A GAMMA TECHNIQUE FOR MEASUMENT OF ACTIVITY OF RADWASTE DRUMS

TRAN QUOC DUNG

1. INTRODUCTION

The various fuel cycle process results in a considerable amount of radioactive waste which is usually stored in large sealed drums (208 l). The waste drums must be checked to satisfy regulations of radioactive waste management.

The Segmented Gamma Scanning technique (SGS) is a traditional tool used for assay of radioactive waste drums [1, 2]. The accuracy of the SGS relied on the assumption that the matrix and the sample activity were both homogeneous for a segment. However, these assumptions are generally not satisfied when waste or scrap is assayed. Inhomogeneous distribution of radioactive source frequently causes the largest [4, 5. In order to increase accuracy, some recent methods were proposed: technique using two identical detectors [3, 6, 7]; technique utilising multichannel scaling to identify inhomogeneity and to correct results of SGS [8]; tomographic techniques [4, 9]; technique of measuring a segment with different geometry and/or some different gamma energy lines of the isotope of interest [10, 11, 12]. Each technique has its advantages and disadvantages. Choosing a measuring technique depends on concrete situation.

This paper presents a technique for determination of gamma activity in waste drums. The basic counting arrangement is similar to the arrangement of SGS, but instead of rotating continuously, step by step the drum is rotated. The assumptions of this technique are: first, contract to the assumption of SGS, the activity in a segment is concentrated as a point source; second, the sample matrix is uniform in a segment. In order to evaluate the performance of this method calculations have been carried out based on the mathematical simulation of gamma ray measurement. The calculation results show that the accuracy of this technique is better than that of SGS for most cases where the mixture of activity and matrix is non-uniform.

2. METHOD : phương pháp .

2.1. Determination of detection efficiency

The basic counting arrangement is similar the arrangement of SGS, but the count-rates of detector corresponding to the rotational increment are recognised. Let us suppose a point source having activity I_t in a segment (see Fig. 1a). The count-rate corresponding to the angle θ is given as

$$C = I_t \cdot \alpha \cdot G \quad (1)$$

where $$G = \exp(-\mu L) / H^2 \quad (2)$$

μ - Linear attenuation coefficient. α - Coefficient that depends [illegible] and characteristic of the detector, and it can be determined by measuring a [illegible]. L, H are the path length of gamma ray in the drum and the source - [illegible]nce, respectively. They depend on the angle θ, the distance from the source to [illegible], the distance from detector to centre of drum (K), and the radius of drum R, as [illegible]

$$L = \frac{(R^2H^2 - K^2r^2\sin^2\theta)^{1/2} - (K\cos\theta - r)r \text{ [illegible]}}{H} \quad (3)$$

$$H = (K^2 + r^2 - 2Kr\cos\theta)^{1/2}. \quad (4)$$

Let us consider the ratio between the count-rates C_i, C_k correspond[illegible] θ_i, θ_k of angle θ, respectively,

$$T_{ik} = \frac{C_i}{C_k} = \frac{H_k^2}{H_i^2}\exp\left[\mu\left(L_k - L_i\right)\right]. \quad (5)$$

This ratio depends on the position of the source, the atten[illegible] and the distance from the detector to the centre of drum. That means , the dis[illegible] source to the centre of the drum (r) can be determined when the paramete[illegible] θ_i and θ_k are known.Then, the detection efficient G_i is calculated by eq.(2), and the [illegible] given as

$$I_t = \frac{C_i}{\alpha \cdot G_i}. \quad (6)$$

Considering the specified cases of $\theta_i = 0^\circ$ and $\theta_k = 180^\circ$ that correspond to the maximum and minimum value of the count rate of detector, respectively (see Fig.1). Then, eq.(5) becomes

$$T = \frac{C_{max}}{C_{min}} = \frac{(r+K)^2 \cdot \exp(2\mu r)}{(K-r)^2} \quad (7)$$

and

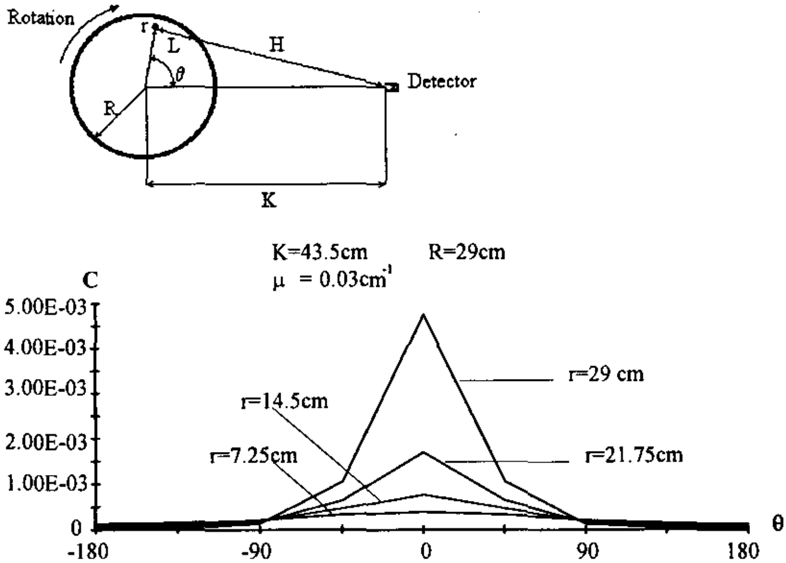
$$G_i = \frac{\exp[-\mu(R-r)]}{(K-r)^2} \quad (8)$$

here G_i corresponds to $\theta_i = 0^\circ$.

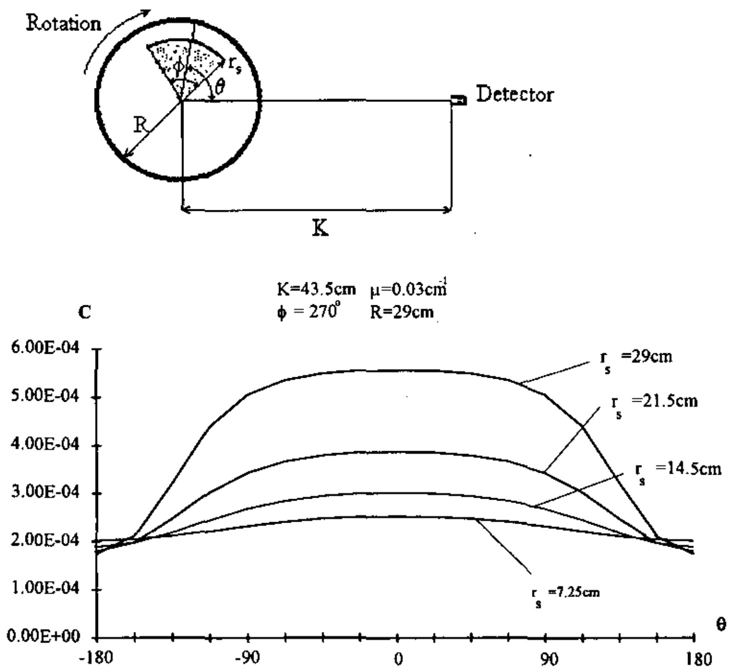
Through using a numerical method, r is determined by solving the equation (7) [13].

2.2. Measurement procedure

Based on the principle given as above, the fourt-step measurement procedure for a segment is shortly presented as follows: First, arrange the measurement like SGS: Determine the factor α by using a standard source; Define the attenuation coefficient μ corresponding to the gamma energy of interest by using a transmission source; Measure the distance from the detector to the centre of drum K. Second, rotate the drum and measure the segment to store count rates for rotational increments of the drum. Third, calculate the ratio between two the fixed angles. Solve the equation (7) or (5) to determine the "imaged radius", r. Calculate the factor G_i by Eqs. (8) or (2). Fourth, calculate the activity of the segment by using Eq. (6).



a) The dependence of count-rate of detector on radial (r) and rotational (θ) position of point source in a segment



b) The dependence of count-rate of detector on size (r_s, ϕ) and rotational (θ) position of source in a segment

Figure 1. Segment measuring arrangement and the variation of count-rate of detector.

Note: here the activity (I_t) and α are assumed equal to 1 without losing the generality

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3. RESULTS AND DISCUSSION

Based on the principle presented above, the aim of calculation is to estimate error of this technique and to compare to the error of SGS. A segment of standard 208 l waste drum with a diameter of 58 cm is modelled here. Gamma ray measurement is made at energies of fission product isotopes from 140 to 1400 keV, and average densities in range of 0.2-1.1 g/cm³. These data have resulted in a range of the average linear attenuation coefficients from 0.01 to 0.14 cm^{-1}. The average linear attenuation coefficients 0.03, 0.06 and 0.12^{-1} are chosen here. An extensive source with different size is considered as radioactive distributions in a segment. The calculation procedure for evaluating the error of SGS and of this technique is presented in Appendix. Table I illustrates the error as the ratio of apparent to true values.

The proposed formalism expressed by equations (1) - (8) based on the assumption that there would be only a point source in a segment. As seen in Fig. 1, both a point source and an extended source distributed nonuniformly have a common characteristic: they have the same effect on count rate of detector when they are rotated. This very characteristic is employed to establish the technical principle of this technique

The results in Table I demonstrate that the accuracy of this technique is better than that of SGS for most of the cases where the activity is nonunifomly distributed in the segment. If the assumption of this technique is satisfied the error can be ignored. Therefore, it can immediately be applied to measure the gamma ray activity in concrete barrels (i.e. homogeneous matrix drums).

When the extensive source is distributed within a half of the homogeneous matrix segment, errors are not over 12% and 25% in case of linear attenuation coefficient 0.03 and 0.06^{-1}, respectively. The maximum error can occur if the source is uniformly distributed in the segment. However, unlike SGS, this method always provides results in the conservative direction (the overestimate of the activity).

Table 1. The systematic error of this technique and SGS for extensive sources in homogenous matrix within in a segment

a) $\mu = 0.03\ cm^{-1}$

ϕ	K (cm)	r (cm)	3.625	7.25	10.875	14.5	18.125	21.75	25.375	29
360^{0}	43. 5	SGS	0.80	0.82	0.86	0.91	1.00	1.12	1.29	1.56
		This technique	1.01	1.04	1.09	1.16	1.26	1.41	1.63	1.97
	87. 0	SGS	0.79	0.80	0.83	0.86	0.90	0.96	1.02	1.13
		This technique	1.01	1.02	1.05	1.09	1.14	1.21	1.31	1.43
		SGS	0.80	0.82	0.86	0.91	1.00	1.12	1.29	1.56

	43. 5	This technique	1.01	1.02	1.04	1.07	1.12	1.18	1.25	1.37
270°		SGS	0.79	0.80	0.83	0.86	0.90	0.96	1.02	1.13
	87. 0	This technique	1.00	1.02	1.03	1.06	1.09	1.14	1.20	1.29
		SGS	0.80	0.82	0.86	0.91	1.00	1.12	1.29	1.56
	43. 5	This technique	1.00	1.01	1.01	1.02	1.03	1.05	1.07	1.11
180°		SGS	0.79	0.80	0.83	0.86	0.90	0.96	1.02	1.13
	87. 0	This technique	1.00	1.01	1.02	1.03	1.04	1.07	1.09	1.13
		SGS	0.79	0.80	0.83	0.86	0.90	0.96	1.02	1.13
	43.5	This technique	1.00	1.01	1.01	1.02	1.04	1.06	1.08	1.11
90°		SGS	0.79	0.80	0.83	0.86	0.90	0.96	1.02	1.13
	87.0	This technique	1.00	1.01	1.01	1.02	1.03	1.04	1.06	1.08

b) $\mu = 0.06\ cm^{-1}$

ϕ	K (cm)	r (cm)	3.625	7.25	10.875	14.5	18.125	21.75	25.375	29
		SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
	43. 5	This technique	1.02	1.07	1.17	1.32	1.55	1.89	2.42	3.33
360°		SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
	87. 0	This technique	1.01	1.05	1.12	1.22	1.36	1.56	10.82	2.26
		SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
	43. 5	This technique	1.01	1.04	1.09	1.16	1.26	1.40	1.60	1.91
270°		SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
	87. 0	This technique	1.01	1.04	1.08	1.15	1.24	1.37	1.56	1.86
		SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
	43. 5	This technique	1.00	1.01	1.03	1.05	1.08	1.13	1.19	1.25
180°		SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
	87. 0	This technique	1.01	1.02	1.04	1.07	1.11	1.17	1.25	1.25
		SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
	43.5	This technique	1.01	1.01	1.03	1.05	1.08	1.12	1.17	1.25
90°		SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
	87.0	This technique	1.00	1.01	1.03	1.04	1.07	1.10	1.14	1.20

c) $\mu = 0.12\ cm^{-1}$

φ	K (cm)	r (cm)	3.625	7.25	10.875	14.5	18.125	[illegible]	[illegible]	29
360°	43. 5	SGS	0.18	0.21	0.26	0.34	0.48	[illegible]	[illegible]	2.11
		This technique	1.04	1.18	1.45	1.92	2.70	[illegible]	[illegible]	11.89
	87. 0	SGS	0.18	0.20	0.24	0.30	0.40	[illegible]	[illegible]	1.31
		This technique	1.04	1.15	1.37	1.72	2.28	[illegible]	[illegible]	7.41
270°	43. 5	SGS	0.18	0.21	0.26	0.34	0.48	[illegible]	1.17	2.11
		This technique	1.03	1.10	1.24	1.46	1.79	[illegible]	3.10	4.68
	87. 0	SGS	0.18	0.20	0.24	0.30	0.40	[illegible]	0.83	1.31
		This technique	1.03	1.10	1.24	1.45	1.79	[illegible]	3.24	5.11
180°	43. 5	SGS	0.18	0.21	0.26	0.34	0.48	0.72	1.17	2.10
		This technique	1.01	1.04	1.09	1.16	1.27	1.42	1.63	1.96
	87. 0	SGS	0.18	0.20	0.24	0.30	0.40	0.56	0.83	1.31
		This technique	1.01	1.05	1.11	1.20	1.33	1.52	1.79	2.23
90°	43.5	SGS	0.18	0.21	0.26	0.34	0.48	0.72	1.17	2.10
		This technique	1.01	1.03	1.07	1.13	1.22	1.34	1.51	1.76
	87.0	SGS	0.18	0.20	0.24	0.30	0.40	0.56	0.83	1.31
		This technique	1.01	1.03	1.07	1.13	1.20	1.31	1.45	1.64

Contrary to the SGS where increasing the sample-to-detector distance is used to reduce errors caused by nonuniformity of sample, this technique can work in a close geometry experimentally taking into account absorption and geometry coefficients. This is useful to reduce measuring time and statistical errors for low activity samples. In addition, The variation of the count of detector corresponding to rotational angle provides an indication the heterogenity of matrix and the source. Therefore, it can be applied to indicate drums that may need further investigation. These drums could then be assayed by using other techniques.

The disadvantage of this method is that its error is still large by effect of heterogenity of matrix. The higher the heterogeneity is, the stronger the effect is. However, nonuniformity of matrix affects fairly the assay results of the source near the centre but inconsiderably the result of the source at the edge.

The analysis of some technical characteristics shows that this technique is applicable to SGS system with modifying the software, and a combination of two techniques can give satisfactory results in practical situations.

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SUMMARY

A gamma assay technique for determination of activity in waste drums is proposed. The assumption of this technique is that the sample activity concentrates as a point source, and the sample matrix is uniform in a segment. Calculation results show that the accuracy of this technique is better than that of the traditional Segmented Gamma Scanning technique for most cases where the mixture of activity and matrix is nonuniform.

TÓM TẮT

MỘT KĨ THUẬT GAM-MA ĐỂ ĐO HOẠT ĐỘ CỦA CÁC THÙNG CHẤT THẢI PHÓNG XẠ

Một kĩ thuật gamma để kiểm xác định hoạt độ của các thùng chất thải phóng xạ được đề nghi trong bài báo này. Giả thuyết của kĩ thuật này là hoạt độ chất thải tập trung nhu một nguồn điểm trong chất độn đồng nhất đối với một phân đoạn đo của thùng. Các kết quả tính toán cho

thấy rằng độ chính xác của kĩ thuật này tốt hơn so với kĩ thuật quét gam-ma phân đoạn truyền thống trong hầu hết các trường hợp khi hỗn hợp của chất phóng xạ và chất độn là không đồng nhất.

Address:

Centre for Nuclear Techniques

217 Nguyen Trai St, D. 1, Hochiminh City, Vietnam

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