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Evaluation of the Platinum Detector Signals for YGN4 Cycle 5

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Abstract

Two Platinum detector assemblies were installed in YGN Unit 4 during the cycle 5, which have the same mechanical design and dimensions as the existing rhodium detectors except the detector emitter material is platinum. By comparing the platinum signals with their symmetric location rhodium signals, the characteristics of raw platinum signals were analyzed. It is found that because the platinum signals are very small the signal response characteristics are strongly impacted by the background signal correction level and method. PHOENIX-4 calculation is performed to evaluate the gamma sensitivity to several physics parameters. Nodal Weighting Factors are introduced to represent the effect from the neighboring assemblies on the platinum detector response by using the Monte Carlo calculation code (MCNP). The normalized calculated and measured detector powers are compared to represent the behavior of platinum detector signals. The results indicate that platinum detector sensitivity has an elevation dependent behavior due to background and leakage current of the cable and detector. Also, the platinum detector sensitivity in fresh assembly appears to gradually increase due to the buildup of the fission product of long decay constants.

1. Introduction

Platinum detectors, which promptly respond to gamma radiation level changes and have little detector depletion dependence, are considered as replacements for the rhodium detectors currently used for power distribution monitoring. Two platinum detector assemblies, each with five 40cm platinum detector elements, were installed in Yonggwang Unit 4 Cycle 5 (YGN4C5) between April of 2000 and March of 2001 in the core location of No.1 and No.41 In-core instrument (ICI) assemblies instead of rhodium detector assemblies. The platinum detector signals are analyzed to evaluate their consistency with their symmetric rhodium detectors by comparing the detector sensitivities. The sensitivity calculations, which are the deposited gamma power to unity fission power density, are performed to evaluate the effect of reactor parameters that may affect gamma power distribution changes by using the PHOENIX-4 assembly code. Pin Weighting Factors (PWF) and Node Weighing Factors (NWF) are introduced to represent the gamma source from the neighboring assemblies. The ROCS code that is currently used in nuclear design calculates the 3-dimensional power distribution in accordance with plant operating conditions. A pin power reconstruction calculation is also performed by MCEDIT code. Combining the NWF and detector power from ROCS/MCEDIT calculations, the calculated powers at each detector level for each of the platinum detector are calculated. The normalized measured and calculated signals are compared to identify the platinum detector operating characteristics. The platinum detector operating characteristics and methods needed to achieve the use of prompt responding detector for replacements with rhodium detector are represented.

2. The measured Data

2.1 Procedure for collecting the Detector signals

The signals of two platinum detectors installed in YGN4 cycle 5 are measured to analyze the characteristics of the prompt-responding detector signal. The measured voltage signal is easily converted to a current signal by applying resistance of 10^6 Ohm in YGN 4 cycle 5. Detector signals at the platinum detector locations are artificially treated as bad signal in Plant Monitoring System (PMS). Only signals of rhodium detectors can be selected without any impact on PMS. Platinum detector signals came from Historical Data Storage Report (HDSR) that comprise Platinum detector voltage signals and some parameters related with plant operation condition at that time. The signals of the platinum detectors collected by HDSR are summarized in Table 1 and 2. As shown in Tables, the background signals of platinum Detector No.1 and No.41 are about 41% and 59% of the average raw platinum detector signal, respectively. The ratios of background-to-raw signal for platinum detectors are several times larger than those of rhodium detector of symmetric locations.

2.2 Characteristics of Platinum Detectors and Their Partner Rhodium Detectors

The platinum detector assemblies have the same geometry as the existing rhodium detector assemblies in YGN 4 except the emitter material is platinum. Platinum detector assembly No.1 is installed in highly burned peripheral/corner location of the core. The normalized assembly power is about 0.5. The symmetric rhodium detector assembly partner is No.45, which has been used in four operating cycles. About 40% of the rhodium was depleted. Detectors of middle three elevations have been depleted more than the top and bottom detectors. Detector No.1 is located in once burned fuel of type “G0”.

Platinum detector assembly No.41 has three symmetric partners. All of them are installed in fresh assemblies of type “H1” which are operated at relatively high power density. Detector No.41 is located in a fresh fuel assembly of type “H1” with 8 Gadolinia (GD) burnable absorber inserts. Two of the three rhodium detector assembly symmetric partners are fresh, No.5 and No30, but No.14 was installed in the previous operating cycle. Detector assembly No.14 has an average detector depletion of about 20%. The magnitude of depletion is elevation dependent. Table 3 shows the partners, their rhodium detector characteristics and the fuel burnup of the detector location.

2.3 Raw Signals of Platinum and Partner Rhodium Detectors for YGN4C5

The platinum detectors and their symmetric rhodium partner data from YGN4C5 are processed for the following information;

The detector sensitivity, S, is defined by

$$S = \frac{(V_r - V_{bg})}{Power} \tag{1}$$

where, V_r : Raw detector output, Volt across 1 Mega Ohm drop resister

V_{bg} : Background wire output

Power : Power density at detector location in MW per slice of the fuel assembly of height 40cm. The power density is quoted from CECOR output of YGN4C5.

The sensitivities are shown in the following figures;

Figure 1. No.1 Platinum Detector in once burned fuel (G0)

Figure 2. No.45 Rhodium Detector (4 cycle old), Partner of No.1 Pt detector in once burned fuel (G0)

Figure 3. No.41 Platinum Detector in fresh fuel (H1)

Figure 4. No.5 Rhodium Detector (Fresh), Partner of No.41 Pt detector in fresh fuel (H1)

Figure 5. No.30 Rhodium detector (Fresh), Partner of No.41 Pt detector in fresh fuel (H1)

Figure 6. No.14 Rhodium detector (1 cycle old), Partner of No.41 Pt detector in fresh fuel (H1)

Observations of these figures above are as follows;

a. The platinum detector sensitivity is about one tenth of the fresh Rhodium detector. (Figure 1,2 versus Figure 4,5)

b. The rhodium detector sensitivities decrease about 15% over one EFPY operation at rated power density (Figure 4, 5, and 6)

c. For fresh rhodium detectors, the sensitivity is independent of elevation (Figure 4 and 5), whereas the depleted detector sensitivity has elevation dependence because of an elevation dependent rhodium depletion. (Figure 2 and 6)

d. Basically, the platinum detector has no depletion effect as shown in Figure 1 and Figure 3. When it is installed in a burned assembly, such as No.1 detector, the sensitivity stays at a constant value from BOC (Figure 1), whereas it is in a fresh assembly, a gradual increase of the sensitivity is observed (Figure 3). This is due to the build-up of the fission products of long decay constants. It takes almost three EFPM until it reaches an equilibrium condition.

e. The ‘apparent’ platinum detector sensitivity shows an elevation dependent behavior. Detectors in higher elevation have small sensitivity.

3. Gamma Power Sensitivity Analysis using the PHOENIX-4

PHOENIX-4 calculation is performed to evaluate the response of platinum detector to the gamma flux for the various reactor parameters such that fuel enrichment, burnable poison rod, boron in moderator, moderator temperature and reactor power level. PHOENIX-4 solves the gamma transport equation with 18- gamma energy group after eigen value neutron flux calculation. The time dependent activation terms are assumed to be at equilibrium, and are treated as prompt components.

PHOENIX-4 is run for each assembly type bearing platinum detector in the core to obtain a burnup dependent value of the “sensitivity”, Q_g, that represents the gamma energy deposited in the detector emitter per unit assembly power, i.e.

$$Q_g = \frac{E_g}{P} \tag{2}$$

Table 4 and 5 show that gamma sensitivity has an independency with fuel enrichment, burnable poison rod, moderator temperature except reactor power gradient among the assemblies. It is found that gamma power could be proportional to neutron fission power of the core in steady state even if we don’t determine exact value. As a result, gamma effective neutron power distribution could be inferred from 3-Dimensional fission power distribution of licensed nodal code. The platinum detectors are sensitive to gamma rays from fuel rods in close proximity to the detector. Because of this selective response and power gradients in the assemblies, the actual power distributions in the core environment must be accounted for in determining the detector response.

4. Nodal Weighting Factors (NWF)

4.1 MCNP Calculations

Because the PHOENIX-4 solution already contains a pin-by-pin distribution, some of the importance weighting already accounted for in the calculation of the detector response, i.e. the power distribution of an infinite array of identical assemblies is account for. The effective weighting factor to apply in a core environment is the ratio of the value obtained in a core environment of a single assembly. In practice, centrally located assemblies do not need a weighting factor in the calculation of the detector response, but peripheral assemblies do. Raw signals from platinum detector assembly No.41 are larger than those of platinum detector No.1, even if assembly power was the same, because there are more assemblies around the fuel type “H1” at detector location No.41 than number of location No.1.

MCNP calculation is performed to obtain the gamma response from each individual fuel pin, which assigning a power of unity to the fuel pin of interest and non-zero to all other pins. These calculations are performed for checker-board geometry to validate the extrapolation of Weighting to the neighboring assemblies.

Introducing the Pin Weighting Factors (PWF) W_i, which represents the contribution of the various pins to the signal, importance of pin-by-pin weighting in an assembly is evaluated with Monte Carlo Method code. W_i s are normalized such that;

$$\sum_i W_i = 1.0 \tag{3}$$

The detector signals become proportional to:

$$S_g = Q_g \sum_i W_i * P_i \tag{4}$$

in which P_i is the pin power distribution in the core environment.

The factor W_i (see figure 7 and 8) are obtained from Monte Carlo calculations performed by the MCNP code, and do not depend on the pin type, enrichment, burnup or power. The Nodal Weighting Factors (NWF) W_{nod_i}, which represents the contribution of the various nodes to the signal, is also calculated to simply combine the 3-dimensional node power from ROCS.

4.2 Gamma Effective Neutron Power from 3-D power distribution

As mentioned above, gamma effective neutron powers at detector location in the core are obtained by applying the node weighing factor such that

$$P_{eff} = \frac{\sum_i W_{nod\_i} P_{nod\_i}}{\sum_i W_{nod\_i}} \tag{5}$$

where, W_{nod_i} : Node-wise Weighting Factor , P_{nod_i} : Nodal Power from ROCS/MCEDIT.

Table 6 shows calculated results of detector signals at each level as a function of assembly burnup. As shown in above table, calculated signals of platinum detector No.41 are larger than those of platinum detector No. 1, which show as a similar behavior of the measured signals.

5. Comparison of Measured and Calculated Sensitivities

The measured and calculated sensitivities at the five detector levels for 14 burnup points are combined and normalized to provide a consist comparison as shown in Tables 7 and 8.

In Table 7, the lower measured sensitivities are the more larger that those of higher level sensitivities. It is considered that there is some leakage current effect dependent on detector level present, similar to effects observed at other CE type plants. If measured sensitivities can be corrected for leakage current and other background signal effects, measured sensitivities could be in better agreement with calculated sensitivities as a function of burnup. However, even with adjustments for leakage current and other background signal effects, the measured sensitivities from platinum detector assembly No.41 will not agree well with the calculated sensitivities. This is due to the build-up effect of fission product at the beginning of cycle. As the core depletes, and an equilibrium fission product condition is reached, the error values between measured and calculated sensitivities become reduced because only calculated signals are made at equilibrium condition.

6. Conclusion and Future Works

The signals from platinum detectors installed in YGN4 cycle 5 were analyzed to verify the reliability of the signals and to establish the analysis method for using signals induced from gamma radiation to measure the core power distribution. Gamma transport calculations in various assemblies were performed with PHOENOX-4 code. Introducing the Node Weighting Factors, prompt gamma effective powers at the detector locations are generated considering neighboring assembly gamma power distributions. With comparison of the measured and calculated signals, it is recognized that there are some items that must be resolved to use platinum detectors to measure the core power distribution.

a. Platinum detector sensitivity is one-tenth of the fresh rhodium detector sensitivity, while background signals are the same magnitude. Therefore, signal-to-noise ratio of platinum detector is smaller than that of rhodium detector. It is necessary to increase the platinum response current or eliminate the background wire make maintain a high signal-to-noise ratio.
b. Platinum detector sensitivity shows an elevation dependent behavior. Detectors in higher elevation have smaller sensitivity, probably due to the leakage current of the cable and detector and background correction method. Reducing the dropping resistor to 0.1 Mega Ohm or increasing the response current by increasing detector diameter or length are achievable solutions to reduce the leakage current and background correction impacts.
c. In fresh fuel assemblies, platinum sensitivity is gradually increased due to the buildup of the fission product of long decay constants. An accurate time dependent gamma source buildup model as a function of past power history is required to represent the buildup effect at the beginning of cycle and reactor power transients. In order to establish the model, extensive development work will be required. A neutron sensitive detector material with low neutron absorption cross section, such as vanadium can be used to directly relate the fission rate seen by the platinum detectors to the output signal from the platinum element.

Other prompt responding detector designs are being considered to overcome the weak points of the platinum detectors installed in YGN4 during cycle5. A feasibility study of a hybrid type of detector composed of vanadium and platinum is being performed in conjunction with the Westinghouse Electric Company to evaluate if it can be a viable type of non-depleting prompt detector.

7. Acknowledgment

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8. Reference

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Table 1. Platinum Detector Signals at ICI Location No. 1

Pt01(G0)			Measured Gamma Signal(V)					
CASE	MWD/MTU	EFPD	Level 1	Level 2	Level 3	Level 4	Level 5	Back Gr.
01	537	15	0.076	0.109	0.103	0.102	0.062	-0.026
02	1094	30	0.075	0.106	0.102	0.098	0.059	-0.029
03	1858	45	0.075	0.105	0.100	0.094	0.056	-0.031
04	2244	60	0.075	0.104	0.098	0.091	0.054	-0.034
05	2777	75	0.074	0.103	0.097	0.090	0.054	-0.035
06	3328	90	0.076	0.103	0.097	0.089	0.053	-0.035
07	3885	105	0.076	0.103	0.096	0.088	0.053	-0.036
08	4430	120	0.077	0.103	0.095	0.087	0.052	-0.036
09	4987	135	0.078	0.103	0.095	0.086	0.053	-0.036
10	6119	165	0.078	0.102	0.094	0.086	0.055	-0.036
11	8324	225	0.080	0.102	0.092	0.084	0.055	-0.037
12	9425	255	0.082	0.100	0.092	0.086	0.059	-0.037
13	11812	320	0.091	0.100	0.090	0.086	0.063	-0.040
14	12914	350	0.091	0.100	0.092	0.088	0.065	-0.040

Table 2. Platinum Detector Signals at ICI Location No.41

Pt41(H1)			Measured Gamma Signal(V)					
CASE	MWD/MTU	EFPD	Level 1	Level 2	Level 3	Level 4	Level 5	Back Gr.
01	537	15	0.125	0.188	0.181	0.163	0.105	-0.052
02	1094	30	0.123	0.184	0.177	0.163	0.098	-0.072
03	1858	45	0.124	0.183	0.174	0.160	0.094	-0.080
04	2244	60	0.126	0.183	0.173	0.158	0.092	-0.084
05	2777	75	0.127	0.182	0.172	0.157	0.093	-0.086
06	3328	90	0.131	0.184	0.172	0.156	0.091	-0.087
07	3885	105	0.133	0.183	0.170	0.154	0.091	-0.089
08	4430	120	0.135	0.183	0.170	0.154	0.090	-0.089
09	4987	135	0.137	0.184	0.169	0.152	0.092	-0.089
10	6119	165	0.137	0.183	0.169	0.153	0.095	-0.090
11	8324	225	0.143	0.184	0.167	0.150	0.097	-0.090
12	9425	255	0.147	0.181	0.165	0.153	0.103	-0.090
13	11812	320	0.164	0.177	0.158	0.150	0.111	-0.091
14	12914	350	0.162	0.175	0.161	0.153	0.112	-0.091

Table 3. Characteristics of Fuel Assemblies bearing Pt Detector

Assembly Type	ICI No.	Cycle Age	Level	Accu. Chg Coulomb	Sensitivity	Burnup
G0	1	0	1	Pt	1.0	11950.24
			2	Pt	1.0	14720.57
			3	Pt	1.0	14715.19
			4	Pt	1.0	14408.99
			5	Pt	1.0	11484.62
	45	4	1	120.8574	0.6327	12050.26
			2	141.5983	0.5696	14817.91
			3	139.7295	0.5753	14776.71
			4	138.3208	0.5796	14121.08
			5	115.1745	0.6499	11603.68
H1	41	0	1	Pt	1.0	523.27
			2	Pt	1.0	682.84
			3	Pt	1.0	692.97
			4	Pt	1.0	669.02
			5	Pt	1.0	507.73
	5	0	1	2.1702	0.9934	527.07
			2	3.1222	0.9905	703.32
			3	3.1445	0.9904	696.34
			4	3.1119	0.9905	676.55
			5	2.3049	0.9930	498.34
	14	1	1	61.4843	0.8131	511.45
			2	72.3984	0.7799	685.12
			3	71.3455	0.7831	694.71
			4	67.3827	0.7952	648.15
			5	57.1719	0.8262	512.77
	30	0	1	2.2629	0.9931	526.83
			2	3.0569	0.9907	688.80
			3	3.2012	0.9903	704.16
			4	3.1230	0.9905	676.98
			5	2.4054	0.9927	516.35

Table 4. Sensitivity and Gamma Power to Reaction Rate Ratio for Pt01 (G0)

Burnup	RRate			Gdose(W)			Gdose/RRate			Normal(G/R)			Ratio	
	G0_100P	G0_70P	G0_40P	G0_100P	G0_70P	G0_40P	G0_100P	G0_70P	G0_40P	G0_100P	G0_70P	G0_40P	70%pwr	40%pwr
0	7.92E+13	5.55E+13	3.17E+13	7.59E-02	5.31E-02	3.04E-02	9.58E-16	9.58E-16	9.58E-16	0.0360	0.0360	0.0360	0.7000	0.4000
1	8.09E+13	5.65E+13	3.21E+13	7.77E-02	5.42E-02	3.08E-02	9.60E-16	9.59E-16	9.59E-16	0.0360	0.0361	0.0361	0.6981	0.3971
150	8.12E+13	5.67E+13	3.22E+13	7.78E-02	5.43E-02	3.09E-02	9.59E-16	9.59E-16	9.59E-16	0.0360	0.0360	0.0361	0.6982	0.3972
500	8.15E+13	5.69E+13	3.24E+13	7.82E-02	5.46E-02	3.11E-02	9.59E-16	9.59E-16	9.59E-16	0.0360	0.0360	0.0361	0.6982	0.3971
1000	8.19E+13	5.72E+13	3.25E+13	7.85E-02	5.48E-02	3.12E-02	9.59E-16	9.59E-16	9.59E-16	0.0360	0.0360	0.0361	0.6981	0.3971
2001	8.24E+13	5.76E+13	3.27E+13	7.90E-02	5.51E-02	3.14E-02	9.58E-16	9.58E-16	9.58E-16	0.0360	0.0360	0.0360	0.6981	0.3971
3000	8.31E+13	5.80E+13	3.30E+13	7.95E-02	5.55E-02	3.16E-02	9.57E-16	9.57E-16	9.57E-16	0.0359	0.0360	0.0360	0.6981	0.3971
4000	8.37E+13	5.85E+13	3.33E+13	8.00E-02	5.58E-02	3.18E-02	9.55E-16	9.55E-16	9.55E-16	0.0359	0.0359	0.0359	0.6981	0.3971
5000	8.45E+13	5.90E+13	3.35E+13	8.05E-02	5.62E-02	3.20E-02	9.54E-16	9.54E-16	9.53E-16	0.0358	0.0358	0.0359	0.6981	0.3971
6000	8.52E+13	5.95E+13	3.38E+13	8.11E-02	5.66E-02	3.22E-02	9.52E-16	9.52E-16	9.51E-16	0.0357	0.0358	0.0358	0.6981	0.3970
7000	8.59E+13	6.00E+13	3.41E+13	8.16E-02	5.70E-02	3.24E-02	9.50E-16	9.50E-16	9.49E-16	0.0357	0.0357	0.0357	0.6981	0.3970
8000	8.67E+13	6.05E+13	3.44E+13	8.22E-02	5.74E-02	3.26E-02	9.47E-16	9.47E-16	9.47E-16	0.0356	0.0356	0.0356	0.6981	0.3970
9000	8.75E+13	6.11E+13	3.48E+13	8.27E-02	5.77E-02	3.28E-02	9.45E-16	9.45E-16	9.45E-16	0.0355	0.0355	0.0356	0.6981	0.3970
10000	8.83E+13	6.16E+13	3.51E+13	8.33E-02	5.81E-02	3.31E-02	9.43E-16	9.43E-16	9.42E-16	0.0354	0.0354	0.0355	0.6980	0.3969
11000	8.91E+13	6.22E+13	3.54E+13	8.38E-02	5.85E-02	3.33E-02	9.41E-16	9.40E-16	9.40E-16	0.0353	0.0353	0.0354	0.6980	0.3969
12000	8.99E+13	6.28E+13	3.57E+13	8.44E-02	5.89E-02	3.35E-02	9.38E-16	9.38E-16	9.37E-16	0.0352	0.0353	0.0353	0.6980	0.3969
14000	9.16E+13	6.40E+13	3.64E+13	8.55E-02	5.97E-02	3.39E-02	9.33E-16	9.33E-16	9.32E-16	0.0351	0.0351	0.0351	0.6980	0.3969
18000	9.51E+13	6.64E+13	3.78E+13	8.78E-02	6.13E-02	3.48E-02	9.23E-16	9.23E-16	9.22E-16	0.0347	0.0347	0.0347	0.6979	0.3968
21999	9.87E+13	6.89E+13	3.92E+13	9.01E-02	6.29E-02	3.58E-02	9.13E-16	9.12E-16	9.11E-16	0.0343	0.0343	0.0343	0.6979	0.3969
25999	1.02E+14	7.16E+13	4.08E+13	9.25E-02	6.46E-02	3.67E-02	9.03E-16	9.02E-16	9.00E-16	0.0339	0.0339	0.0339	0.6980	0.3970
29999	1.06E+14	7.44E+13	4.24E+13	9.50E-02	6.63E-02	3.77E-02	8.92E-16	8.91E-16	8.90E-16	0.0335	0.0335	0.0335	0.6980	0.3971
33999	1.11E+14	7.73E+13	4.41E+13	9.75E-02	6.81E-02	3.87E-02	8.82E-16	8.81E-16	8.79E-16	0.0331	0.0331	0.0331	0.6981	0.3974
37999	1.15E+14	8.02E+13	4.58E+13	1.00E-01	6.99E-02	3.98E-02	8.73E-16	8.71E-16	8.69E-16	0.0328	0.0328	0.0327	0.6983	0.3976
41999	1.19E+14	8.33E+13	4.76E+13	1.03E-01	7.18E-02	4.09E-02	8.63E-16	8.62E-16	8.59E-16	0.0324	0.0324	0.0323	0.6984	0.3979
45999	1.23E+14	8.64E+13	4.94E+13	1.06E-01	7.37E-02	4.20E-02	8.55E-16	8.53E-16	8.51E-16	0.0321	0.0321	0.0320	0.6985	0.3981
49999	1.28E+14	8.95E+13	5.12E+13	1.08E-01	7.57E-02	4.31E-02	8.47E-16	8.46E-16	8.43E-16	0.0318	0.0318	0.0317	0.6986	0.3984
53999	1.32E+14	9.25E+13	5.30E+13	1.11E-01	7.76E-02	4.42E-02	8.40E-16	8.39E-16	8.35E-16	0.0316	0.0315	0.0314	0.6988	0.3986
57999	1.36E+14	9.54E+13	5.46E+13	1.14E-01	7.94E-02	4.53E-02	8.34E-16	8.33E-16	8.29E-16	0.0313	0.0313	0.0312	0.6989	0.3988
61999	1.40E+14	9.81E+13	5.62E+13	1.16E-01	8.12E-02	4.63E-02	8.30E-16	8.28E-16	8.24E-16	0.0312	0.0311	0.0310	0.6989	0.3988
65999	1.44E+14	1.01E+14	5.77E+13	1.19E-01	8.29E-02	4.73E-02	8.26E-16	8.24E-16	8.20E-16	0.0310	0.0310	0.0309	0.6989	0.3989
70000	1.47E+14	1.03E+14	5.90E+13	1.21E-01	8.45E-02	4.82E-02	8.23E-16	8.21E-16	8.18E-16	0.0309	0.0308	0.0308	0.6989	0.3989
74000	1.50E+14	1.05E+14	6.01E+13	1.23E-01	8.59E-02	4.90E-02	8.21E-16	8.19E-16	8.15E-16	0.0308	0.0308	0.0307	0.6989	0.3988

Table 5. Sensitivity and Gamma Power to Reaction Rate Ratio for Pt41 (H1)

Burnup	RRate			Gdose(W)			Gdose/RRate			Normal(G/R)			Ratio	
	H1_100P	H1_70P	H1_40P	H1_100P	H1_70P	H1_40P	H1_100P	H1_70P	H1_40P	H1_100P	H1_70P	H1_40P	70%pwr	40%pwr
0	8.04E+13	5.63E+13	3.22E+13	7.93E-02	5.55E-02	3.17E-02	9.86E-16	9.86E-16	9.86E-16	0.0372	0.0372	0.0373	0.7000	0.4000
1	8.21E+13	5.73E+13	3.26E+13	8.11E-02	5.66E-02	3.22E-02	9.88E-16	9.88E-16	9.87E-16	0.0373	0.0373	0.0373	0.6981	0.3971
150	8.23E+13	5.74E+13	3.27E+13	8.12E-02	5.67E-02	3.23E-02	9.87E-16	9.87E-16	9.87E-16	0.0372	0.0373	0.0373	0.6982	0.3972
500	8.26E+13	5.77E+13	3.28E+13	8.15E-02	5.69E-02	3.24E-02	9.87E-16	9.87E-16	9.87E-16	0.0372	0.0373	0.0373	0.6981	0.3972
1000	8.29E+13	5.79E+13	3.29E+13	8.18E-02	5.71E-02	3.25E-02	9.87E-16	9.87E-16	9.87E-16	0.0372	0.0372	0.0373	0.6980	0.3971
2001	8.33E+13	5.82E+13	3.31E+13	8.21E-02	5.73E-02	3.26E-02	9.85E-16	9.85E-16	9.85E-16	0.0372	0.0372	0.0372	0.6981	0.3971
3000	8.38E+13	5.85E+13	3.33E+13	8.24E-02	5.75E-02	3.27E-02	9.84E-16	9.84E-16	9.84E-16	0.0371	0.0371	0.0372	0.6981	0.3971
4000	8.42E+13	5.88E+13	3.35E+13	8.27E-02	5.78E-02	3.29E-02	9.82E-16	9.82E-16	9.82E-16	0.0371	0.0371	0.0371	0.6981	0.3971
5000	8.47E+13	5.91E+13	3.36E+13	8.30E-02	5.80E-02	3.30E-02	9.80E-16	9.80E-16	9.80E-16	0.0370	0.0370	0.0370	0.6981	0.3971
6000	8.51E+13	5.94E+13	3.38E+13	8.33E-02	5.81E-02	3.31E-02	9.78E-16	9.78E-16	9.78E-16	0.0369	0.0369	0.0370	0.6981	0.3971
7000	8.55E+13	5.97E+13	3.40E+13	8.35E-02	5.83E-02	3.32E-02	9.76E-16	9.76E-16	9.76E-16	0.0368	0.0369	0.0369	0.6981	0.3971
8000	8.58E+13	5.99E+13	3.41E+13	8.37E-02	5.84E-02	3.32E-02	9.75E-16	9.75E-16	9.74E-16	0.0368	0.0368	0.0368	0.6981	0.3970
9000	8.61E+13	6.01E+13	3.42E+13	8.38E-02	5.85E-02	3.33E-02	9.72E-16	9.72E-16	9.72E-16	0.0367	0.0367	0.0367	0.6980	0.3970
10000	8.64E+13	6.03E+13	3.43E+13	8.38E-02	5.85E-02	3.33E-02	9.70E-16	9.70E-16	9.70E-16	0.0366	0.0366	0.0366	0.6980	0.3970
11000	8.66E+13	6.05E+13	3.44E+13	8.38E-02	5.85E-02	3.33E-02	9.68E-16	9.68E-16	9.67E-16	0.0365	0.0365	0.0366	0.6980	0.3969
12000	8.69E+13	6.07E+13	3.45E+13	8.39E-02	5.86E-02	3.33E-02	9.66E-16	9.66E-16	9.65E-16	0.0364	0.0364	0.0365	0.6980	0.3968
14000	8.82E+13	6.15E+13	3.50E+13	8.47E-02	5.91E-02	3.36E-02	9.61E-16	9.60E-16	9.60E-16	0.0362	0.0363	0.0363	0.6979	0.3968
18000	9.13E+13	6.38E+13	3.63E+13	8.68E-02	6.05E-02	3.44E-02	9.50E-16	9.50E-16	9.49E-16	0.0358	0.0358	0.0359	0.6979	0.3967
21999	9.47E+13	6.61E+13	3.76E+13	8.89E-02	6.20E-02	3.53E-02	9.39E-16	9.38E-16	9.37E-16	0.0354	0.0354	0.0354	0.6979	0.3968
25999	9.82E+13	6.86E+13	3.91E+13	9.11E-02	6.36E-02	3.62E-02	9.28E-16	9.27E-16	9.26E-16	0.0350	0.0350	0.0350	0.6979	0.3969
29999	1.02E+14	7.12E+13	4.06E+13	9.34E-02	6.52E-02	3.71E-02	9.17E-16	9.16E-16	9.14E-16	0.0346	0.0346	0.0345	0.6980	0.3970
33999	1.06E+14	7.39E+13	4.21E+13	9.58E-02	6.69E-02	3.81E-02	9.06E-16	9.05E-16	9.03E-16	0.0342	0.0342	0.0341	0.6981	0.3972
37999	1.10E+14	7.67E+13	4.38E+13	9.83E-02	6.86E-02	3.91E-02	8.95E-16	8.94E-16	8.92E-16	0.0338	0.0338	0.0337	0.6982	0.3974
41999	1.14E+14	7.97E+13	4.55E+13	1.01E-01	7.04E-02	4.01E-02	8.85E-16	8.84E-16	8.82E-16	0.0334	0.0334	0.0333	0.6983	0.3977
45999	1.18E+14	8.27E+13	4.72E+13	1.03E-01	7.23E-02	4.12E-02	8.76E-16	8.74E-16	8.72E-16	0.0330	0.0330	0.0329	0.6984	0.3980
49999	1.22E+14	8.57E+13	4.90E+13	1.06E-01	7.41E-02	4.23E-02	8.67E-16	8.65E-16	8.62E-16	0.0327	0.0327	0.0326	0.6985	0.3982
53999	1.27E+14	8.87E+13	5.08E+13	1.09E-01	7.60E-02	4.34E-02	8.59E-16	8.57E-16	8.54E-16	0.0324	0.0323	0.0323	0.6987	0.3984
57999	1.31E+14	9.17E+13	5.25E+13	1.11E-01	7.79E-02	4.44E-02	8.51E-16	8.50E-16	8.46E-16	0.0321	0.0321	0.0320	0.6988	0.3987
61999	1.35E+14	9.46E+13	5.42E+13	1.14E-01	7.97E-02	4.55E-02	8.45E-16	8.43E-16	8.40E-16	0.0319	0.0318	0.0317	0.6989	0.3988
65999	1.39E+14	9.73E+13	5.57E+13	1.17E-01	8.15E-02	4.65E-02	8.40E-16	8.38E-16	8.34E-16	0.0317	0.0316	0.0315	0.6989	0.3989
70000	1.42E+14	9.98E+13	5.72E+13	1.19E-01	8.32E-02	4.75E-02	8.35E-16	8.33E-16	8.30E-16	0.0315	0.0315	0.0314	0.6989	0.3989
74000	1.46E+14	1.02E+14	5.85E+13	1.21E-01	8.48E-02	4.84E-02	8.32E-16	8.30E-16	8.27E-16	0.0314	0.0313	0.0312	0.6989	0.3989

Table 6. Calculated Results of Platinum Detector Powers (MW/40cm)

		Level 1		Level 2		Level 3		Level 4		Level 5	
Assembly Type		G0	H1	G0	H1	G0	H1	G0	H1	G0	H1
Case No.	Burnup	Level 1	Level 1	Level 2	Level 2	Level 3	Level 3	Level 4	Level 4	Level 5	Level 5
00	0	0.349099	0.641127	0.300739	0.546202	0.312767	0.562889	0.301056	0.537461	0.346270	0.613744
01	537	0.751311	1.383168	0.296596	0.539090	0.312445	0.563506	0.305215	0.546856	0.355683	0.633688
02	1094	0.346979	0.635517	0.292354	0.529614	0.303411	0.545244	0.297904	0.531941	0.354568	0.629790
03	1858	0.352209	0.644053	0.293435	0.531247	0.302168	0.542707	0.295689	0.527586	0.352814	0.625620
04	2244	0.359780	0.656798	0.294723	0.532902	0.301241	0.540301	0.295604	0.526817	0.356817	0.631881
05	2777	0.364392	0.664584	0.295222	0.533320	0.299871	0.537501	0.294059	0.523716	0.357026	0.631602
06	3328	0.372381	0.678239	0.297183	0.536351	0.298803	0.535090	0.292012	0.519406	0.356368	0.629306
07	3885	0.377560	0.686828	0.297544	0.536630	0.297580	0.532472	0.290904	0.517069	0.357858	0.631173
08	4430	0.381994	0.694025	0.297737	0.536494	0.296513	0.530264	0.290083	0.515292	0.359598	0.633327
09	4987	0.385076	0.698846	0.297335	0.535754	0.295187	0.527782	0.288924	0.513128	0.360556	0.634306
10	6119	0.388736	0.704839	0.297748	0.536569	0.294890	0.527328	0.288726	0.512627	0.362080	0.636289
11	8324	0.397013	0.719954	0.299326	0.540390	0.292253	0.523449	0.282609	0.502138	0.354400	0.621967
12	9425	0.399760	0.725675	0.296964	0.537528	0.290418	0.521225	0.284480	0.506816	0.363405	0.637611
13	11812	0.427582	0.776972	0.301960	0.545797	0.285150	0.510538	0.275829	0.489670	0.356604	0.624689
14	12914	0.431941	0.774198	0.287217	0.509539	0.281047	0.495089	0.292134	0.511240	0.415796	0.722702

Table 7. Comparison of Normalized Measured & Calculated Sensitivities for Pt Detector No.1

Pt01(G0)			Measured - Calculated					(Measured-Calculated)/Measured				
CASE	MWD/MTU	EFPD	Level 1	Level 2	Level 3	Level 4	Level 5	Level 1	Level 2	Level 3	Level 4	Level 5
01	537	15	0.01381	0.01048	-0.00413	0.00151	-0.02167	6.4%	5.0%	-2.1%	0.8%	-12.2%
02	1094	30	0.01359	0.00889	-0.00134	0.00023	-0.02137	6.4%	4.2%	-0.7%	0.1%	-12.0%
03	1858	45	0.01357	0.01000	0.00009	-0.00085	-0.02281	6.3%	4.8%	0.0%	-0.4%	-12.9%
04	2244	60	0.01410	0.00980	-0.00027	-0.00215	-0.02147	6.6%	4.7%	-0.1%	-1.1%	-12.1%
05	2777	75	0.01216	0.01005	0.00036	-0.00190	-0.02066	5.7%	4.8%	0.2%	-1.0%	-11.6%
06	3328	90	0.01233	0.00920	0.00106	-0.00196	-0.02064	5.8%	4.4%	0.5%	-1.0%	-11.6%
07	3885	105	0.00929	0.00855	0.00061	-0.00121	-0.01725	4.4%	4.1%	0.3%	-0.6%	-9.5%
08	4430	120	0.01212	0.01049	0.00060	-0.00242	-0.02079	5.7%	5.0%	0.3%	-1.2%	-11.6%
09	4987	135	0.01179	0.01013	0.00127	-0.00311	-0.02008	5.6%	4.8%	0.6%	-1.6%	-11.2%
10	6119	165	0.01215	0.00974	0.00060	-0.00299	-0.01950	5.7%	4.6%	0.3%	-1.5%	-10.8%
11	8324	225	0.01174	0.00936	0.00029	-0.00242	-0.01896	5.5%	4.5%	0.1%	-1.2%	-10.5%
12	9425	255	0.01174	0.01170	0.00161	-0.00332	-0.02174	5.5%	5.5%	0.8%	-1.7%	-12.2%
13	11812	320	0.01379	0.00824	-0.00011	-0.00360	-0.01833	6.4%	4.0%	-0.1%	-1.8%	-10.1%
14	12914	350	0.01325	0.00716	-0.00047	-0.00338	-0.01656	6.2%	3.4%	-0.2%	-1.7%	-9.1%

Table 8. Comparison of Normalized Measured & Calculated Sensitivities for Pt Detector No.41

Pt41(H1)			Measured - Calculated					(Measured-Calculated)/Measured				
CASE	MWD/MTU	EFPD	Level 1	Level 2	Level 3	Level 4	Level 5	Level 1	Level 2	Level 3	Level 4	Level 5
01	537	15	0.00404	0.01300	0.00348	-0.00588	-0.01464	2.0%	6.1%	1.7%	-3.0%	-7.9%
02	1094	30	0.00515	0.00945	0.00156	-0.00287	-0.01329	2.5%	4.5%	0.8%	-1.5%	-7.1%
03	1858	45	0.00543	0.00908	0.00130	-0.00234	-0.01346	2.6%	4.4%	0.6%	-1.2%	-7.2%
04	2244	60	0.00569	0.00833	0.00106	-0.00267	-0.01241	2.8%	4.0%	0.5%	-1.4%	-6.6%
05	2777	75	0.00573	0.00799	0.00103	-0.00300	-0.01176	2.8%	3.9%	0.5%	-1.5%	-6.2%
06	3328	90	0.00580	0.00798	0.00095	-0.00299	-0.01174	2.8%	3.8%	0.5%	-1.5%	-6.2%
07	3885	105	0.00431	0.00597	-0.00003	-0.00258	-0.00768	2.1%	2.9%	0.0%	-1.3%	-4.0%
08	4430	120	0.00663	0.00724	0.00064	-0.00317	-0.01134	3.2%	3.5%	0.3%	-1.6%	-6.0%
09	4987	135	0.00665	0.00774	0.00060	-0.00398	-0.01101	3.2%	3.7%	0.3%	-2.0%	-5.8%
10	6119	165	0.00679	0.00769	0.00091	-0.00373	-0.01166	3.3%	3.7%	0.5%	-1.9%	-6.2%
11	8324	225	0.00678	0.00739	0.00129	-0.00377	-0.01170	3.3%	3.6%	0.6%	-1.9%	-6.2%
12	9425	255	0.00794	0.00998	0.00298	-0.00575	-0.01515	3.8%	4.8%	1.5%	-3.0%	-8.2%
13	11812	320	0.00987	0.00694	0.00014	-0.00473	-0.01222	4.7%	3.4%	0.1%	-2.4%	-6.5%
14	12914	350	0.00882	0.00595	0.00056	-0.00379	-0.01154	4.2%	2.9%	0.3%	-1.9%	-6.1%

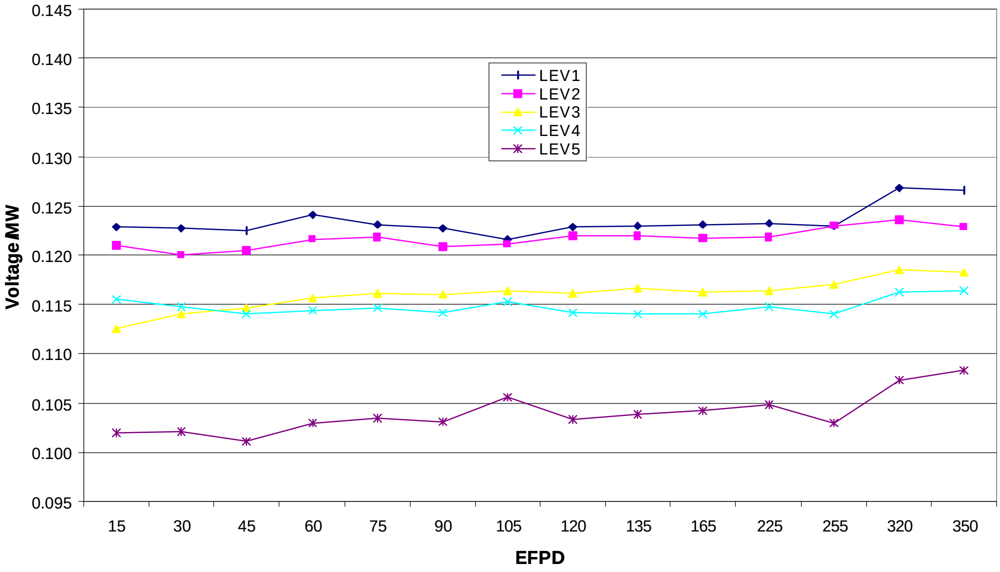

Figure 1. No.1 Platinum Detector in once burned fuel (G0)

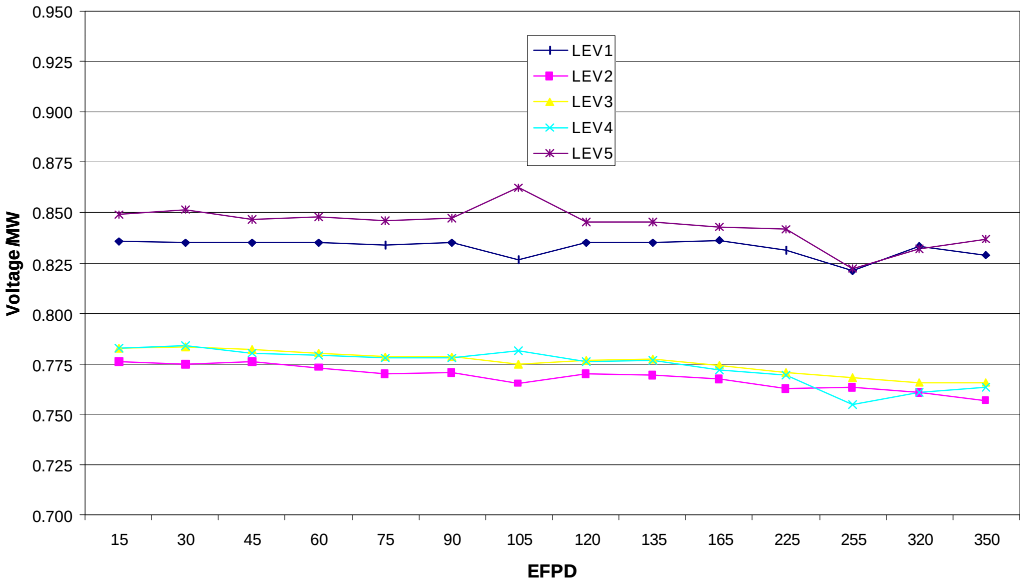

Figure 2. No.45 Rhodium Detector (4 cycle old), Partner of No.1 Pt detector in once burned fuel (G0)

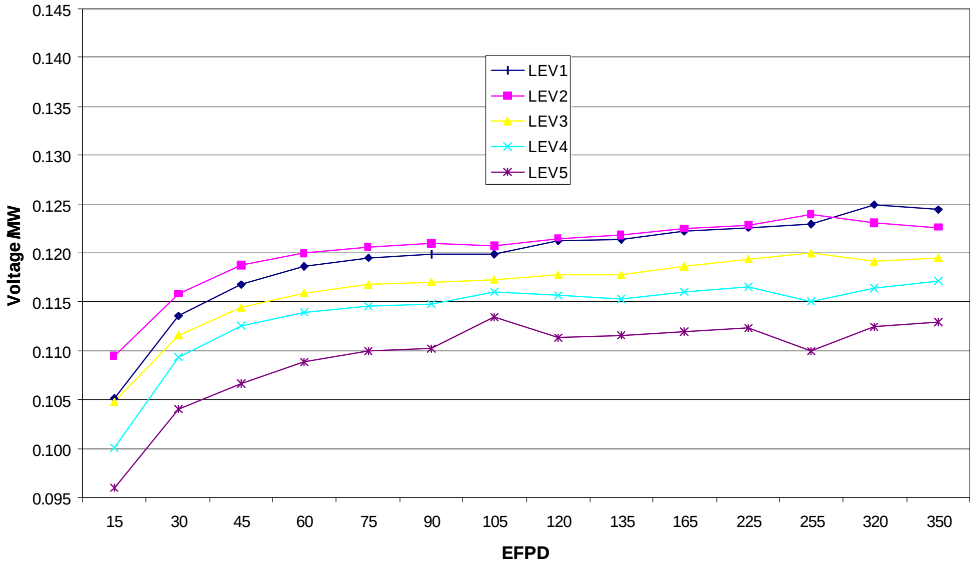

Figure 3. No.41 Platinum Detector in fresh fuel (H1)

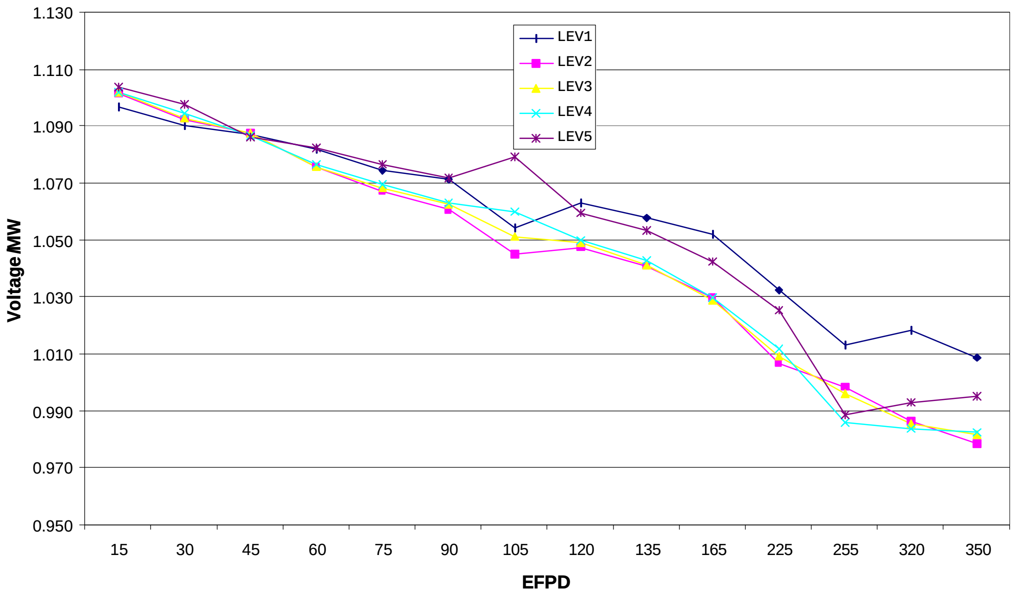

Figure 4. No.5 Rhodium Detector (Fresh), Partner of No.41 Pt detector in fresh fuel (H1)

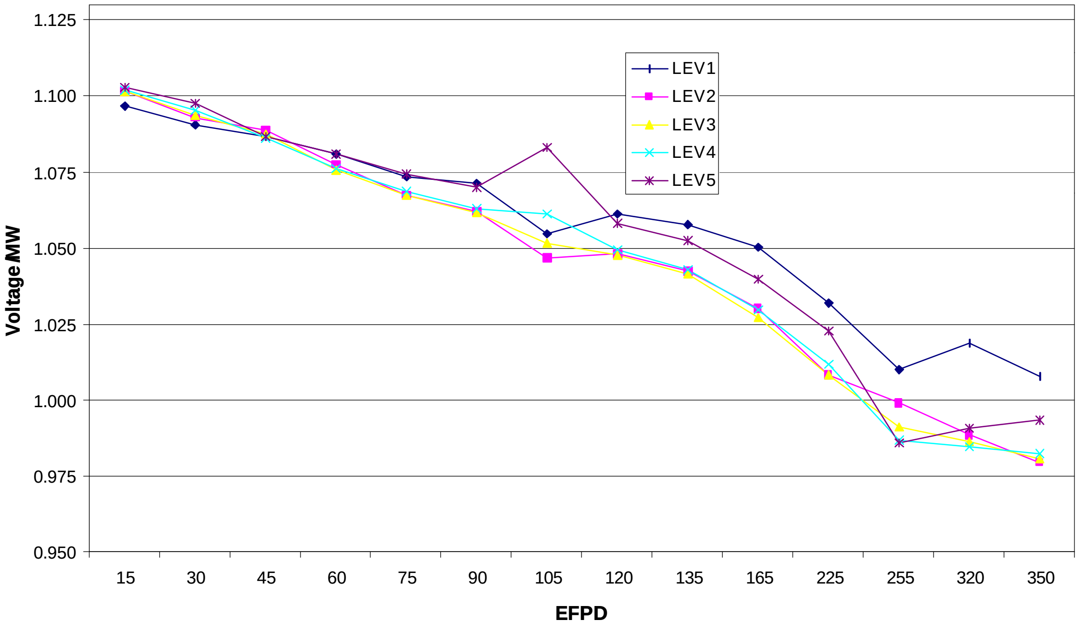

Figure 5. No.30 Rhodium detector (Fresh), Partner of No.41 Pt detector in fresh fuel (H1)

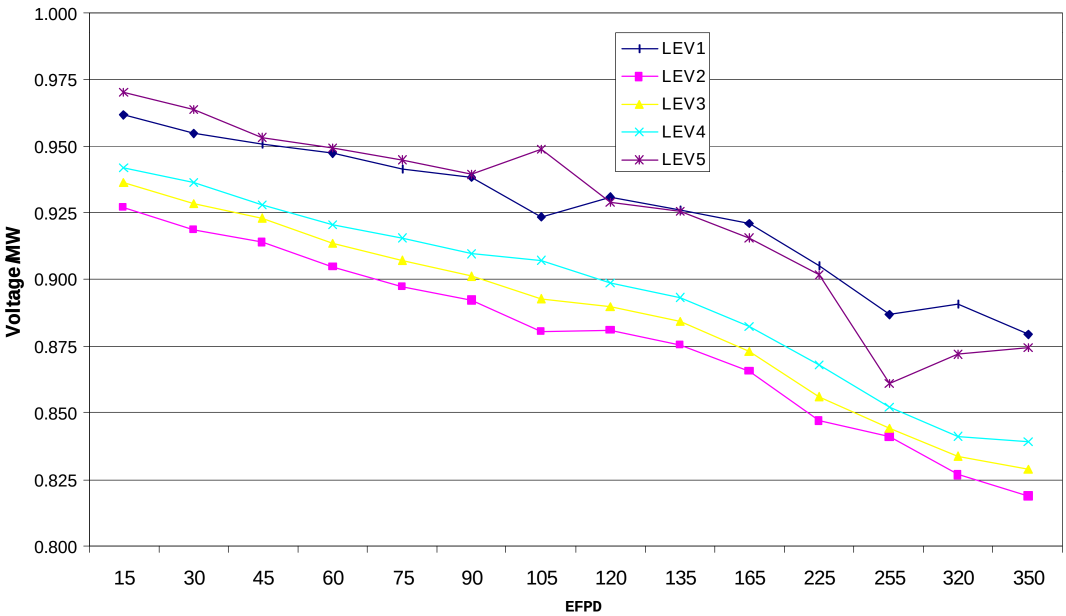

Figure 6. No.14 Rhodium detector (1 cycle old), Partner of No.41 Pt detector in fresh fuel (H1)

0.019805								0.000116	0.000160	0.000053	0.000157	0.000020	0.000032	0.000062	0.006552
								0.000102	0.000022	0.000014	0.000076	0.000078	0.000038	0.000049	0.000062
								0.000086	0.000145	0.000120	0.000102	0.000062	0.000162	0.000038	0.000032
								0.000035	0.000075	0.000038			0.000062	0.000078	0.000020
								0.000083	0.000130	0.000136			0.000102	0.000076	0.000157
								0.000401	0.000217	0.000149	0.000136	0.000038	0.000120	0.000014	0.000053
								0.000300	0.000215	0.000217	0.000130	0.000075	0.000145	0.000022	0.000160
								0.000260	0.000300	0.000401	0.000083	0.000035	0.000086	0.000102	0.000116
0.001852	0.001228	0.001204	0.000980	0.000912	0.000822	0.000662	0.000769	0.000486	0.000471	0.000235	0.000140	0.000201	0.000100	0.000037	0.000090
0.002364	0.002090	0.001732	0.001222	0.001418	0.001122	0.001327	0.000662	0.000655	0.000404	0.000197	0.000138	0.000112	0.000042	0.000142	0.000079
0.004091	0.003108	0.002763	0.002744	0.002764	0.002230	0.001122	0.000822	0.000654	0.000411	0.000315	0.000203	0.000235	0.000157	0.000096	0.000091
0.005795	0.004536	0.004381			0.002764	0.001418	0.000912	0.000622	0.000397	0.000351			0.000125	0.000228	0.000147
0.010058	0.008043	0.007819			0.002744	0.001222	0.000980	0.000817	0.000433	0.000391			0.000103	0.000219	0.000040
0.020183	0.020099	0.011262	0.007819	0.004381	0.002763	0.001732	0.001204	0.000714	0.000455	0.000377	0.000208	0.000178	0.000130	0.000198	0.000125
0.053999	0.038981	0.020099	0.008043	0.004536	0.003108	0.002090	0.001228	0.000956	0.000509	0.000558	0.000395	0.000293	0.000216	0.000372	0.000142
0.390551	0.053999	0.020183	0.010058	0.005795	0.004091	0.002364	0.001852	0.001221	0.000893	0.000634	0.000428	0.000389	0.000445	0.000405	0.019805
Pt															

Figure 7. Pin Weighting Factors without GD Rods

0.019779								0.000116	0.000159	0.000053	0.000157	0.000020	0.000032	0.000062	0.006579
								0.000102	0.000022	0.000014	0.000076	0.000078	0.000038	0.000049	0.000062
								0.000086	0.000145	0.000120	0.000101	0.000083	0.000162	0.000038	0.000032
								0.000035	0.000075	0.000039			0.000083	0.000078	0.000020
								0.000083	0.000130	0.000136			0.000101	0.000076	0.000157
								0.000401	0.000211	0.000149	0.000136	0.000039	0.000120	0.000014	0.000053
								0.000300	0.000210	0.000211	0.000130	0.000075	0.000145	0.000022	0.000159
								0.000260	0.000300	0.000401	0.000083	0.000035	0.000086	0.000102	0.000116
0.001852	0.001228	0.001208	0.000986	0.000912	0.000804	0.000651	0.000770	0.000457	0.000475	0.000235	0.000140	0.000201	0.000100	0.000037	0.000090
0.002379	0.002087	0.001732	0.001265	0.001402	0.001131	0.001330	0.000651	0.000655	0.000404	0.000197	0.000138	0.000112	0.000042	0.000142	0.000079
0.004103	0.003115	0.002751	0.002746	0.002781	0.002187	0.001131	0.000804	0.000654	0.000401	0.000315	0.000203	0.000235	0.000157	0.000096	0.000091
0.005796	0.004534	0.004392			0.002781	0.001402	0.000912	0.000620	0.000397	0.000351			0.000125	0.000228	0.000147
0.010056	0.008055	0.007840			0.002746	0.001265	0.000986	0.000812	0.000433	0.000391			0.000103	0.000219	0.000039
0.020177	0.020107	0.011313	0.007840	0.004392	0.002751	0.001732	0.001208	0.000715	0.000455	0.000377	0.000208	0.000178	0.000130	0.000198	0.000125
0.054007	0.038997	0.020107	0.008055	0.004534	0.003115	0.002087	0.001228	0.000956	0.000509	0.000558	0.000395	0.000293	0.000216	0.000372	0.000143
0.390794	0.054007	0.020177	0.010056	0.005796	0.004103	0.002379	0.001852	0.001238	0.000893	0.000634	0.000428	0.000389	0.000445	0.000405	0.019779
Pt															

Figure 8. Pin Weighting Factors with GD Rods