LIMITATION OF THE SEGMENTED GAMMA SCANNING TECHNIQUE AND AN ADDITIONAL METHOD FOR ASSAY OF RADWASTE DRUMS

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ABSTRACT

In this paper the limitation of the Segmented Gamma Scanning technique is shown, while an additional method available to determine the activity of the barrels of radioactive waste has been proposed. The assumption of this technique is that the sample activity is concentrate 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 non-uniform.

Keywords: radwaste, gamma measurement, segmented gamma scanning.

TÓM TẮT

Hạn chế của kĩ thuật quét gam-ma phân đoạn và một phương pháp bổ sung để kiểm tra các thùng chất thải phóng xạ

Trong bài báo này những hạn chế của kĩ thuật quét gam-ma phân đoạn đã được chỉ ra, đồng thời một phương pháp gam-ma bổ sung để xác định hoạt độ của các thùng chất thải phóng xạ đã được đề nghị. Giả thuyết của kĩ thuật này là hoạt độ chất thải tập trung như 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.

Từ khóa: chất thải phóng xạ, quét tia gamma phân đoạn, các phép đo gamma.

1. Introduction

The operation of nuclear power plants results in the production of a considerable amount of radioactive waste which is usually stored in large sealed drums (208 l). The waste must be checked to satisfy regulations of radioactive waste management.

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Segmented Gamma Scanner (SGS) has been a traditional tool used for assay of radioactive waste drums [1,13]. The accuracy of the SGS was 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 [3,4]. In order to increase accuracy, some recent methods were proposed: technique using two identical detectors [2,5,6]; technique utilising multichannel scaling to identify inhomogeneity and to correct results of the SGS [11]; tomographic techniques [3,10]; technique of measuring a segment with different geometry and/or some different gamma energy lines of the isotope of interest [7,8,9]. Each technique has had its advantages and disadvantages. Choosing a measuring technique depends on concrete situation.

This paper presents the limitation of the SGS technique and an additional gamma method for determination of gamma activity in waste drums is proposed. The basic counting arrangement is similar to the arrangement of the 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 the 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 the SGS for most cases where the mixture of activity and matrix is non-uniform.

2. Mathematical simulation

2.1. Estimate of systematic errors

The drum is divided into a series of horizontal segments. If the measuring result for each segment is good the final result for the whole drum would be accurate. Therefore 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 g/cm^3. These data have resulted in a range of the average linear attenuation coefficients from 0.01 to 0.14 cm^{-1}. A point source at different distances from the centre of drum and an extensive source with different size is considered as radioactive distributions in a segment (see Fig. 1and 2).

2.2. Determination of detection efficiency

The basic counting arrangement is similar the arrangement of the 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. 1). The count-rate corresponding to the angle θ is given as

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

$$\text{Where } G = \exp(-\mu L) / H^2 \quad (2)$$

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

$$L = \frac{(R^2H^2 - K^2r^2\sin^2\theta)^{1/2} - (K\cos\theta - r)r}{H} \tag{3}$$

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

Let us consider the ratio between the count-rates C_i, C_k corresponding to the values θ_i, θ_k of angle θ, respectively,

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

This ratio depends on the position of the source, the attenuation coefficient and the distance from the detector to the centre of drum. That means, the distance from the point source to the centre of the drum (r) can be determined when the parameters of T_{ik}, μ, K, θ_i and θ_k are known. Then, the detection efficient G_i is calculated by Eq.(2), and the activity is given as

$$I_t = \frac{C_i}{\alpha \cdot G_i} \tag{6}$$

Considering the specified cases of $\theta_i = 0^o$ and $\theta_k = 180^o$ that correspond to the maximum and minimum value of the count rate of detector, respectively (see Fig.1and Fig.2). Then, Eq.(5) becomes

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

and

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

Here G_i corresponds to $\theta_i = 0^o$.

Through using a numerical method, r is determined by solving the equation (7) [12].

2.3. Measurement procedure

Based on the principle, the measurement procedure for a segment is shortly presented as follows: First, arrange the measurement like the 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 Eq. (8) or (2). Fourth, calculate the activity of the segment by using Eq.(6).

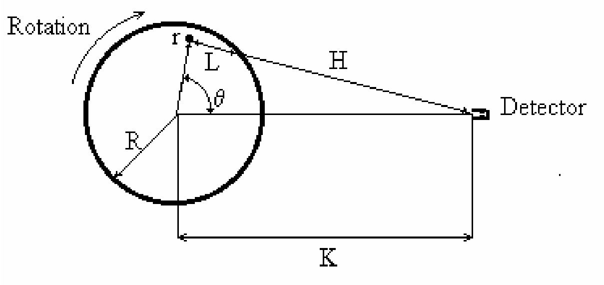

Figure 1.

Segment measuring arrangement for a point source.

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

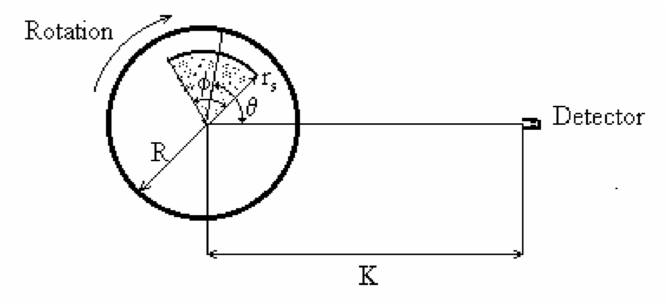

Figure 2.

Segment measuring arrangement for an extensive source.

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

3. Discussion

Two cases are considered here: a point source at different distances from the centre of drum (Fig.1) and an extensive source with different size (Fig. 2). Cases for high and medium inhomogeneity of matrix are studied. The aim of calculation is to estimate error of this technique and to compare to the error of the 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 g/cm^3. 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 of 0.03, 0.06 and 0.12cm^{-1} are chosen here. An extensive source with different sizes is considered as radioactive distributions in a segment. Table 1 and Table 2 illustrate the error as the ratio of apparent to true values. The proposed formalism expressed by the equations from (1) to (8) was based on the assumption that there would be only a point source in a segment. Both a point source and an extended source distributed non-uniformly have a common characteristic: they have the same effect on count-rate of detector when they are rotated. This characteristic is employed to establish the technical principle of this technique.

The results demonstrate that the accuracy of this technique is better than that of the SGS for most of the cases where the activity is non-unifomly 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 of 0.03 and 0.06cm^{-1}, respectively. The maximum error can occur if the source is uniformly distributed in the segment. However, unlike the SGS, this technique always provides results in the conservative direction (the overestimate of the activity).

Table 1. *The errors for a point source at different positions in homogeneous matrix*

μ (cm^{-1})	Method	r (cm)							
		0	*5*	*10*	*15*	*20*	*23*	*26*	*29*
0.12	SGS	0.18	0.20	0.29	0.48	0.91	1.39	2.22	4.17
	This technique	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.06	SGS	0.53	0.56	0.64	0.80	1.06	1.31	1.68	2.35
	This technique	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.03	SGS	0.79	0.80	0.85	0.94	1.01	1.20	1.35	1.61
	This technique	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 2. *The errors for extensive sources in homogenous matrix within in a segment.*

a) μ = 0.03 cm^{-1}

ϕ	K (cm)	r (cm)	3.62	7.25	10.87	14.50	18.12	21.75	25.37	29.00
		SGS	0.80	0.82	0.86	0.91	1.00	1.12	1.29	1.56
	43.5	This technique	1.01	1.04	1.09	1.16	1.26	1.41	1.63	1.97
360 o		SGS	0.79	0.80	0.83	0.86	0.90	0.96	1.02	1.13
	87.0	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 o		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 o		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^o		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)	3.62	7.25	10.87	14.50	18.12	21.75	25.37	29.00
360^o	43. 5	SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
		This technique	1.02	1.07	1.17	1.32	1.55	1.89	2.42	3.33
	87. 0	SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
		This technique	1.01	1.05	1.12	1.22	1.36	1.56	10.82	2.26
270^o	43. 5	SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
		This technique	1.01	1.04	1.09	1.16	1.26	1.40	1.60	1.91
	87. 0	SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
		This technique	1.01	1.04	1.08	1.15	1.24	1.37	1.56	1.86
180^o	43. 5	SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
		This technique	1.00	1.01	1.03	1.05	1.08	1.13	1.19	1.25
	87. 0	SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
		This technique	1.01	1.02	1.04	1.07	1.11	1.17	1.25	1.25
90^o	43.5	SGS	0.54	0.57	0.62	0.70	0.83	1.01	1.29	1.77
		This technique	1.01	1.01	1.03	1.05	1.08	1.12	1.17	1.25
	87.0	SGS	0.54	0.56	0.60	0.65	0.73	0.83	0.98	1.21
		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)	3.62	7.25	10.87	14.50	18.12	21.75	25.37	29.00
360^o	43. 5	SGS	0.18	0.21	0.26	0.34	0.48	0.72	1.17	2.11
		This technique	1.04	1.18	1.45	1.92	2.70	4.07	6.60	11.89
	87. 0	SGS	0.18	0.20	0.24	0.30	0.40	0.56	0.83	1.31
		This technique	1.04	1.15	1.37	1.72	2.28	3.18	4.67	7.41
	43. 5	SGS	0.18	0.21	0.26	0.34	0.48	0.72	1.17	2.11
		This technique	1.03	1.10	1.24	1.46	1.79	2.30	3.10	4.68

270°		SGS	0.18	0.20	0.24	0.30	0.40	0.56	0.83	1.31
	87. 0	This technique	1.03	1.10	1.24	1.45	1.79	2.33	3.24	5.11
		SGS	0.18	0.21	0.26	0.34	0.48	0.72	1.17	2.10
	43. 5	This technique	1.01	1.04	1.09	1.16	1.27	1.42	1.63	1.96
180°		SGS	0.18	0.20	0.24	0.30	0.40	0.56	0.83	1.31
	87. 0	This technique	1.01	1.05	1.11	1.20	1.33	1.52	1.79	2.23
		SGS	0.18	0.21	0.26	0.34	0.48	0.72	1.17	2.10
	43.5	This technique	1.01	1.03	1.07	1.13	1.22	1.34	1.51	1.76
90°		SGS	0.18	0.20	0.24	0.30	0.40	0.56	0.83	1.31
	87.0	This technique	1.01	1.03	1.07	1.13	1.20	1.31	1.45	1.64

In the case of a point source at different positions in an uniform matrix, the results given by the proposed method are excellent as seen in Table 1 . Moreover, contrary to the SGS where increasing the sample-to-detector distance is used to reduce errors caused by non-uniformity of sample, this technique can be applied 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 on heterogeneity 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.

However, the disadvantage of this technique is that its error is still large due to effect of heterogeneity of matrix. The higher the heterogeneity is, the stronger the effect is. However, non-uniformity of matrix affects fairly to the assay results of the source near the centre but inconsiderably for the result of the source at the edge.

By analysing some technical characteristics it can be showed that this technique is applicable to the SGS system with modifying the software, and a combination of two techniques can give satisfactory results in practical situations.

REFERENCES

1. C.W. Bjork (1987), "Current Segmented Gamma Scanner Technology", *Proceeding of. 3rd International. Confference. on Facility Operation Safeguards Interface*, San-Diego, California.
2. A. Cesana, M Terrani and G. Sandrelli (1993), "Gamma Activity Determination in Waste Drums from Nuclear Plants", *Applied Radiations and. Isotopes*, vol. 44, no. 3, pp.517.
3. F. Levai, Z. Nagy, Tran Quoc Dung (1995), "Low Resolution Combined Emission-Transmission Imaging Techniques for Matrix Characterization and Assay of Waste",

Proceeding of the 17th ESARDA Symposium. on Safeguards and Nuclear Material Management, Aachen, Germany, pp. 9-11.

4. Tran Quoc Dung (1997), "Calculation of the systematic error and correction factors in gamma waste assay system", *Annals of Nuclear Energy*, vol.24, no.1.
5. Tran Quoc Dung (1997), "Modification to the technique using two detector for assay of radioactive waste drums", *Annals of Nuclear Energy,* vol. 24, no. 8, pp. 645-657.
6. Tran Quoc Dung, Nguyen Duc Thanh, Luu Anh Tuyen, Lo Thai Son, Ngo Minh Triết (2007), "Experimental study of systematic errors of gamma technique for assay of radioactive waste drums" *IAEA-CN-156/WM-5, IAEA Proceeding of International. Confference on Research Reactors*, Sydney, Australia.
7. Tran Quoc Dung (1998), "New measuring technique for assay of radioactive material in waste drums", *Progress in Nuclear Energy,* vol. 33, no. 4, pp. 403.
8. Tran Quoc Dung, Tran Ha Anh, Nguyen Duc Thanh (2005), "Evaluation of performance of a new measuring technique for assay of radioactive waste", *Annals of Nuclear Energy*, vol. 32, Iss.13.
9. Tran Quoc Dung, Nguyen Duc Thanh, Luu Anh Tuyen, Lo Thai Son, Phan Trong Phuc (2009), -"Evaluation of a gamma technique for the assay of radioactive waste drums using two measurements from opposing directions", *Applied Radiations and. Isotope.,* vol. 67, Iss. 1, pp. 164-169.
10. R. J. Estep, K. B. Sherwood (1991), "Prototype Tomographic Gamma Scanner for assaying 208 l Drums", *Transactions of the American Nuclear Society*., 63.
11. B. M. Gillespie (1994), "Inhomogeinetiy Detection and Correction in Drum Waste Assay Systems", *Proceeding of International. Confference on. on International Safeguards*, Vienna.
12. Phan Văn Hạp và cộng sự (1970), *Phương pháp tính,* Nxb Đại học, Hanoi.
13. J. K. Sprinkle and S. T. Hsue (1987), "Recent Advantage in Segmented Gamma Scanner Analysis", *Proceeding of . 3rd International. Confference. on Facility Operation Safeguards Interface, San-Diego, California.*

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