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RESPONSE CHARACTERISTICS OF SELF-POWERED FLUX DETECTORS IN CANDU REACTORS

by

C.J. ALLAN

Paper presented at the International Symposium on
Nuclear Power Plant Control and Instrumentation,
April 24-28, 1978, Cannes, France

Chalk River Nuclear Laboratories
Chalk River, Ontario

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Caractéristiques de réponse des détecteurs de flux autonomes dans les réacteurs CANDU

par

C.J. Allan

Résumé

Dans le cadre du développement d'un nouvel ensemble détecteur de flux pour les réacteurs CANDU de l'avenir, les sensibilités d'une variété de détecteurs autonomes au platine, au cobalt et au vanadium ont été déterminées dans un coeur CANDU simulé installé dans le reacteur d'essai ZED-2 à Chalk River. Alors que les détecteurs au cobalt et au vanadium avaient des émetteurs massifs, les détecteurs au platine étaient de deux types ayant:

- soit des émetteurs en platine massif
- soit des émetteurs comprenant une gaine de platine sur un noyau en Inconel.

Presque tous les signaux provenant des détecteurs au cobalt et au vanadium sont dus à des événements neutroniques dans les émetteurs. Dans le cas de ces détecteurs, on a mesuré les sensibilités totales par longueur unitaire. Dans les détecteurs au platine, les rayons gamma du réacteur et les neutrons contribuent tous les deux de façon appréciable aux signaux de sortie. C'est pourquoi, en plus de la sensibilité totale, on a déterminé les sensibilités aux rayons gamma et aux neutrons individuels de ces détecteurs.

On a constaté que les sensibilités des détecteurs dépendent en premier lieu du diamètre de l'émetteur et que les variations observées peuvent être décrites au moyen des lois de la puissance.

Rapport présenté au Colloque international sur le contrôle et l'instrumentation des centrales nucléaires, tenu à Cannes, France, du 24 au 28 avril 1978.

L'Energie Atomique du Canada, Limitée
Laboratoires Nucléaires de Chalk River
Chalk River, Ontario, K0J 1J0

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ABSTRACT

As part of the development of a new flux-detector assembly for future CANDU reactors, the sensitivities of a variety of vanadium, cobalt and platinum self-powered detectors have been determined in a simulated CANDU core installed in the ZED-2 test reactor at CRNL. While the vanadium and cobalt detectors had solid emitters, the platinum detectors were of two types, having either

- solid platinum emitters, or
- emitters consisting of a platinum sheath over an Inconel core.

Almost all of the signal from the cobalt and vanadium detectors is due to neutron events in the emitters. For these detectors we have measured the total sensitivities per unit length. For the platinum detectors, reactor γ-rays and neutrons both contribute appreciably to the output signal, and in addition to the total sensitivity, we have determined the individual neutron and γ-ray sensitivities for these detectors.

It was found that the detector sensitivities depend primarily on emitter diameter and that the observed variations can be fitted by means of power laws.

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RESPONSE CHARACTERISTICS OF SELF-POWERED FLUX DETECTORS IN CANDU REACTORS

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1. INTRODUCTION

Self-powered flux detectors are used extensively in CANDU power reactors [1]. Detectors with V emitters are used for flux mapping [2], while those with Pt emitters are used for bulk and spatial flux control [2], and for overpower protection.

The flux-detector assemblies now used in CANDU reactors contain several detectors coiled on a Zircaloy former (∿ 1 cm OD), installed in a Zircaloy guide tube. The assemblies are normally located in the D_2O moderator, between the fuel channels. To replace a faulty flux detector requires removal of a complete detector assembly. A new assembly is being developed that will permit the replacement of individual detectors and enable detectors to be calibrated in-situ. The new detectors will be straight, rather than coiled, to maintain a reasonable size for the assembly. To achieve the required spatial resolution, the active lengths of the detectors will be reduced by a factor of ∿ 4 for the V (flux-mapping) detectors and a factor of ∿ 3 for the Pt (control/safety system) detectors. To compensate for the resulting loss in output signal, the diameters of the detectors will be increased, to increase the sensitivity per unit length.

To determine the improvement to be obtained by increasing detector diameter, a variety of V and Pt detectors were irradiated in a simulated CANDU power reactor core installed in the ZED-2 test reactor at CRNL; the test assembly used is shown schematically in Fig. 1. Additional irradiations were carried out in a thermal column of the NRU research reactor at CRNL. Although not of immediate interest for CANDU reactors, several Co detectors were also tested.

2. VANADIUM AND COBALT DETECTORS

The variation in sensitivity per unit length for the straight V detectors irradiated in the ZED-2 reactor is plotted in Fig. 2, as a function of emitter diameter. Also included are results obtained by previous workers [3,4,5], and results obtained for coiled detectors irradiated in the NRU thermal column. The sensitivities of the latter detectors are defined in terms of the neutron flux measured at the surface of the detectors, while for the ZED-2 irradiations the sensitivities are expressed in terms of the flux at the surface of the detector test assembly.

Since the signal from a vanadium detector is predominantly due to the beta-decay of ^{52}V, following neutron capture in ^{51}V, the sensitivity per unit length is expected to vary as the square of the emitter diameter, at least for small emitter diameters. As can be seen from Fig. 2, the sensitivity per unit length does follow a square law for emitter diameters $\lesssim$ 0.6 mm, but for larger diameters the sensitivity increases more slowly. This is to be expected since, as the emitter diameter increases, the escape efficiency for electrons generated in the interior of the emitter decreases. For emitter diameters considerably greater than the β-particle range we would expect the sensitivity to vary linearly with diameter, and in practice, even less than linearly, because of increased neutron self-shielding .

A least-squares fit to a power law of the sensitivities determined for the V detectors in ZED-2 gives

$$S = 2.05\times10^{-24}\ D^{1.23}\ A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1}) \qquad (1)$$

where D is the emitter diameter, in mm.

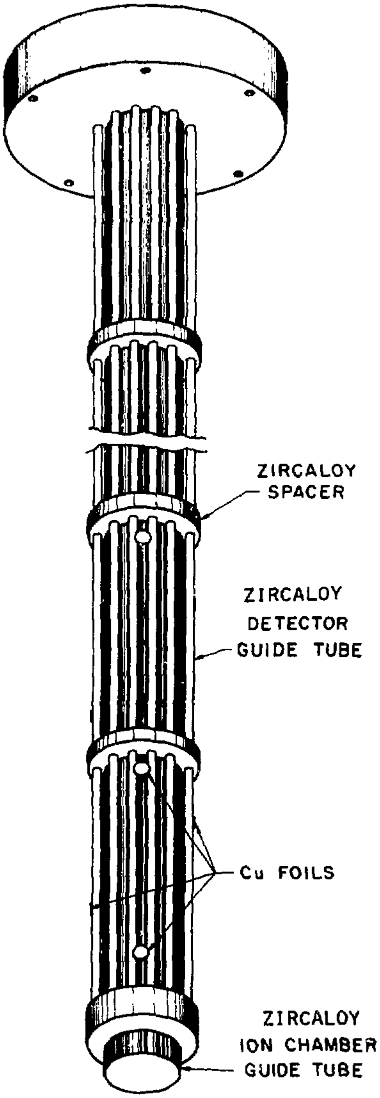

FIGURE 1 - SCHEMATIC REPRESENTATION OF THE TEST ASSEMBLY USED TO IRRADIATE SELF-POWERED DETECTORS IN THE ZED-2 REACTOR

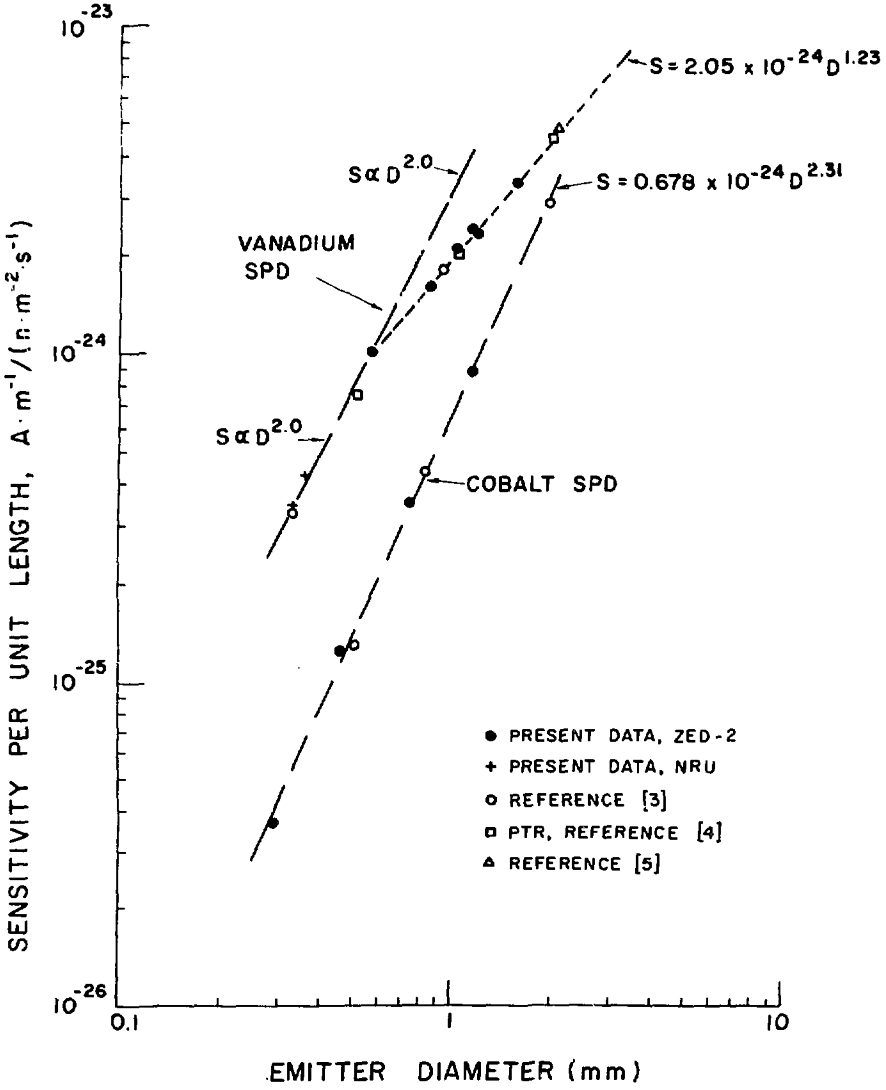

FIGURE 2 - THE SENSITIVITY PER UNIT LENGTH AS A FUNCTION OF EMITTER DIAMETER FOR V and Co SELF-POWERED DETECTORS

Equation (1) fits the data well for emitter diameters $\gtrsim 0.5$ mm, as shown in Fig. 2, and Table I, which summarizes the experimental data. Thus, the sensitivity per unit length depends primarily on the emitter diameter and does not vary appreciably with insulation thickness.

Also shown on Fig. 2 and in Table I are the results obtained here for Co detectors, as well as values determined previously [3]. The Co results are reasonably well fit by the expression

$$S = 0.68\mathrm{x}10^{-24}\ D^{2.31}\ \mathrm{A{\cdot}m^{-1}/(n{\cdot}m^{-2}{\cdot}s^{-1})} \qquad (2)$$

where, again, D is the emitter diameter, in mm.
Here the sensitivity varies more strongly with diameter than a square law, but this is not surprising, since the signal results from a two-step process, radiative neutron capture followed by a γ-ray interaction which liberates an electron. Ignoring self-shielding, the neutron-capture process is expected to vary as the square of the emitter diameter, while there is evidence, from experiments with external γ-rays, that the γ-ray response varies linearly with emitter diameter. Thus, one would expect the sensitivity per unit length of Co detectors to vary as the cube of the emitter diameter, but in practice the sensitivity increases more slowly because of increased self-shielding, and insulation thickness, with increasing detector diameter.

3. PLATINUM DETECTORS

The currents generated by V and Co self-powered detectors are dominated by neutron-induced events. The situation is not so simple for Pt detectors since, in a CANDU reactor, a significant fraction of the total signal is due to reactor γ-rays. As for Co detectors, we expect the neutron sensitivity to vary as the cube of emitter diameter, and the γ-ray-induced current to vary linearly with emitter diameter. Hence, the ratio of neutron to γ-ray-induced currents can be expected to increase significantly with increasing detector size, and we now consider the implications of this.

At a mid-lattice position in a CANDU reactor, only ∿ 70% of reactor γ-rays are prompt [6]. Thus, the signal from a Pt detector does not follow reactor flux transients promptly.

If we assume that the total current, I_T, is a linear superposition of a γ-ray-induced current, I_γ, and a neutron-induced current, I_n, i.e.

$$I_T = I_\gamma + I_n \qquad (3)$$

then

$$\frac{I_{\mathrm{prompt}}}{I_T} \simeq 0.7\,\frac{I_\gamma}{I_T} + \frac{I_n}{I_T} \qquad (4)$$

We define three sensitivities per unit length for Pt detectors; a total sensitivity, S_T, given by

$$S_T = I_T/\phi L \qquad (5)$$

a neutron sensitivity, S_n, given by

$$S_n = I_n/\phi L \qquad (6)$$

and a γ-ray sensitivity, S_γ, given by

TABLE I

SUMMARY OF THE EXPERIMENTAL DATA FOR THE VANADIUM AND COBALT DETECTORS

Detector Serial No.	Type	OD (mm)	Sheath Wall (mm)	Insulation Thickness (mm)	Emitter		Sensitivity per Unit Length $A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})$	
					Diameter (mm)	Length (mm)	Measured	Fitted
TC-1115	V	1.57	0.26	0.24	0.57	317	1.03×10^{-24}	1.03×10^{-24}*
TC-0806	V	2.19	0.39	0.29	0.84	300	1.62	1.65
TC-1015	V	2.18	0.26	0.33	1.01	317	2.11	2.07
TC-1109	V	2.18	0.36	0.17	1.12	315	2.42	2.36
TC-0805	V	3.0	0.53	0.40	1.14	292	2.35	2.41
TC-1108	V	2.96	0.48	0.25	1.51	315	3.39	3.40
UC-0201	Co	1.00	0.18	0.18	0.29	1069	0.037×10^{-24}	0.039×10^{-24}**
UC-0202	Co	1.59	0.28	0.29	0.46	981	0.125	0.113
Reference [3]	Co	1.58	-	-	0.51	300	0.129	0.143
UC-0601	Co	2.20	0.40	0.33	0.74	995	0.352	0.338
Reference [3]	Co	2.11	-	-	0.81	321	0.446	0.417
UC-0602	Co	2.98	0.48	0.45	1.13	1059	0.889	0.899
Reference [3]	Co	3.51	-	-	1.91	230	2.90	3.02

*$S = 2.05\times10^{-24}\ D^{1.23}\ A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})$

**$S = 0.68\times10^{-24}\ D^{2.31}\ A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})$

$$S_\gamma = I_\gamma/\phi L \tag{7}$$

where ϕ is the neutron flux, and
L is the length of the detector.
Note that the γ-ray sensitivity is defined here in terms of the neutron flux, and so will depend on the neutron to γ-ray flux ratio.

The neutron sensitivity will decrease with irradiation while the γ-ray sensitivity will remain essentially constant. Thus, the prompt-response fraction will vary with irradiation, as will the total sensitivity, S_T, the variation depending on the initial neutron and γ-ray sensitivities. Therefore, to properly assess the impact of changes in geometry on the performance of Pt detectors it is necessary to determine how the neutron/γ-ray sensitivity ratio, as well as the total sensitivity, vary with geometry. Both properties will depend on reactor type and detector location, i.e. the neutron/γ-ray flux ratio. The values reported here apply to a mid-lattice position of a CANDU reactor, as simulated in ZED-2, with the detectors mounted in the detector assembly illustrated in Fig. 1, and for an irradiation time of ∿ 1 hour, i.e. long-lived γ-ray contributions are not included.

Two types of Pt detectors were tested, some with solid platinum emitters, and others with emitters consisting of a core of Inconel surrounded by a thin (∿ 0.05 mm) layer of platinum. It was expected that the sensitivities of the latter, designated as Pt-clad detectors, would vary less with irradiation than those of the solid-emitter type. An important additional advantage is the much smaller amount of Pt required, which has the potential for a significant saving in cost.

The experimental data on the Pt detectors are given in Table II. Although it is relatively straightforward to determine the total sensitivities, determining the neutron and γ-ray sensitivities is complicated by the fact that it is difficult, if not impossible, to generate neutrons without also generating γ-rays. Furthermore, the γ-ray sensitivity determined in a ^{60}Co Gammacell, a frequently quoted sensitivity, does not provide an accurate measure of a Pt detector's sensitivity to reactor γ-rays because of differences between the two γ-ray energy spectra.

For the majority of the detectors tested, the neutron sensitivities were determined in ZED-2 by means of a γ-ray/neutron flux perturbation method [7]. If the total sensitivities determined in two different reactor environments, A and B, having neutron fluxes ϕ_A and ϕ_B, are defined as S_{TA} and S_{TB}, and the neutron-induced and γ-ray-induced currents are I_{nA}, I_{nB} and $I_{\gamma A}$, $I_{\gamma B}$, respectively, then

$$\frac{S_{\gamma A}}{S_{nA}} = \frac{S_{TB}/S_{TA} - 1}{I_{\gamma B}\phi_{nA}/I_{\gamma A}\phi_{nB} - S_{TB}/S_{TA}} \tag{8}$$

Since the total sensitivities and neutron fluxes are readily determined, equation (8) can be solved for the ratio $S_{\gamma A}/S_{nA}$ provided the ratio $I_{\gamma B}/I_{\gamma A}$ can be determined.

For our experiments, condition A corresponds to a normal mid-lattice position, while condition B was obtained by locating the flux-detector assembly at the centre of a thermal flux pit, formed by removing the five

TABLE II

SUMMARY OF THE EXPERIMENTAL DATA FOR THE PLATINUM DETECTORS

DETECTOR								SENSITIVITY PER UNIT LENGTH						
SERIAL NO.	TYPE	OD (mm)	SHEATH WALL (mm)	(g/m)	EMITTER DIAMETER (mm)	INSULATION THICKNESS (mm)	CLADDING THICKNESS (mm)	S_n $A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$ $x10^{25}$		S_γ $A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$ $x10^{25}$			S_T $A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$ $x10^{25}$	
								MEASURED	FITTED	MEASURED	FITTED		MEASURED	FITTED
											S_{γ_1}	S_{γ_2}		
TC-1114	Solid	1.56	0.22	7.81	0.59	0.27	NA	1.02±0.10	1.05*	0.83±0.09	0.82	0.85	1.85±0.03	1.87*
TC-1001	Solid	2.18	0.27	13.7	0.97	0.34	NA	2.45±0.15	2.38	1.21±0.15	1.17	1.16	3.65±0.04	3.58
TC-0804	Solid	3.0	0.53	34.7	1.08	0.43	NA	2.98±0.12	2.84	1.16±0.12	1.26	1.14	4.14±0.04	4.13
TC-0107	Solid	3.0	0.45	30.4	1.44	0.33	NA	4.35±0.24	4.57	1.61±0.18	1.55	1.67	5.96±0.07	6.02
UC-0604	Clad	1.56	0.28	9.8	0.56	0.22	0.03	0.57±0.07	0.57**	0.61±0.07	0.60	0.63	1.18	1.15
TC-1017	Clad	2.18	0.35	17.0	0.81	0.34	0.055	1.10±0.10	1.11	0.80±0.10	0.85	0.79	1.90±0.03	1.98
TC-1203	Clad	2.20	0.24	12.5	1.01	0.36	0.046	1.57±0.10	1.66	1.05±0.10	1.05	1.01	2.62±0.03	2.73
TC-1113	Clad	2.18	0.32	15.8	1.06	0.24	0.045	1.82±0.18	1.81	1.38±0.18	1.10	1.31	3.20±0.10	2.94
TC-1111	Clad	2.96	0.48	31.5	1.09	0.46	0.059	2.02±0.09	1.91	0.95±0.09	1.13	0.97	2.97±0.05	3.06
TC-1202	Clad	2.98	0.33	23.2	1.40	0.46	0.062	2.86±0.13	3.01	1.34±0.13	1.43	1.32	4.20±0.10	4.41
TC-1204	Clad	2.98	0.45	30.2	1.44	0.32	0.062	3.30±0.15	3.17	1.55±0.15	1.47	1.65	4.85±0.10	4.60

*Solid Pt:
$S_n = 2.50x10^{-25}\ D^{1.65}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$
$S_{\gamma_1} = 1.20x10^{-25}\ D^{0.71}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$
$S_{\gamma_2} = 0.70x10^{-25}\ D^{0.87}/\sqrt{T}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$
$S_T = 3.73x10^{-25}\ D^{1.31}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$

**Pt-Clad:
$S_n = 1.63x10^{-25}\ D^{1.82}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$
$S_{\gamma_1} = 1.04x10^{-25}\ D^{0.95}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$
$S_{\gamma_2} = 0.59x10^{-25}\ D^{1.22}/T^{0.51}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$
$S_T = 2.70x10^{-25}\ D^{1.47}\ A \cdot m^{-1}/(n \cdot m^{-2} \cdot s^{-1})$

central fuel assemblies in ZED-2, and surrounding it with an annulus of Bi, ∿ 2.5 cm thick, to suppress the γ-ray flux relative to the neutron flux.

The ratio $I_{\gamma B}/I_{\gamma A}$ was determined using a coiled, self-powered detector having a lead emitter and an Inconel sheath. This detector was inserted in the central, ion-chamber guide tube of the detector assembly. (See Fig. 1.)

It was found that the Pb detector had an appreciable neutron sensitivity and the raw data had to be corrected to take account of this. The neutron sensitivity was measured, independently, in the NRU thermal column, as follows:

The detector was first irradiated in the thermal column inside a thin (∿ 0.24 cm) annulus of ^{6}LiF, which reduced the neutron flux to a negligible level, without appreciably affecting the γ-ray field. This provides a direct measure of I_γ in the thermal column. A second irradiation, without the ^{6}LiF annulus, yields $I_\gamma+I_n$, from which we obtain I_n, and hence S_n.

The neutron sensitivities of two coiled detectors with solid Pt emitters, and a coiled Pt-clad detector, were also determined in the thermal column using this technique. The results are summarized in Table III. As can be seen, the neutron sensitivity of the Pb detector is comparable to that of the solid Pt detectors. It is postulated that this large neutron sensitivity results from neutron-capture γ-rays generated in the Inconel sheath. This hypothesis is supported by the greater neutron sensitivity of Pt detector TC-0803, compared with that of TC-0802, which would be expected from the greater sheath thickness of the former. The neutron sensitivities of detectors TC-0802 and TC-0803 imply a contribution of ∿ $1.9\text{x}10^{-27}$ $\text{A}\cdot\text{m}^{-1}/(\text{n}\cdot\text{m}^{-2}\cdot\text{s}^{-1})$ per g/m of Inconel in the sheath, whereas the neutron sensitivity of the Pb detector implies a contribution of ∿ $1.8\text{x}10^{-27}$ $\text{A}\cdot\text{m}^{-1}/(\text{n}\cdot\text{m}^{-2}\cdot\text{s}^{-1})$ per g/m of Inconel. This good agreement is significant. In addition, Lynch et al. [1] found that coiling a Pt detector increased its total sensitivity by ∿ 26%, presumably due to neutron-capture events in adjacent coils.

We now return to a consideration of the ZED-2 perturbation experiments. After correcting the signal from the Pb detector for its neutron sensitivity, the ratio $I_{\gamma B}/I_{\gamma A}$ was found to be

$$I_{\gamma B}/I_{\gamma A} = 0.20 \pm 0.10 \qquad (9)$$

while the neutron flux ratio, determined by Cu foils, was found to be

$$\phi_{nB}/\phi_{nA} = 1.18 \pm 0.02 \qquad (10)$$

The ratio of the γ-ray intensities is poorly defined, but the 50% uncertainty results in an uncertainty in neutron sensitivity of only ∿ 10%.

The neutron, γ-ray and total sensitivities obtained for the Pt detectors are summarized in Table II and plotted in Fig. 3 as a function of emitter diameter.

Each set of measured sensitivities, S_n, S_γ, and S_T, has been fitted to a simple power law. For the detectors with solid emitters we obtain

TABLE III

NEUTRON SENSITIVITIES FOR COILED SELF-POWERED DETECTORS DETERMINED IN THE NRU THERMAL COLUMN

Detector Serial No.	Type	OD (mm)	Sheath Wall Thickness		Emitter		S_n
			(mm)	(g/m)	Diameter (mm)	Length (mm)	$A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})$
UC-0703	Pb	2.67	0.48	27.8	0.81	1194	$0.49\text{x}10^{-25}$
TC-0802	solid Pt	1.52	0.26	8.7	0.51	3000	$0.90\text{x}10^{-25}$
TC-0803	solid Pt	2.03	0.51	20.5	0.51	3000	$1.12\text{x}10^{-25}$
UC-0605	Pt-clad	2.99	0.45	30.3	1.44	997	$3.75\text{x}10^{-25}$

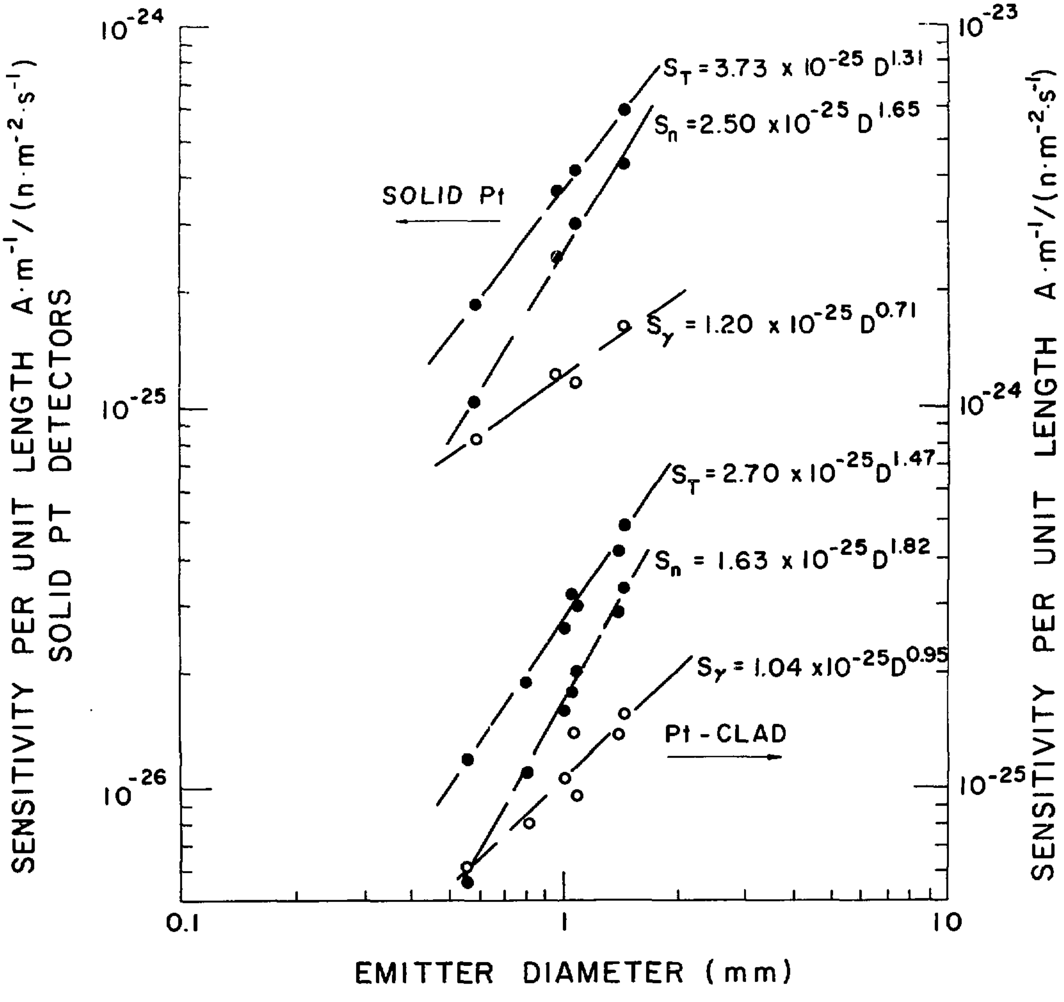

FIGURE 3 - THE NEUTRON, γ-RAY AND TOTAL SENSITIVITIES PER UNIT LENGTH, AS A FUNCTION OF EMITTER DIAMETER FOR SOLID AND CLAD Pt DETECTORS

$$S_n = 2.50\times10^{-25}\ D^{1.65}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (11)$$

$$S_\gamma = 1.20\times10^{-25}\ D^{0.71}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (12)$$

$$S_T = 3.73\times10^{-25}\ D^{1.31}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (13)$$

and for the Pt-clad detectors,

$$S_n = 1.63\times10^{-25}\ D^{1.82}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (14)$$

$$S_\gamma = 1.04\times10^{-25}\ D^{0.95}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (15)$$

$$S_T = 2.70\times10^{-25}\ D^{1.47}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (16)$$

Let us consider first the γ-ray sensitivities. As seen from Table II, the measured γ-ray sensitivities for the Pt-clad detectors are close to those for the solid Pt detectors, for comparable geometries. This supports the proposition that the γ-ray sensitivity is essentially a surface effect. The fact that the fits give exponents smaller than unity is believed to result from a decreasing γ-ray sensitivity with increasing insulation thickness. The effect of insulation thickness on γ-ray sensitivity can be seen by comparing the results for detectors TC-1203, TC-1113 and TC-1111. Since insulation thickness does affect significantly the γ-ray sensitivity of the Pt-clad detectors we have fitted these γ-ray sensitivities to a function of the form

$$S_\gamma = kD^\alpha/T^\beta \qquad (17)$$

where T is the insulation thickness, in mm.
The best fit is given by

$$S_\gamma = 0.59\times10^{-25}\ D^{1.22}/T^{0.51}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (18)$$

The quality of the fit obtained using equation (18) is significantly better than that obtained using equation (15), as can be seen from Table II.

The data for the solid Pt detectors were fitted to equation (17), but with $\beta = 0.5$ (i.e. only α was allowed to vary, because of the limited number of data points). The result was

$$S_\gamma = 0.70\times10^{-25}\ D^{0.87}/\sqrt{T}\ \mathrm{A\cdot m^{-1}/(n\cdot m^{-2}\cdot s^{-1})} \qquad (19)$$

This fit is only marginally better than that obtained using equation (12).

We now consider the neutron sensitivities. As can be seen from Table II, the measured sensitivities of the solid detectors are significantly greater than those of the Pt-clad detectors, for comparable geometries. This is not unexpected because of the smaller neutron absorption cross section of Inconel compared to Pt. The dominant parameter affecting sensitivity is the emitter diameter, although the insulation thickness does appear to have a secondary effect.

Based on the variation in sensitivity with emitter diameter obtained for Co detectors, we would expect the neutron sensitivity of the Pt detectors to increase with emitter diameter somewhat more rapidly than a square law. However, the increase is less rapid than a square law. It is tempting to explain this "discrepancy" by the fact that γ-rays from neutron-capture events in the sheath contribute a significant fraction of the total neutron sensitivity, i.e.

$$S_n = S_n^E + S_n^S \tag{20}$$

where the superscripts E and S refer to emitter and sheath, respectively. Thus, we expect S_n^E to increase with emitter diameter in a manner similar to Co detectors, while S_n^S would increase less rapidly than a square law.

However, the dependence of S_n^S on various detector parameters is not obvious, but it is likely to be a relatively complex function of detector geometry. The situation is further complicated by the fact that, for Pt-clad detectors, S_n^E must depend on the relative amounts of Inconel and platinum in the emitter. Because of the limited data set, the results of a multi-parameter fit that includes all the important variables would not be physically meaningful, and has not been attempted. Thus, we are not able at present to separate neutron sensitivities into their various components.

4. SUMMARY AND CONCLUSIONS

Sensitivities have been determined for vanadium and cobalt self-powered detectors, and these have been found to depend primarily on emitter diameter, and to vary as simple power laws of the diameter. The situation with Pt detectors is more complicated, because reactor γ-rays contribute significantly to total sensitivity. The external γ-ray response appears to be primarily a surface effect, and the sensitivity varies approximately linearly with emitter diameter and approximately inversely as the square root of the insulation thickness.

The neutron sensitivity, S_n, of platinum detectors also varies with emitter diameter as a power law. However, there is good evidence that a significant fraction of the neutron sensitivity can be attributed to neutron-capture events in the detector sheath, as well as the emitter. Additional experiments are needed to elucidate this situation.

The neutron and γ-ray sensitivities reported here are valid for the reactor environment in which they were determined. Since the test reactor lattice simulates a CANDU power reactor core the values for S_n are valid for such a reactor. However, the values for S_γ are not strictly applicable to the power reactor environment because they were determined after an irradiation of only ∿ 1 hour. It is estimated that at equilibrium the γ-ray sensitivities would be ∿ 10% higher.

As a rule of thumb, the total sensitivity of a Pt-clad detector is, initially, ∿ 25% lower than that of a solid Pt detector of comparable geometry. This lower sensitivity is primarily due to a lower neutron sensitivity. However, since the neutron sensitivity due to absorption in Inconel will burn out at only ∿ 1/7 the rate of that due to neutron absorption in Pt, the Pt-clad detector is judged to be superior to the solid-emitter type.

[illegible]. ACKNOWLEDGEMENT

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