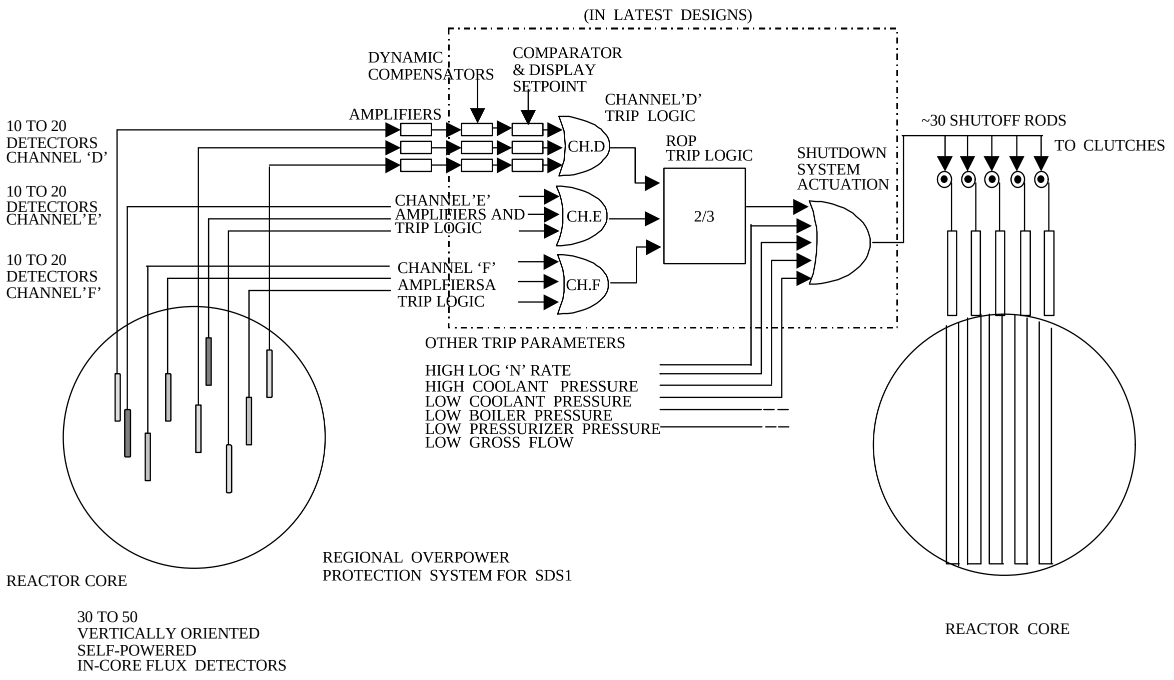

Fig.1 ROP Trip Logic for Shutdown System No. 1

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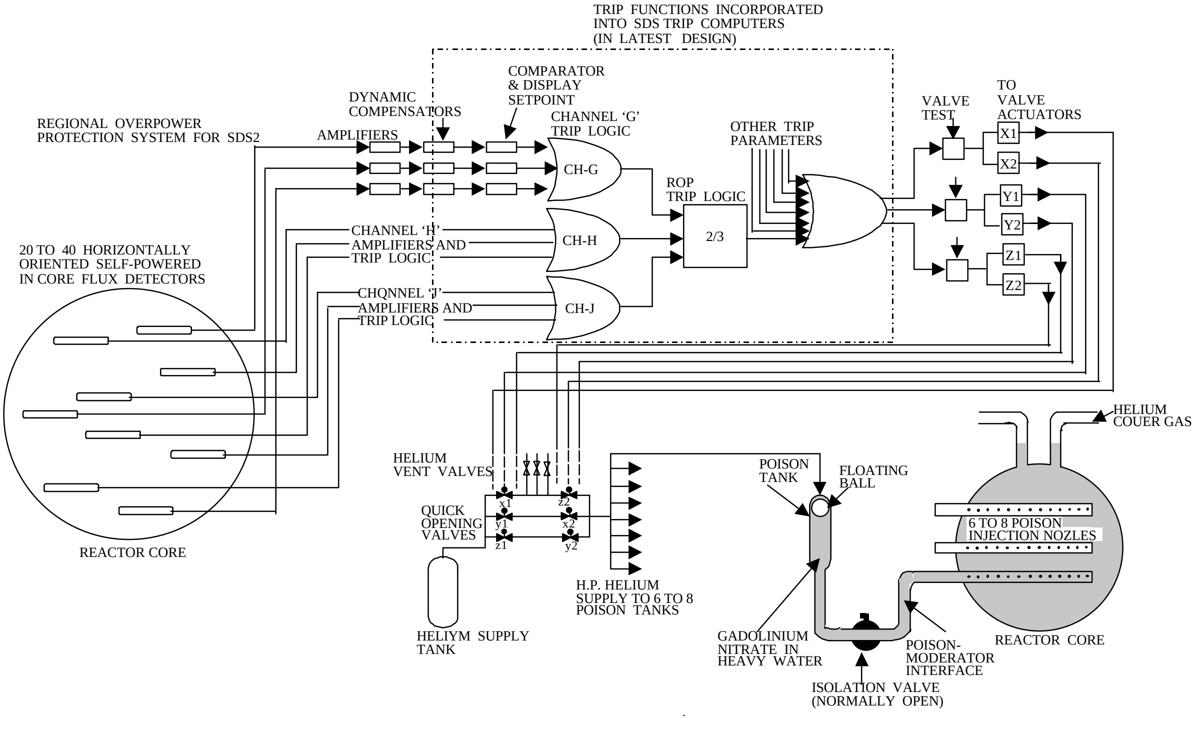

Fig.2 ROP Trip Logic for Shutdown System No. 2