New Cobalt SPND Initial Sensitivity Calculation Model Based on SPGD Model for Monte-Carlo Simulation

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1. Introduction

Self-Powered Detector (SPD) is one of devices for in-core fluxes detecting without external electricity source. SPD can be classified into Self-Powered Neutron Detector (SPND) and Self-Powered Gamma Detector (SPGD) according to the decay chain of emitter material. SPD consisted with emitter, insulator and collector. When neutrons or gammas reacted with emitter material, it generates electrons and these electrons cross insulator area to make electric signal in collector area. For calculating sensitivity of SPD with Monte-Carlo code such as MCNP, many physical components must be considered. Although many studies have been conducted for computational simulation of SPD, the sensitivity evaluation to cobalt SPND has not shown good results due to the complex decay chain of cobalt-59. Unlike other SPNDs (rhodium, vanadium, etc.), cobalt shows that prompt signal and relatively low signal comparing with other delayed signal SPNDs. For this reason, in this paper, computational simulation for initial sensitivity calculation was performed using the methodology used for SPGD with prompt signals.

2. Equations

When emitter generates electrons continuously, electric field is formed in insulator region. This electric field defined as function of radius and charge density. SPND has typical cylindrical geometry and in the cylindrical symmetry, electric field E obeys Poisson equation [4]. So, it can be expressed that electric field in insulator region as equation (1).

$$\frac{\partial E}{\partial r} + \frac{E}{r} = \frac{\rho(r)}{\varepsilon} \qquad (1)$$

E : electric field, r : radius
$\rho(r)$: charge density, ε : dielectric constant

And with first linear order differential equation's solver is used for equation (1) to transformation function of the radius of an electric field. Boundary condition was set to have no potential difference inside the insulator. With this boundary condition, equation (1) can be derived as equation (2).

$$E(r) = \frac{1}{r\varepsilon}\left(\int_{r_i}^{r} \rho(r) r dr - \frac{1}{\ln\left(\frac{r_o}{r_i}\right)} \int_{r_i}^{r_o} dr \frac{1}{r} \int_{r_i}^{r} \rho(r) r dr\right) \qquad (2)$$

r_o and r_i each means that insulator inner radius and outer radius such as figure 1.

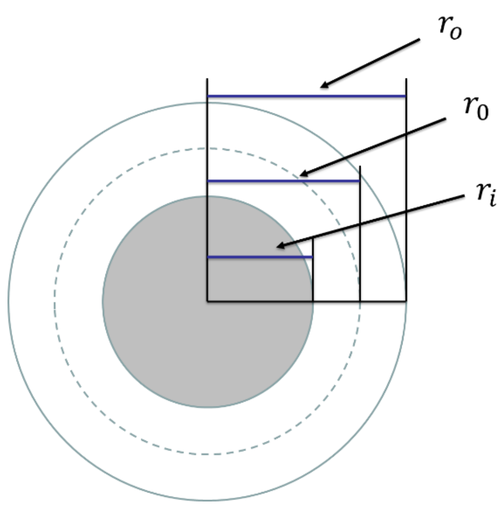

Figure 1. Cross-section of SPND (only emitter and insulator) and radius approximation.

Because of space charge effect, it needs to consider additional equations driven from equation (2). Fraction f means that refers to the fraction at which electrons generated in the emitter return due to the spatial charge effect. It can be expressed as equation (3).

$$f = \frac{\ln(r_o)}{\ln(r_o/r_i)} - \frac{1}{\ln\left(\frac{r_o}{r_i}\right)} \frac{\int_{r_i}^{r_o} r\ln(r)\,\rho(r)dr}{\int_{r_i}^{r_o} r\rho(r)dr} \quad (3)$$

And for increasing calculation accuracy insulator region is divided as several ring shape such as figure 2. Equation (4) is derived with divided insulator.

$$f = \frac{\ln(r_o)}{\ln(r_o/r_i)} - \frac{1}{\ln\left(\frac{r_o}{r_i}\right)} \frac{\sum_{j=1}^{n} \overline{r_j}\ln(\overline{r_j})\,\rho_j \Delta r_j}{\sum_{j=1}^{n} \overline{r_j}\rho_j \Delta r_j} \quad (4)$$

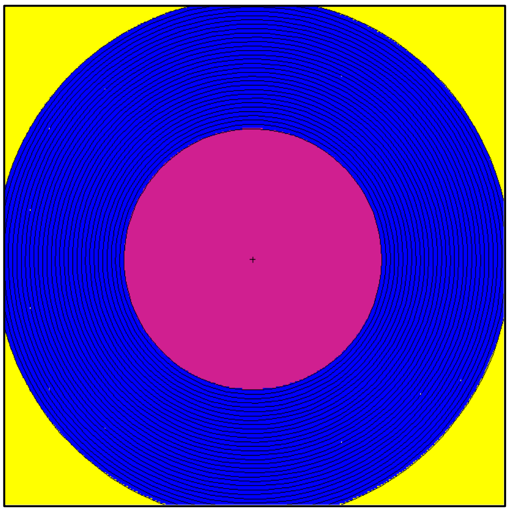

Figure 2. SPND's divided insulator shape

With f fraction rate, emitter to sheath current can be calculated with equation (5) and sensitivity calculation using emitter to sheath current and neutron flux such as equation (6).

$$J_{es} = J_{ei} - f(J_{ei} - J_{is}) = (1 - f)J_{ei} + fJ_{is} \quad (5)$$

$$Sensitivity = \frac{J_{es}}{\phi} \quad (6)$$

3. Co-SPND Sensitivity Calculations

For the sensitivity calculation, arbitrary SPND is modeled such as table 2. Because of using cz command for geometry modeling, length is infinite.

Table 2. Specification of the SPND model.

Part	Material	Density (g/cm3)	Length (cm)	Radius (cm)
Emitter	Co-59	8.9	Infinite	0.05
Insulator	Al_2O_3	1.9	Infinite	0.052
Collector	Inconel-600	8.44	Infinite	0.1

And source neutron spectrum was set as typical light water reactor's one. Source term place at outer region of SPND collector. And neutron flux tallied at SPND collector with F4 tally.

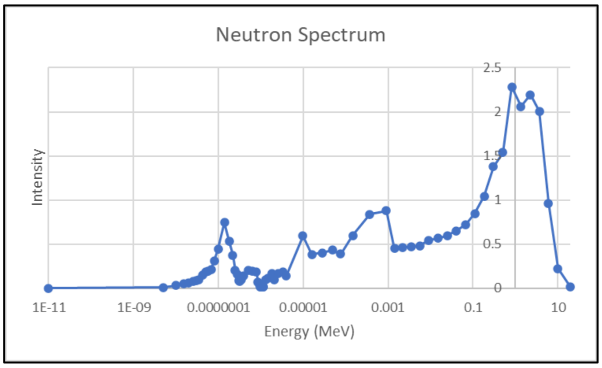

Figure 3. Neutron spectrum for SPND sensitivity calculation.

Charge density was calculated with +F8 tally at divided insulator, current calculation was done with F2 tally. Charge density calculation result is shown in figure 2. F fraction was calculated as 43.4 %.

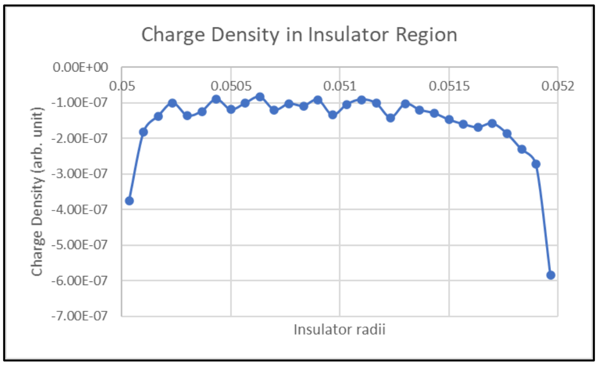

Figure 4. Charge density in insulator region for SPND sensitivity calculation.

Finally, with equation (5) and (6), sensitivity result calculation result for only one electron is 9.18844E-24 A/nv-Cm and statical error is 3.65 %.

4. Conclusion

In this paper, new Co SPND sensitivity calculation model was suggested based on SPGD's one and MC method. With this model, Co-SPND sensitivity calculation is done for arbitrary SPND model. And also, calculation result shows that model can calculate reasonable level of sensitivity.

Reference

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