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Calculation of the Neutron Sensitivity in Rh Self-Powered Detector

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Abstract

For the application of the neutron flux mapping, an accurate calculation of the sensitivity is required because the sensitivity is proportional to the neutron flux density. Sensitivity is defined as the current per unit length per unit neutron flux and it mainly depends on the depression factor(f), the escape probability from the emitter($\varepsilon 1$) and the charge build-up factor of the insulator layer(c). A Monte Carlo simulation was accomplished to calculate the sensitivity of rhodium emitter material and alumina(Al_2O_3) insulator with a cylindrical geometry, based on the (n,β) interaction and on other interaction including the secondary electron generation for the more accurate estimation of the sensitivity. From the simulation results, factors for the sensitivity were accurately calculated and compared with other theoretical and experimental values. In addition, the sensitivity linearly increases and saturates as the emitter radius increases. The accomplished method is useful in the analysis for the change of SPND sensitivity as a function of burn-up and in the optimum design of SPND.

1. Introduction

Self-powered neutron detector (SPND) is being widely used in the present reactor for both safety and flux mapping. In general, SPND is divided into gamma and neutron sensitive type, and is subdivided with respect to the delayed response and prompt response related to the relevant emitter material. Compared with other neutron sensors, SPND is a good in-core detector due to small size, low cost and the relatively simple electronics required in conjunction with its usage. It has, on the other hand, several disadvantages such as the low level of output current, the slow response time, the severe sensitivity to change in the neutron energy spectrum and the difficulty of long term usage. SPND contains a neutron sensitive emitter surrounded by a insulator. A metallic sheath encloses the cylindrical assembly.

In this paper, the sensitivity of detectors is accurately calculated by a Monte Carlo simulations of for the flux mapping are given for the several sizes of the emitter(Rh) radius and the insulator(Al_2O_3) thickness.

2. Calculation of neutron sensitivity

Among the events which contribute the output current signal of SPND, there are some unwanted events. From the Figure 1 which shows the signal generation mechanism of SPND, the event 1 from the beta decay due to the neutron capture and its event causes to other interaction including the secondary electron generation. Other events should be suppressed. For the calculation of neutron sensitivity, the event 1 should be only considered, and the sensitivity is defined at the steady-state in which the neutron flux is constant over time. [1]

The neutron capture rate per unit volume for thermal neutron is defined as follows.

$$\text{neutron capture rate} = \Sigma_{th} \times \phi_{th} \times f$$
$$= \bar{\Sigma} \times \bar{\phi} \times f$$

where

$\bar{\Sigma}$ = the macroscopic neutron cross section at thermal energy

$\bar{\phi}$ = the neutron flux at neutron thermal energy

f = the neutron depression factor at neutron thermal energy

When electrons are generated during the neutron capture phenomena in emitter material, the normalized decay energy spectrum without considering coulombs effects is given by [2],[3]

$$B(E') = 105 / (16 \times E_b^{3.5}) \times (E_b - E')^2 \times \sqrt{E'}$$

$B(E')$ is normalized so that

$$\int_0^{E_b} B(E')dE' = 1$$

From the above equation, sensitivity per unit neutron flux per unit emitter length is given by

$$I = q \times V / L \times (\varepsilon 1 \times \varepsilon 2 \times \bar{\Sigma} \times f)$$
$$= q \times \sigma \times N \times (A \times \varepsilon 1 \times \varepsilon 2 \times f)$$
$$= 1.74 \times 10^{-18} \times (A \times \varepsilon 1 \times \varepsilon 2 \times f)$$

where

q =the electron charge

V = the emitter volume

L = the emitter length

f = the flux depression factor for a cylindrical emitter rod [4]

$\varepsilon 1$ = the escape probability from the emitter into the insulator region(contains the normalized beta decay energy spectrum)

$\varepsilon 2$ = 1-c, the escape probalility from the emitter surface to R_0

c = the charge build-up factor of the layer

N = the atomic density of the rhodium

σ = the microscopic neutron cross section at thermal energy

A = the area of the emitter

For the simulation, we assumed that the beta decaying electrons are distributed uniformly throughout the emitter volume, the neutron flux density is in the steady state. The space charge of electrons also assumed to be distributed uniformly in the insulator layer. From the reference[3], the position where the electric field is zero within the insulator. Thus the position is given for [3], [5], [6]

$$R_0 = R_i \times [(1-k^2)/(2 \times \ln(1/k))]^{1/2}$$

where

R_0 = the radius when the electric field is zero measured from the center of the emitter.

R_i = outer radius of the insulator

$k = R_e / R_i$

R_e = radius of the emitter

If electrons reach to R_0 within insulator, they contribute to the output signal because electric field cause to the drift motion of those electrons under the steady state condition. Figure 2 shows that the shape of electric potential V(R) and the uniform charge distribution within the insulator. Depression factor(f) for rhodium are found from Weinberg and Wigner calculations. [4] For the calculation of the sensitivity, we must know the escape probability.

3. Simulations and Results

Figure 3 shows the simulation in the cylindrical geometry with the rhodium emitter(Rh) and the alumina insulator(Al_2O_3).

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The result is shown in the figure 4 that the output signal or sensitivity linearly increases and saturates as the emitter radius increases. As the increase of the emitter radius increases surely the number of electrons , but also the escape probability decreases. Thus, the optimum value of the emitter radius exists.

Figure 5 show the values of the escape probability from the emitter into the insulator region($\varepsilon 1$), figure 6 show the charge build-up factor of the layer(c) and table1 show the comparison of the escape probability with Warren's result for the variance of the emitter radius. The result of this simulation is generally higher than Warren's result.

The sensitivity of rhodium detector with R_e=0.0254 cm, R_i=0.0508 cm fits better to the experimental value as shown table 2

4. Conclusions

This paper calculated the escape probability, the charge build-up factor and the sensitivity using the Monte Carlo simulation, it will be useful in the optimum design of SPND. Also, the sensitivity for rhodium detectors was almostly similar with experimental results. A further study on the sensitivity change due to burn-up will be necessary.

Reference

[1] G.N.Knoll, Radiation Detection and Measurement, John Willy & Sons Inc., p.507 (1889)

[2] J. Orear, A. H. Rosenfeld, and R. A. Schluter, Nuclear Physics, p.79, A Couse Given by Enrico Fermi at the University of Chicago, University of Chicago Press (1950)

[3] R. M. Eisberg, Fundamentals of Modern Physics, p.620, John Wiley and Sons, New York (1961)

[4] A. M. Weinberg and E. P. Wigner, The Physical Theory of Neutron Chain Reactors, p.707,the University of Chicago Press, Chicago (1958)

[5] H. D Warren, Calculation Model for Self-Powered Neutron Detector, Nuclear Science and Engineering 48, 331-342 (1972)

[6] W. Jaschik and W. Seifritz, Model for Calculating Prompt-Response Self-Powered Neutron Detectors, Nuclear Science and Engineering 53, 61-78(1974)

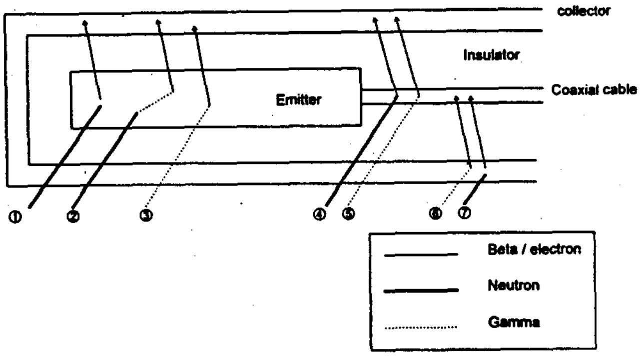

Figure 1 Some of possible events in the Rhodium detector

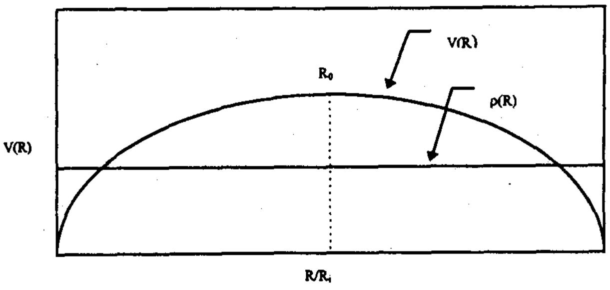

Figure 2 Potential peek at the insulator

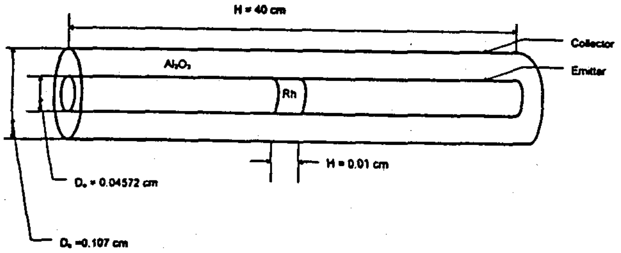

Figure 3 The cylindrical geometry of the rhodium detector

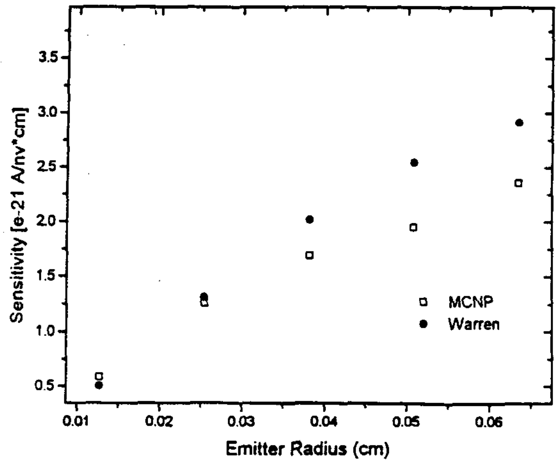

Figure 4 The sensitivity as the emitter radius increase

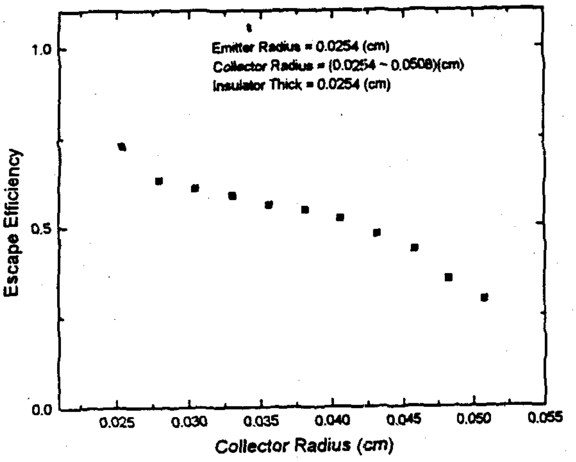

Figure 5 Beta escape probability

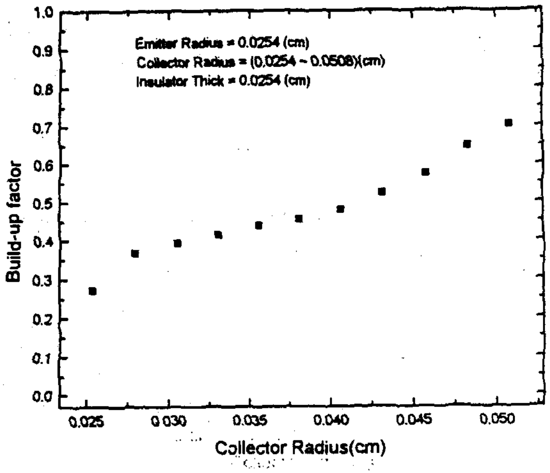

Figure 6 The charge builb-up factor

Emitter Radius (cm)	Escape probability(ε) H. D. Warren	Escape probability(ε) this simulation
0.0127	0.787	0.885
0.0254	0.623	0.765
0.0381	0.496	0.580
0.0508	0.401	0.447
0.0635	0.331	0.346

Table 1 Comparison with the escape probability at H. D. Warren paper

	This simulation	H. D. Warren	N. Goldstein	Experimental
Sensitivity (10^{-21}amp/nv cm)	1.25	1.31	1.51	1.2

Talble 2 Comparison with the sensitivity at the experimental data and other papers