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Snapshot Analysis for Rhodium Fixed Incore Detector using BEACON Methodology

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Abstract

The purpose of this report is to process the rhodium detector data of the Yonggwang Nuclear Unit 4 Cycle 5 core for the measured power distribution by using the BEACON methodology. Rhodium snapshots of the YGN 4 Cycle 5 have been analyzed by both BEACON/SPNOVA and CECOR to compare the results of both codes. By analyzing a large number of snapshots obtained during normal plant operation, BEACON/SPNOVA gave some competitive results against CECOR code. Reviewing the results of this analysis, the BEACON/SPNOVA can be used for the snapshot analysis of Korean Standard Nuclear Power (KSNP) plants.

Ⅰ. Introduction

Rhodium snapshots of the YGN 4 Cycle 5 have been analyzed by both CECOR[1] and SPNOVA[2] to verify the functionality of BEACON[3] system for the Korean Standard Nuclear Power (KSNP) plants.

The CECOR code synthesizes three-dimensional box and peak pin power distributions for a number of fixed incore detector signals through the use of pre-fit coefficient data from detailed, two-dimensional multi-group diffusion theory calculations. These data, which are a function of local assembly or axial nodal burnups, are input to the code through the coefficient library file. The coefficients include the power to signal ratio, W', for converting the signals to box power; the coupling coefficients, <CC>, for obtaining powers in uninstrumented assemblies from the powers in instrumented assemblies and pin/box factors for obtaining peak pin powers.

The SPNOVA code provides the capability to perform 0-D, 1-D, 2-D, and 3-D analysis of PWR cores in static and neutron kinetic modes for both square assembly and hexagonal assembly geometries. The SPNOVA code uses the Nodal Expansion Method to solve the inner iteration. Pin power reconstruction is available, consistent with ANC[4]. The methodology is fast enough to allow the use of identical methods to the ANC design code in on-line applications such as BEACON.

The BEACON system also uses the measured detector signals, in conjunction with BEACON predicted detector signals from the current reactor state, to adjust the ANC based prediction of the current reactor power distribution. The nodal power distribution in the prediction is adjusted based on relationship between the measured to predicted detector signal values. Since there are only a relatively small number of fuel assemblies that contain incore detectors, the adjustment that are required to adjust each node in the predicted core power distribution are developed from the adjustment factors calculated in the measurement locations. BEACON performs a series of spline interpolations using the current three dimensional calculated power distribution from ANC model within BEACON as the basis function. In this fashion, nodal adjustment factors are derived for all ANC nodes in all assemblies. The greater the amount of axial and radial measurements, the greater the accuracy of the resulting measured core power distribution.

This report includes the conversion of Rh snapshots to the BEACON/SPNOVA format, the snapshot analysis by BEACON/SPNOVA methodology for the measured power distribution, the evaluation of SPNOVA's capability for the detector analysis, and the comparison of the monitored power distribution between BEACON and CECOR.

II. Plant Data

Fourteen snapshots were taken from April 19, 2000 to March 22, 2001 of YGN Unit 4 Cycle 5 core, and were processed by CECOR code at the plant site. The reactor was mostly at hot full power (HFP) and all control rod out (ARO) condition during the snapshot collections. Plant conditions and file IDs for the snapshots are summarized in Table 1. The reactor has 45 detector assemblies radially, and each assembly consists of five axially distributed 40cm long detector elements as shown in Fig. 1.

Two rhodium detectors were replaced into platinum detector for some plant site tests. The locations of the rhodium and platinum detectors are also shown in Fig. 1. Because SPNOVA does not have the cross section library of platinum isotopes, the snapshots of platinum detectors were not used in this analysis.

In KSNP plants, highly depleted rhodium detectors are replaced with fresh ones at the beginning of each cycle operation. Moderately depleted detectors, if judged to be usable for another cycle operation, stay in the reactors. Therefore, the detectors of different degree of depletion are mixed for the power distribution monitoring.

III. Conversion of CECOR snapshots to BEACON/SPNOVA Format

There is a difference in the Rh fixed incore detector signal treatment between CECOR and BEACON.

BEACON	Detector Current	I	in micro-Ampre
	Background Current		in micro-Ampre
CECOR	raw detector flux	F	in 10E14 nv
	Detector sensitivity	S	in 10E-14 volt/nv
	Background Signal		in Volt

In the YGN4 plant, the detector current is measured in volt across the drop resistor of 1.0E6 ohms. The detector current, I, in micro-Ampre can be obtained by I = F * S. Ref. 1 indicates that F is defined as an uncompensated signal. However, according to plant operator in YGN unit 3, the YGN's detector flux has been background current corrected already. Therefore, no further background current correction is required. The conversion of CECOR snapshot to BEACON format and the generation of SPNOVA input file for the snapshot analysis were automated in a FORTRAN program for processing.

IV. SPNOVA BOC Model Generation

The SPNOVA model for Rh fixed incore detector snapshot analysis is generated in the following steps: i) generation of ANC model, ii) conversion of ANC to SPNOVA model, iii) placement of the incore detectors in the model, and iv) creation of input data related with Rh fixed incore detector at BOC conditions (i.e., the coefficients of the fitting equations for rhodium absorption cross section and thimble flux correction factors, electron escape probability, the relative rhodium nuclide concentration for all detectors, the accumulated electron charge for all detectors in Coulomb, and the tolerance factors).

Input data are assembled in an ascii file as input to BEPREPN[5] code which produces the complete SPNOVA BOC model (binary files) such as geometry file, cross section file, burn up file, power distribution file, xenon distribution file, and calibration file.

A detailed process of the SPNOVA model generation is documented in Ref. 6. Each Rh-neutron reaction produces one electron. However, a fraction of these electrons reaches to the outside sheath and produces the electric current. This fraction is called 'electron escape probability', often abbreviated as β. The status of each Rh detector can be seen from the Rh fixed incore detector related input data such as relative Rh nuclide concentration and the accumulated electron charge at BOC. Using these data the electron escape probability is derived as 0.435.

V. Rh Snapshots Analysis by BEACON Methodology

For the purpose of investigation of the sensitivity of core depletion model (measured power vs. predicted power), fourteen Rh snapshots of YGN4 Cycle 5 have been analyzed by SPNOVA code using the BEACON methodology. The first step is to deplete the BOC model up to the snapshot burnup steps. The depletion was made at HFP ARO condition. Fig. 2 shows the comparison of the critical boron concentration between SPNOVA and measurements. Consistent trend is observed.

At each burnup step, the SPNOVA burnup file and xenon file were stored, then the Rh snapshot analysis follows. One of the key result of the analysis is the comparison of the core average Rh detector currents between prediction and measurement. Fig.3 shows that estimated electron escape probability of 0.435 underestimate the Rh current by 3.7%. Therefore, the electron escape probability is changed to 0.472 and re-analyzed the snapshots. The results show that the predicted core average Rh detector currents agrees well to the measurements. Therefore, it is seen that the Rh detector model in SPNOVA describes the detector behavior very well.

Further confirmation of the Rh detector model, including the Rh depletion and the electron escape probability, can be made by the accumulated electron charge between prediction and measurement at the burnup of the last snapshot, 12914.4 MWD/MTU, for all detector as shown in Table 2. The differences are within 3%, but BEACON slightly underestimate the accumulated electron charge.

At each Rh snapshot analysis, the predicted power distribution is corrected by the measured detector currents which produce the measured power distribution. Table 3 shows the comparison of the power peaking factor and the axial offset between SPNOVA prediction and after-correction. The predicted boron concentrations and Fdh are almost the same as the measured. And the difference between predicted Fq and measured Fq is very small at BOC and MOC, but is 2.39% at EOL. This means that the SPNOVA model is well modeled and the prediction by SPNOVA is very close to the measurement.

Table 4 shows the comparison between CECOR and BEACON results. Generally the power peaking factors, Fq and Fdh, are fairly consistent. The comparison of the measured assembly power for all assemblies were made to check the agreement of the two results. As the results show that the % difference of peaking factors is within 3%, and the RMSs of % power difference over the core are less than 2%, it can be concluded that both code systems have nearly equal computational accuracy.

VI. Conclusion

If BEACON system have to be used as a core monitoring tool instead of CECOR code in KSNP, its functionality should be proved seriously. In this paper, to investigate one of the functionality of BEACON system, KEPRI calculates 14 three dimensional measured power distributions using BEACON system and compares them with those of conventional core monitoring code, CECOR. Power peaking factor (Fq) and peak enthalpy increment (Fdh) are selected to check the functionality. Final analysis shows that the difference of two codes for each parameter was less than 3% respectively. Overall root-mean-square of node-wise power difference between two codes also was calculated less then 1.8%. All results show BEACON system has a good solver to estimate power at uninstrumented node from the measured detector signals. From the above observation, therefore, KEPRI concludes that BEACON system can be used as a tool to calculate measured power distribution using 225 Rh detector signals.

But BEACON system slightly overestimates Fq and FdH. It maybe related with the underestimate of accumulated electron charge at each snapshot burunp. At present it is very difficult to conclude those phenomena will be repeated for the case of other plants or fuel cycles. Therefore, further study will be focused on the discrepancy between BEACON system and CECOR code theoretically and statistically.

References

[1] Combustion Engineering Inc., "User's Manual for CECOR," CE NPSD-104.

[2] Westinghouse Electric Company, "User's Manual for SPNOVA," CMP-03-15.

[3] BEACON Core Monitoring and Operations Support System (WCAP-12472-P-A), Addendum 1, Jan. 2000.

[4] Westinghouse Electric Company, "User's Manual for ANC," ASD-99-067

[5] Westinghouse Electric Company, "User's Manual for BEPREPN," ASD-03-11.

[6] Yu Sun Choi, et al.,"Evaluation of Yonggwang Unit 4 Cycle 5 using SPNOVA Code," May 2004, Korean Nuclear Society Spring Meeting (to be published).

Table 1. YGN Unit 4 Cycle 5 Rhodium Fixed Incore Detector Snapshot Information

No	Snapshot File	Date	Burnup (MWD/MTU)	Power (%)	Boron (PPM)	ASI	Lead Bank Position (cm)
1	Z28604BC	04/19/00	537.2	99.7	1089.	-015	381
2	Z286F675	05/04/00	1094.2	99.7	1044.	-.009	379
3	Z28844B1	05/25/00	1858.4	99.6	998.	-.002	379
4	Z288EA4A	06/04/00	2244.2	99.7	968.	.004	377
5	Z289D4B2	06/19/00	2776.9	99.6	931.	.005	377
6	Z28AC4C1	07/04/00	3328.1	99.7	915.	.013	375
7	Z28BB667	07/19/00	3884.7	99.7	875.	.023	374
8	Z28CA4B1	08/03/00	4430.2	99.7	833.	.019	374
9	Z28D9654	08/18/00	4986.5	99.6	799.	.021	375
10	Z28F84B1	09/18/00	6119.5	99.8	724.	.018	377
11	Z29344B1	11/17/00	8323.5	99.6	597.	.028	381
12	Z29524B0	12/17/00	9424.8	99.6	519.	.020	379
13	Z29934B1	02/20/01	11812.0	99.9	315.	.025	369
14	Z29B14B1	03/22/01	12914.4	99.7	198.	.024	373

Table 2. Comparison of Accumulated Electron Charge at EOL between BEACON/SPNOVA and Measurements

FID	Level 1			Level 2			Level 3			Level 4			Level 5		
No	Meas	SPN	% diff	Meas	SPN	% diff	Meas	SPN	% diff	Meas	SPN	% diff	Meas	SPN	% diff
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	178.0	181.8	-2.1	204.4	207.8	-1.7	201.0	204.5	-1.7	199.0	202.2	-1.6	168.8	171.3	-1.5
3	192.3	196.6	-2.2	218.7	221.8	-1.4	217.8	220.7	-1.3	212.2	215.5	-1.5	184.1	186.2	-1.1
4	110.3	110.8	-0.4	125.2	125.9	-0.6	124.7	125.1	-0.3	121.2	121.6	-0.3	101.1	102.0	-0.9
5	57.8	59.6	-3.0	69.2	68.3	1.3	66.4	66.8	-0.5	64.8	64.4	0.6	51.6	52.9	-2.5
6	130.3	132.2	-1.5	151.3	153.3	-1.3	150.3	152.3	-1.3	147.0	149.3	-1.6	123.8	126.1	-1.8
7	50.7	51.1	-0.8	58.5	57.7	1.4	57.5	56.9	1.0	56.6	55.8	1.5	48.6	47.5	2.4
8	115.9	116.8	-0.8	126.3	128.4	-1.6	128.4	129.0	-0.4	127.2	127.4	-0.2	112.3	112.0	0.3
9	122.0	123.1	-0.9	136.2	136.2	0.0	134.9	134.9	0.0	133.2	133.0	0.1	118.9	117.2	1.5
10	115.1	117.2	-1.8	127.8	129.4	-1.2	128.7	129.4	-0.6	127.6	128.0	-0.3	111.8	112.6	-0.7
11	120.4	121.9	-1.2	138.8	138.3	0.4	134.2	134.4	-0.2	131.9	131.7	0.1	115.0	113.9	1.0
12	58.7	59.3	-1.0	66.7	66.6	0.1	66.1	65.8	0.4	65.7	64.4	2.0	56.2	55.1	2.1
13	194.2	197.5	-1.7	219.0	222.1	-1.4	217.7	220.5	-1.3	215.6	217.9	-1.1	184.7	187.1	-1.3
14	109.4	111.6	-2.0	127.1	128.0	-0.7	125.1	125.8	-0.6	117.7	120.5	-2.3	101.1	101.9	-0.7
15	114.1	114.8	-0.6	124.8	126.0	-0.9	125.6	126.4	-0.6	124.0	125.3	-1.0	113.2	112.6	0.5
16	129.8	131.7	-1.5	143.4	144.8	-0.9	142.5	143.6	-0.7	142.0	142.3	-0.2	125.0	124.3	0.5
17	112.6	114.5	-1.6	124.1	125.7	-1.2	123.4	125.1	-1.3	123.5	124.7	-1.0	112.5	112.3	0.2
18	114.4	115.3	-0.8	128.4	129.4	-0.8	127.4	128.3	-0.7	121.8	124.5	-2.2	106.5	108.0	-1.4
19	124.3	126.8	-2.0	139.4	141.6	-1.6	137.8	139.8	-1.5	134.0	135.9	-1.4	116.0	116.9	-0.8
20	120.0	120.5	-0.4	132.4	133.3	-0.7	131.8	132.7	-0.7	132.2	132.7	-0.3	118.0	118.0	0.0
21	126.3	128.7	-1.9	140.1	142.1	-1.4	138.9	140.6	-1.2	138.2	139.1	-0.6	121.5	121.6	-0.1
22	174.3	177.8	-2.0	198.5	201.8	-1.6	197.9	200.9	-1.5	195.6	198.5	-1.4	167.4	169.9	-1.4
23	119.1	121.5	-2.0	130.8	133.0	-1.6	132.5	134.6	-1.6	132.9	134.9	-1.4	122.5	123.4	-0.7
24	174.5	178.1	-2.0	198.0	201.3	-1.7	195.6	199.1	-1.7	195.5	198.3	-1.4	166.1	168.6	-1.5
25	126.2	128.8	-2.0	138.6	141.3	-1.9	137.7	140.1	-1.7	136.0	138.1	-1.5	120.6	121.0	-0.4
26	118.7	120.1	-1.1	129.5	131.4	-1.4	131.5	133.7	-1.6	130.0	131.1	-0.8	116.2	116.9	-0.6
27	125.2	127.5	-1.8	140.1	142.1	-1.4	139.2	140.4	-0.8	134.3	136.5	-1.6	115.3	116.4	-0.9
28	113.8	115.3	-1.3	128.9	129.6	-0.5	127.4	128.3	-0.7	123.7	125.3	-1.2	108.0	108.4	-0.4
29	114.3	114.8	-0.5	126.2	126.9	-0.6	126.8	127.5	-0.5	127.2	127.1	0.1	112.9	113.0	-0.1
30	58.6	59.6	-1.6	68.0	68.3	-0.5	67.0	66.8	0.4	64.8	64.4	0.6	53.0	52.9	0.3
31	192.3	196.1	-1.9	219.2	222.2	-1.4	218.4	220.8	-1.1	216.2	218.4	-1.0	184.7	187.1	-1.3
32	121.8	124.4	-2.1	134.5	136.5	-1.5	134.3	135.7	-1.0	129.8	132.3	-1.9	117.2	117.1	0.1
33	122.8	123.9	-0.9	136.5	137.1	-0.5	136.5	136.9	-0.3	136.5	136.3	0.2	120.1	119.8	0.3
34	60.0	59.3	1.3	67.4	66.6	1.2	65.8	65.8	0.0	65.5	64.4	1.6	56.6	55.1	2.7
35	115.8	117.4	-1.4	125.7	128.4	-2.1	127.9	129.2	-1.0	128.5	128.6	-0.1	111.5	112.7	-1.1
36	121.7	122.6	-0.7	133.7	135.1	-1.0	133.9	134.8	-0.7	134.2	133.8	0.3	116.2	116.4	-0.2
37	117.3	117.5	-0.1	128.1	129.2	-0.8	129.3	129.4	-0.1	128.6	128.2	0.3	112.1	111.9	0.2
38	137.8	140.0	-1.6	157.1	159.6	-1.5	156.3	158.7	-1.5	158.1	159.8	-1.1	134.9	136.1	-0.9
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	129.3	131.4	-1.6	149.7	151.9	-1.4	148.7	151.0	-1.5	149.2	151.0	-1.2	127.3	129.0	-1.3
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	108.4	109.3	-0.8	124.8	125.5	-0.5	124.3	124.6	-0.3	120.1	121.0	-0.7	101.8	102.6	-0.8
43	192.0	195.9	-2.0	219.0	222.2	-1.4	217.9	220.8	-1.3	214.9	217.6	-1.3	184.1	186.7	-1.4
44	178.1	181.7	-2.0	203.3	206.9	-1.8	201.3	204.7	-1.7	198.0	201.5	-1.8	169.7	172.5	-1.6
45	143.4	146.0	-1.8	166.4	169.0	-1.5	164.3	167.0	-1.6	162.4	165.0	-1.6	136.4	138.9	-1.8

* Meas : Measurments from snapshot
* SPN : BEACON/SPNOVA

Table 3. Comparison of Measured and Predicted Power

No	Burnup	Boron			Fq			FdH			A/O		
		Pred*	Meas**	(P-M)	Pred	Meas	(P-M)/P	Pred	Meas	(P-M)/P	Pred	Meas	(P-M)
1	537	1090	1090	0	1.716	1.727	-0.64%	1.539	1.535	0.26%	-0.5	0.9	-1.4
2	1094	1035	1035	0	1.697	1.709	-0.71%	1.532	1.531	0.07%	-0.9	0.3	-1.2
3	1858	978	978	0	1.688	1.691	-0.18%	1.528	1.529	-0.07%	-1.5	-0.4	-1.1
4	2244	949	949	0	1.682	1.688	-0.36%	1.524	1.527	-0.20%	-1.8	-1	-0.8
5	2777	909	909	0	1.674	1.679	-0.30%	1.519	1.524	-0.33%	-2.1	-1.1	-1
6	3328	867	866	1	1.672	1.681	-0.54%	1.514	1.521	-0.46%	-2.4	-2	-0.4
7	3885	826	824	2	1.674	1.693	-1.14%	1.512	1.52	-0.53%	-2.8	-3	0.2
8	4430	787	785	2	1.676	1.684	-0.48%	1.509	1.518	-0.60%	-3.1	-2.6	-0.5
9	4987	748	747	1	1.682	1.688	-0.36%	1.507	1.516	-0.60%	-3.4	-2.8	-0.6
10	6120	674	674	0	1.703	1.685	1.06%	1.506	1.515	-0.60%	-4	-2.4	-1.6
11	8324	541	542	-1	1.727	1.704	1.33%	1.506	1.511	-0.33%	-4.6	-3.4	-1.2
12	9425	466	467	-1	1.695	1.679	0.94%	1.494	1.499	-0.33%	-3.6	-2.6	-1
13	11812	266	256	10	1.632	1.671	-2.39%	1.457	1.464	-0.48%	-1.7	-3.5	1.8
14	12914	168	162	6	1.619	1.639	-1.24%	1.441	1.445	-0.28%	-1.9	-3.2	1.3

Pred* : SPNOVA Depletion Calculation (prediction)
Meas** : BEACON Snapshot Calculation (after-correction)

Table 4. Comparison between CECOR and BEACON Results

BU	Fq			Fdh/Fr			% Difference of Measured Assembly Power Distribution (RMS)
	BEACON	CECOR	(BEACON-CECOR)/100	BEACON	CECOR	(BEACON-CECOR)/100	
537	1.727	1.7295	-0.25%	1.535	1.518	1.70%	1.79
1094	1.709	1.7039	0.51%	1.531	1.5139	1.71%	1.76
1858	1.691	1.6769	1.41%	1.529	1.5104	1.86%	1.72
2244	1.688	1.6612	2.68%	1.527	1.5091	1.79%	1.70
2777	1.679	1.6556	2.34%	1.524	1.5065	1.75%	1.67
3328	1.681	1.6664	1.46%	1.521	1.5054	1.56%	1.63
3885	1.693	1.6819	1.11%	1.52	1.5047	1.53%	1.61
4430	1.684	1.6708	1.32%	1.518	1.5046	1.34%	1.59
4987	1.688	1.6728	1.52%	1.516	1.5058	1.02%	1.58
6119	1.685	1.6612	2.38%	1.515	1.5102	0.48%	1.57
8324	1.704	1.6843	1.97%	1.511	1.5163	-0.53%	1.55
9425	1.679	1.658	2.10%	1.499	1.5057	-0.67%	1.54
11812	1.671	1.6579	1.31%	1.464	1.4764	-1.24%	1.64
12914	1.639	1.6401	-0.11%	1.445	1.4724	-2.74%	1.76

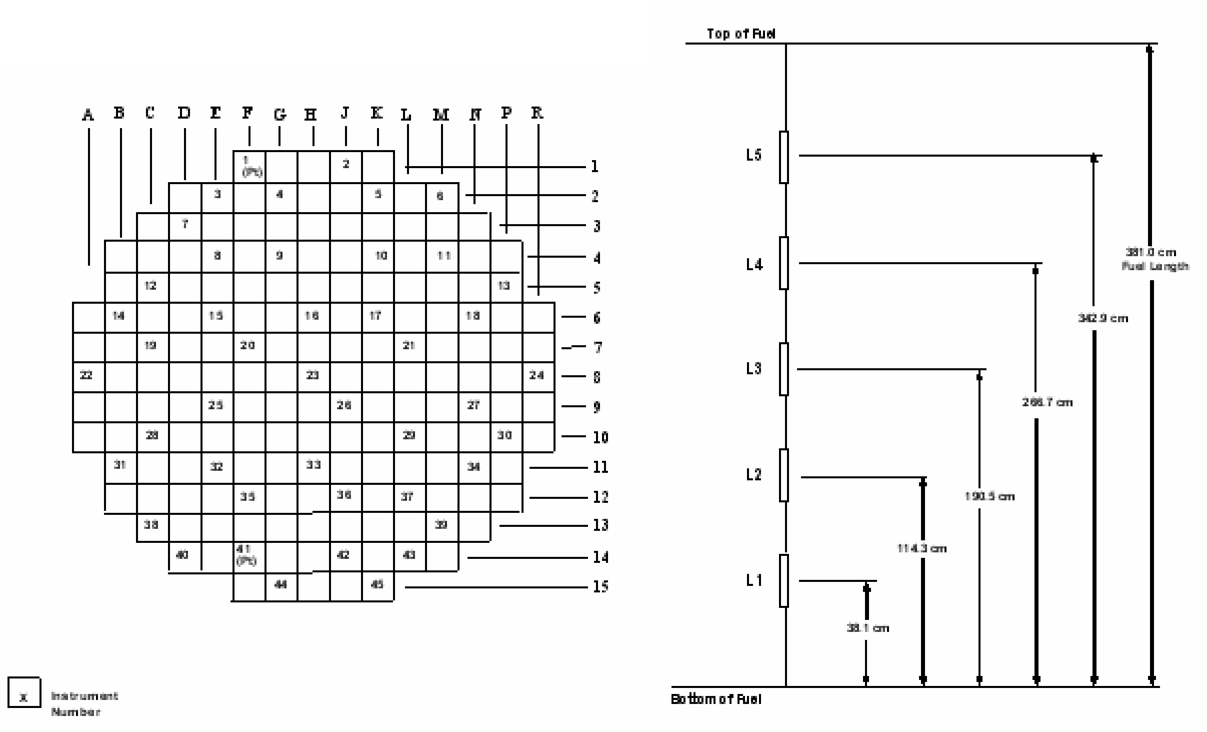

Figure 1. Yonggwang Unit 4 Radial and Axial Detector Location

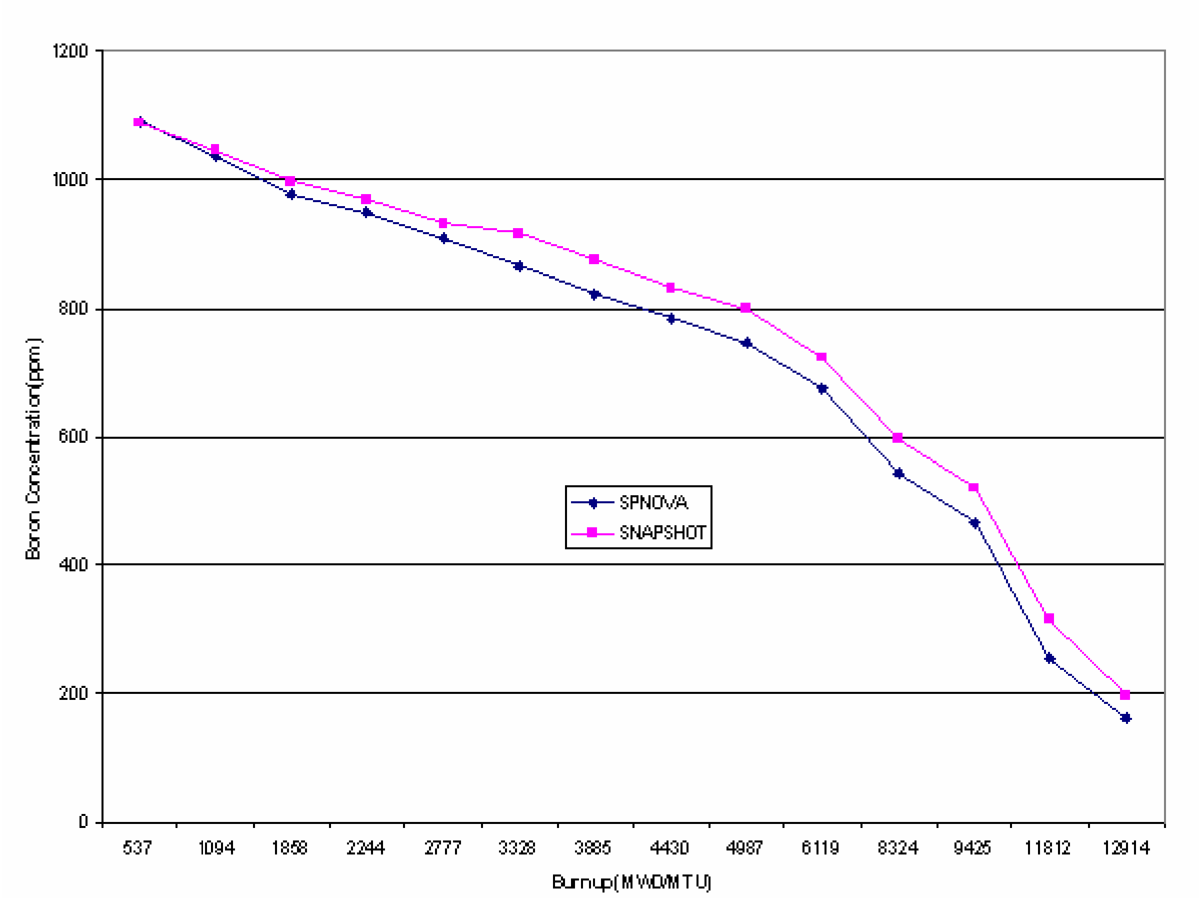

Figure 2. Comparison of Boron Concentration between SPNOVA and Snapshot

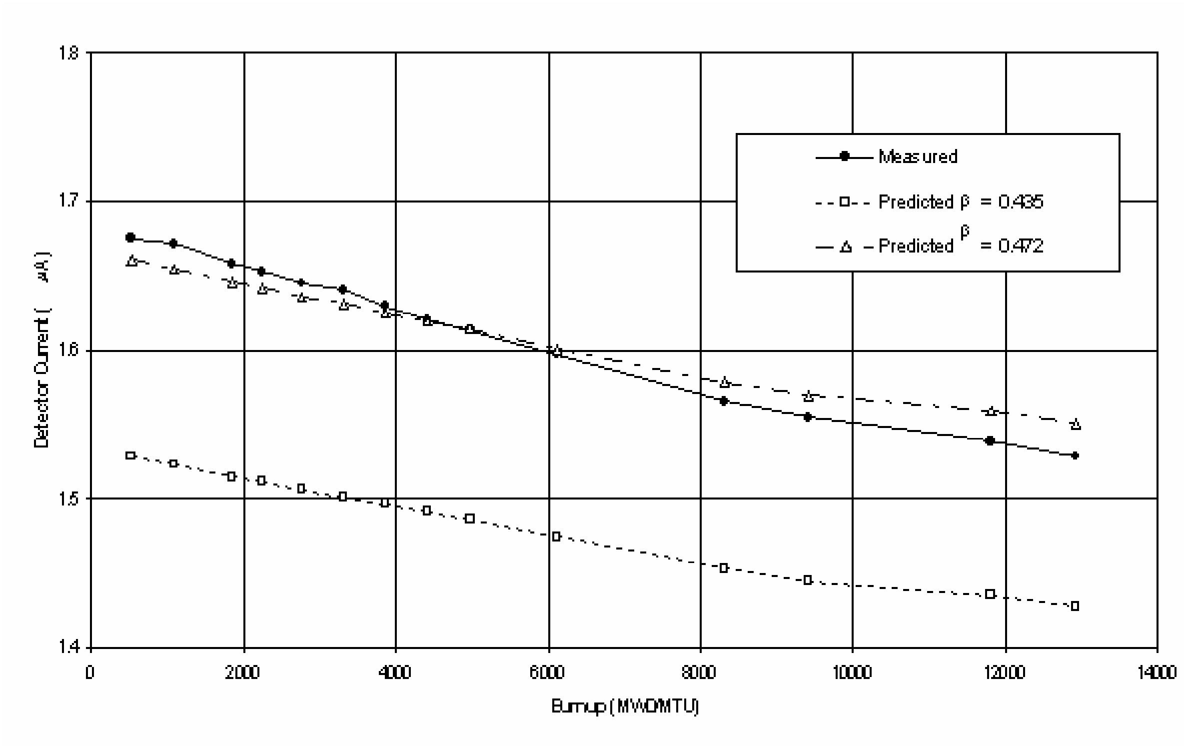

Figure 3. Yonggwang Unit 4 Cycle 5 Rh Fixed Incore Detector Current