Effect of Geometrical Configuration of Radioactive Sources on Radiation Intensity in Beta-voltaic Nuclear Battery System: a preliminary result

Khairul Basar[a)], Robi D. Riupassa, Reza Bachtiar and Muldani D. Badrianto

Nuclear Physics and Biophysics Research Division, Faculty of Mathematics and Natural Sciences,
Institut Teknologi Bandung

[a)]Corresponding author: khbasar@fi.itb.ac.id

Abstract. It is known that one main problem in the application of beta-voltaic nuclear battery system is its low efficiency. The efficiency of the beta-voltaic nuclear battery system mainly depends on three aspects: source of radioactive radiation, interface between materials in the system and process of converting electron-hole pair to electric current in the semiconductor material. In this work, we show the effect of geometrical configuration of radioactive sources on radiation intensity of beta-voltaic nuclear battery system.

INTRODUCTION

Beta-voltaic nuclear battery is one kind of nuclear battery that uses semiconductors for converting radioactive decay energy into electrical energy. It has many advantages such as possibility to construct as micro-batteries, has stable output voltage and current and possibility to operate in long time periods. One famous application of this type of power source is as power source in cardiac-pacemaker[1].

The technology of applying beta-voltaic nuclear battery in many aspects is widely growth. The main and important aspect is the efficiency of beta-voltaic nuclear battery. The efficiency of beta-voltaic consists three parts: efficiency of material converting radioactive energy to electric power, efficiency of interfacing material, and efficiency of radioactive source[2]. It has been reported that the overall efficiency of beta-voltaic system not more than 11% [3]. However theoretically, it might reach 23% [4]. Research on efficiency of radioactive source can be done in at least three ways: the selection of the type of radioactive source, variations of radioactive source configuration and the geometry of beta-voltaic. Research on the radioactive source configuration has no direct influence on the overall efficiency value beta-voltaic system, but it related to the optimal use of radioactive source materials.

In this paper we discuss about the effect of geometrical configuration of radioactive source to the radiation intensity of beta-voltaic nuclear battery system. The optimal use of radioactive materials will be discussed. In this preliminary result, we focus only with strip configuration of radioactive source.

THEORETICAL BACKGROUND

According to Loevinger [5], the intensity of point type of radioactive source is expressed as follow

$$I = \frac{k}{r^2}\left(\left[c - re^{1-\left(\frac{r}{c}\right)}\right]_1 + \left[re^{1-r}\right]_2\right) \tag{1}$$

4th International Conference on Advances in Nuclear Science and Engineering (ICANSE 2013)
AIP Conf. Proc. 1615, 256-259 (2014); doi: 10.1063/1.4895892

where k is a constant, r is the distance from the point source to the detector and c is constant which is depend on the energy of radioactive particle emitted from radioactive source. The constant c is calculated as follow

$$c = 3.11\exp(-0.55E_0) \qquad (2)$$

where E_0 is the maximum energy of radioactive particle. The square bracket with index 1 in equation (1) means that its value equal to zero for $r \geq c$ as explained by Loevinger [5]. The total intensity resulted from radioactive source can be obtained by integration of the equation (1) over the whole area of radioactive source.

METHODS AND CALCULATION

In order to analyze the optimal use of radioactive source material, we compare the relative area of radioactive with specific configuration to the relative radiation intensity calculated using that configuration. Here, relative area is obtained by

$$A_{rel} = \frac{A_{conf}}{A_{total}} \qquad (3)$$

where A_{conf} is area of specific configuration of radioactive material, which is means the use of radioactive material and A_{total} is area of full configuration. We assume that the full configuration covered square area with size $l\times l$. If the intensity produced by full configuration area, which means the maximum use of radioactive material, give by I_{total} and the intensity produced by specific configuration is I_{conf}, then the relative intensity is obtained by

$$I_{rel} = \frac{I_{conf}}{I_{total}} \qquad (4)$$

We designed several geometrical configurations (strip type) of radioactive materials determined by one or two parameters as shown in Figure 1. The constant k = 0.776 keV/dis and E_0 = 223 keV are used in the calculation by assuming that the radioactive source is Pm-147 [5]. The beta-detector is assumed as point detector placed at height z from the center of radioactive source.

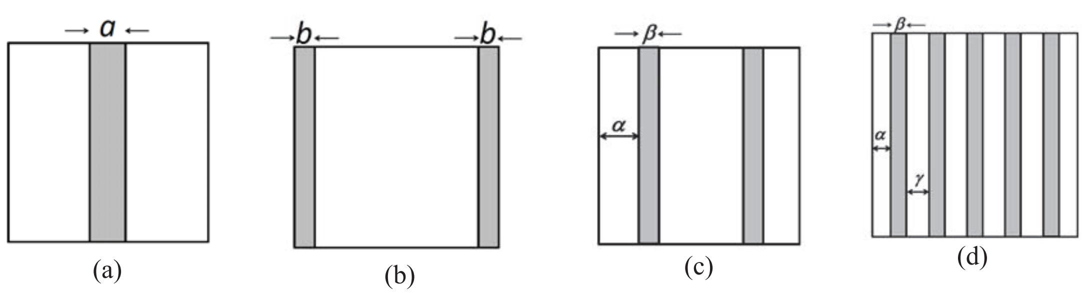

FIGURE 1. Several geometrical configurations with parameters a, b, α, β and γ.

RESULTS AND ANALYSIS

The calculation results for several configurations which give same relative area were compared for same value of A_{rel}. The results for configurations of type (a), (b), (c) and (d) as indicated in Figure 1 are shown in Table 1. The geometrical parameters: a, b, α, β and γ are written as relative value to the size of whole area, l. Relative area of radioactive source (A_{rel}) and relative intensity produced by the radioactive source (I_{rel}) are presented in percentage. For type (a) configuration, the parameter a/l is proportional to the relative area A_{rel}, while for type (b) and (c) configurations, the parameters β/l are proportional to the relative area A_{rel}.

TABLE 1. Calculation results for configurations of type (a), (b), (c) and (d) as indicated in Figure 1.

Configurations	**Parameter(s)**			A_{rel} **(%)**	I_{rel} **(%)**
	a/l				
	0.1			10	10.97
	0.2			20	21.87
	0.3			30	32.63
	0.4			40	43.21
(a)	0.5			50	53.54
	0.6			60	63.57
	0.7			70	73.26
	0.8			80	82.58
	0.9			90	91.50
	β/l				
	0.05			10	8.50
	0.1			20	17.42
	0.15			30	26.74
(b)	0.2			40	36.43
	0.25			50	46.46
	0.3			60	56.79
	0.35			70	67.37
	0.4			80	78.13
	α/l	β/l			
	0.05	0.05		10	8.92
	0.05	0.1		20	18.24
	0.05	0.15		30	27.93
	0.05	0.2		40	37.96
	0.05	0.25		50	48.29
	0.05	0.3		60	58.86
	0.05	0.35		70	69.63
	0.05	0.4		80	80.53
	0.1	0.05		10	9.32
	0.1	0.1		20	19.01
	0.1	0.15		30	29.04
	0.1	0.2		40	39.37
(c)	0.1	0.25		50	49.94
	0.1	0.3		60	60.71
	0.1	0.35		70	71.61
	0.1	0.4		80	82.58
	0.2	0.05		10	10.03
	0.2	0.1		20	20.36
	0.2	0.15		30	30.93
	0.2	0.2		40	41.70
	0.2	0.25		50	52.60
	0.2	0.3		60	63.57
	0.3	0.05		10	10.58
	0.3	0.1		20	21.34
	0.3	0.15		30	32.24
	0.3	0.2		40	43.21
	α/l	β/l	γ/l		
	0.05	0.05	0.05	50	50.67
	0.05	0.05	0.1	30	29.72
	0.05	0.05	0.15	30	30.21
(d)	0.05	0.05	0.2	20	19.50
	0.05	0.1	0.05	60	60.26
	0.05	0.1	0.1	50	50.11
	0.05	0.1	0.15	40	39.58
	0.05	0.1	0.2	40	39.91

It is obtained from the calculations that type (a) configuration gives more relative intensity compare to other type of configuration for similar relative area A_{rel}. Type (a) configuration gives relative intensity greater than relative area as shown in Table 1. From calculation results, it is obtained that the optimal configuration for situation where the beta detector is a point type and located at height z above the center is type (a) configuration. It is because in type (a) configuration, the radioactive source is distributed in the middle part of source area. It is also easy to understand that the type (b) configuration gives the smallest relative intensity compare to other type of configuration for some specific relative area of radioactive materials since in type (b) configuration the radioactive materials distributed far from the beta detector. The relative intensity I_{rel} for type (c) and (d) configurations depend on the configuration parameters α, β, γ. However, similar conclusions can be obtained that the configurations which radioactive materials distributed near the middle area will give high relative intensity.

In these calculations, the beta detector is assumed as a point type detector. More realistic model of beta detector (not point type) is needed to obtain better results. Other type of configurations for example square type, circular type etc. might give more interesting results.

CONCLUSIONS

Preliminary results on effect of geometrical configuration of radioactive sources in beta-voltaic nuclear battery system have been presented for strip type configuration. It is concluded that the type (a) configuration gives optimal use of radioactive materials.

REFERENCES

1. M. Mohamadian, S. A. H. Feghhi, and H. Afariadeh, "Geometrical Optimization of GaN Betavoltaic Microbattery," Proceedings of the 7th WSEAS International Conference on Power Systems, Beijing, China (2007).
2. G. N. Yakubova, "Nuclear Batteries With Tritium And Promethium-147 Sources," Ph.D. thesis, University of Illinois at Urbana-Champaign, 2010.
3. L. C. Olsen, Energy Conversion **13**, 117 (1973).
4. S. Tin and A. Lal, "Ultra-High Efficiency High Power Density Thinned-Down Silicon Carbide Betavoltaics," Proceedings of the PowerMEMS (2009).
5. W. F. Lindle, "Pm^{147}-Silicon Betavoltaic Bettery Fesibility," Sandia Laboratory (1966).


The 4th International Conference
on Advances in Nuclear Science and
(ICANSE 2013)
Denpasar - Bali, Indonesia, September
Organized by :
Supported by :


The 4th International Conference
on Advances in Nuclear Science and
EXIT