EVALUATION OF COMBINATION OF DIFFERENT METHODS FOR DETERMINATION OF ACTIVITY OF RADIOACTIVE WASTE IN SEALED DRUM

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ABSTRACT

This paper presents a method that could diminish systematic errors of gamma techniques for assay of radwaste drums. The idea is the combination of Segmented Gamma Scanning technique and technique using two identical detectors. The results show that the maximum errors are small in comparison with those of SGS technique and technique using two detectors. This combinative method corresponds well to determine activity of radioactive in low density waste drums, such as organic materials: rags, protective clothing, shoes, gloves etc...

Keywords: gamma techniques, radioactive waste, gamma spectrometry

TÓM TẮT

Đánh giá việc kết hợp các kĩ thuật khác nhau để xác định hoạt độ các thùng thải phóng xạ

Bài báo này trình bày một phương pháp có thể làm giảm sai số hệ thống trong việc kiểm tra các thùng chất thải bằng kĩ thuật gamma. Ý tưởng của phương pháp là kết hợp hai kĩ thuật đo Quét Gamma Phân đoạn và dùng hai đầu dò đồng nhất. Các kết quả cho thấy sai số là nhỏ so với các kĩ thuật đo riêng lẻ và kĩ thuật sử dụng hai đầu dò. Phương pháp kết hợp đáp ứng tốt cho việc xác định hoạt độ của các chất thải phóng xạ trong các thùng chứa các chất độn có mật độ thấp như túi, giày, găng tay, quần áo bảo hộ v.v…

Từ khóa: kĩ thuật gamma, chất thải phóng xạ, phổ kế gam-ma.

1. Introduction

The operation of nuclear industry results in the production of a considerable amount of radioactive waste, which is usually stored in large sealed drums. Because of the requirements of radioactive waste management, determination of activity of isotope in the drum is necessary.

The Segmented Gamma Scanner (SGS) is a traditional technique that has been used for almost practical cases [1,2]. However, the accuracy depends on many factors: non-uniform distribution of radioactive source within the drum; inhomogeneous

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distribution of non-radioactive materials [3]; the lump effect, especially for uranium and plutonium assay [2]; the drum-to-detector distance [3].

In order to increase the accuracy some recent methods were proposed: technique using two identical detectors [4,5,6]; technique of measuring a drum with different geometry and/or some different gamma energy lines of the isotope of interest [7,8,9]; gamma tomographic techniques [10, 11].

To reduce the systematic errors the method of combination of SGS technique and technique using two identical detectors was studied by simulation of measuring system. The results are shown in this paper.

2. Study and results

2.1. Gamma techniques for assay of radwaste drums

Segmented gamma scanning is an important measurement tool for assay of radioactive waste. It was developed by Los Alamos National Laboratory (USA) in early 1970's. SGS has been using the assumptions that the radioactive source and sample matrix are uniform for a segment. The procedures for using the SGS can cause errors if the sample does not satisfy the assumptions.

The basic idea of this technique is to divide the drum into a series of horizontal segments and to assay each segment in a conventional gamma measurement. When all segments have been measured, the total assay result for the drum is given by summing the results of each segment. The accurate results are obtained by using the assumption of a uniform radial distribution of source in each segment. To minimize the potential error caused by non-uniform distribution of material within the segments, the drum is rotated during the measurement as shown in Figure 1.

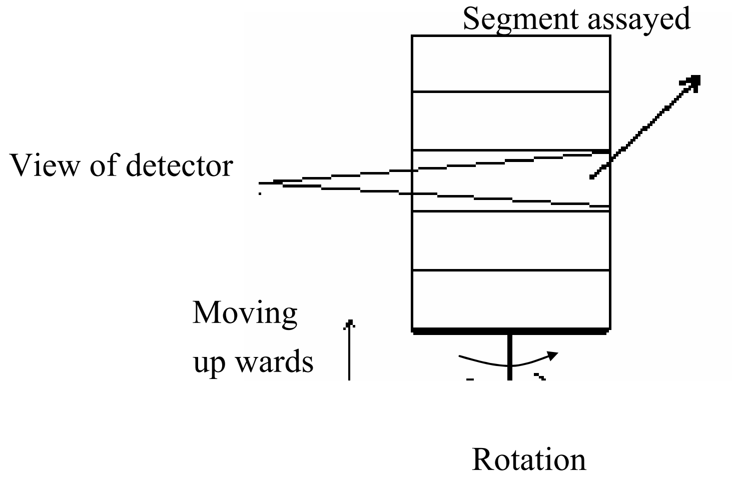
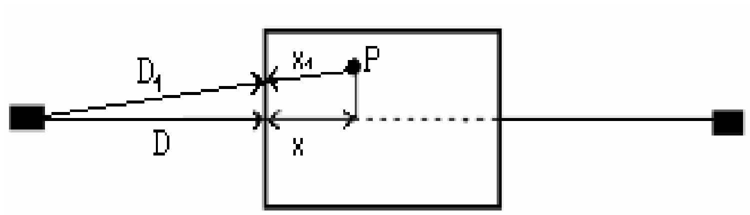


***Figure 1**. Schematic of the Segmented Gamma-ray Assay of a waste drum*

The investigation demonstrates that very large error can be introduced in the result when a heterogeneous waste drum is assayed by SGS. The measurement errors increase rapidly as a function of increasing attenuation coefficient. The distance from drum to detector also influences the results. The shorter the distance is, the larger the error is. The inhomogeneity of matrix adds to the measurement error. The higher the heterogeneity is, the stronger the effect is. The error caused by the inhomogeneity of matrix is small in comparison with that caused by nonuniformity of radioactive source. The error strongly depends on the radioactive distribution. The more nonuniform the distribution is, the more inaccurate the result is.

Segmented gamma scanning technique can be used for most practical cases. However, for assay of the drums containing low density waste, mainly consisting of organic materials (contaminated paper, rags, protective clothing, shoes…) from operation of nuclear plant, another measuring technique has been studied

The principles of this technique were given by A. Cesana et al [4]. Two identical detectors are set on the drum axis at the same distance from the bases as shown in Figure 2.



Detector 1 Detector 2

Figure 2. *Illustration of technique using two identical detectors*

The total activity is: $I = \frac{(C_1C_2)^{1/2}}{G}$ (1)

Where C_1, C_2 are count rates of detector 1 and detector 2, respectively. The geometric mean of the efficiencies is defined as

$$G = \frac{\alpha}{D^2}.e^{-\mu_1 L/2} \quad (2)$$

Where L is the length of the drum. The value of G can be determined directly by experiment using a calibrated source placed next to one base of the drum. In the general case of a random distribution of activity, the drum can be subdivided into an appropriate number of thin sheet. I_i – activity of the i-th sheet at the depth x_i.

So, the geometric mean G becomes:

$$G_T = \frac{\alpha}{I.D^2}.\left(\sum_i I_i e^{-\mu_1 x_i}.\sum_i I_i e^{-\mu_1 (L-x_i)}\right)^{1/2}$$

$$= \frac{\alpha}{D^2}.e^{-\mu_1 L/2}\left\{1+2\sum_i\sum_{j>i}\frac{I_i I_j}{I^2}\left[\cosh\left[\mu_1\left(x_i - x_j\right)\right]-1\right]\right\}^{1/2} \quad (3)$$

When the linear attenuation coefficient (μ) is low and/or total activity is concentrated in a small fraction of drum volume, expression (3) approaches expression (2). In general case, the error will increase when μ is high and (x_i-x_j) is large. In order to estimate this error, a set of two source layers with their different distances of source is modeled. The investigation shows that the accuracy of the result of this technique depends on the distance from detector to drum bases (D), the coefficient μ and the distribution of radioactive in the drum.

2.2. Combination of the techniques

In order to reduce systematic errors of each above techniques, a technique based on the combination of them was considered. The schematic of the method is shown as Figure 3. It consists of two identical detector 1 and 2 that are set on the drum axis at the same distance from the bases and detector 3 scans the drum which is rotated during measurement.

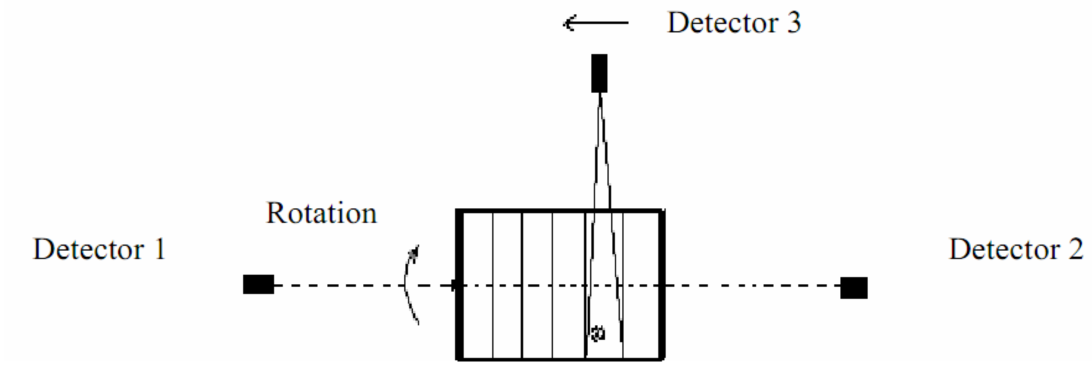


***Figure 3**. Schematic of combination of SGS and technique using two identical detectors*

The measurement result by SGS technique determines activity $I_{Si}= \gamma_i .I_{di}$ for i-th segment. Where I_{di} – "true" activity of i-th segment and

$$\frac{I_{Si} - I_{di}}{I_{di}}.100\% = (\gamma_i - 1)100\%$$

is the error of SGS technique.

Using expression (3) the approximate value of factor G_T, called f_{gd} can be collected.

$$f_{gd} = \frac{\alpha}{D^2}.e^{-\mu_1 L/2}\left\{1+2\sum_i\sum_{j>i}\frac{\gamma_i.I_{di}.\gamma_j.I_{dj}}{\left(\sum\gamma_i I_{di}\right)^2}\left[\cosh\left[\mu_1\left(x_i - x_j\right)\right]-1\right]\right\}^{1/2} \quad (4)$$

After determining factor f_{gd}, approximate activity $I_{gd} = \frac{(C_1C_2)^{1/2}}{f_{gd}}$ is collected.

According to expression (3) we have G_T as follows,

$$G_T = \frac{\alpha}{D^2}.e^{-\mu_1 L/2}\left\{1+2\sum_i\sum_{j>i}\frac{I_{di}.I_{dj}}{I_d^2}\left[\cosh\left[\mu_1\left(x_i - x_j\right)\right]-1\right]\right\}^{1/2} \quad (5)$$

Generally, activity $I = \frac{(C_1C_2)^{1/2}}{f}$, the change of f for G_T gives "true" activity I_d . The change of f for f_{gd} and G gives approximate activity I_{gd} and I_0 respectively.

For proven of the preeminence of combination of the techniques, the satisfaction of two conditions is

$| I_d – I_0 | > | I_d – I_{gd} |$ (6)

$| I_d – I_S | > | I_d – I_{gd} |$ (7)

Where $I_S = \sum I_{Si}$,

As $I_d = \frac{(C_1C_2)^{1/2}}{G_T}$; $I_{gd} = \frac{(C_1C_2)^{1/2}}{f_{gd}}$ then $I_{gd} = I_d.\frac{G_T}{f_{gd}}$ (8)

The error of this combinative method is (γ_c –1)100%, where $\gamma_c = G_T/f_{gd}$

Because choosing drum is a random process, a computer program has been created for random test. Choosing random values of γ_i, put on inequalities (6) and (7) it will lead result that the correction of the random values of I_S examine the satisfaction of inequality (6) and (7), at the same time get out the minimum, maximum values of γ_c

Using standard drum 210 liter with diameter R = 29cm, length L = 86cm, distance from detector to drum D = 150cm, number of segments 6. Linear attenuation coefficient μ is from $0.01cm^{-1}$ to $0.12cm^{-1}$. Doing 2000 times random tests both inequalities for each value of γ. For each value of μ, the value of γ_i gives the errors from minimum (S_{min}) to maximum (S_{max}) values of SGS technique.

Table 1 and 2 show the comparison of errors among three techniques. The error of SGS technique is caused by point source in uniform matrix. In all cases, μ from 0.01 to 0.12 cm^{-1}, the error interval of combination technique is always small in comparison with the error interval of SGS technique, and the error of combination technique is small in comparison with the maximum error of technique using two detectors. Here P is the probability so that the value of activity of the combinative method is better than the value of SGS technique and technique using two detectors. The value P (%) is 100% when $\mu = 0.01cm^{-1}$ and reduces when μ increases.

***Table 1**. Comparison of errors between three techniques.*
The "true" activity I_{di} is supposed equal to 1(MBq)

μ (cm^{-1})	SGS		Two detector S_{max}	Combination of two techniques		P(%)
	S_{min}	S_{max}		S_{min}	S_{max}	
0.01	-1%	30%	53%	-1%	1%	100
0.02	-11%	44%	117 %	-5%	4%	85.85
0.03	-21%	61%	220%	-10%	8%	79.25
0.06	-47%	125%	1010%	-27%	39%	64.9
0.08	-61%	179%	2480%	-37%	95%	56.95
0.12	-82%	317%	13880%	-52%	285%	50.6

***Table 2.** The error of the combination technique.*
The value I_{di} is randomly chosen from 0 to 10 (mCi)

μ (cm^{-1})	P'(%)	Combination two techniques	
		S_{min}	S_{max}
0.01	100	-1%	1%
0.03	82.65	-9%	9%
0.08	64.65	-39%	87%

3. Conclusion

The above results show that the errors are reduced by combination of the different techniques. For all coefficient μ the maximum errors are small in comparison with those of SGS technique and technique using two detectors. In case of low linear attenuation coefficient (<0.03 cm^{-1}) this method is very good.

The combination of the different techniques can be used to determine radioactive activity in low density waste drums, such as organic materials: rags, protective clothing, shoes, gloves etc…

REFERENCES

1. C.W. Bjork (1987), "Current Segmented Gamma Scanner Technology", *Proceeding of. 3rd International Conference 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. 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.
4. Tran Quoc Dung, "Modification to the technique using two detector for assay of radioactive waste drums", *Annals of Nuclear Energy*, Vol. 24, no. 8, p. 645-657.
5. 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. Conference on Research Reactors*, Sydney, Australia.
6. 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.
7. 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.
8. 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.
9. R. J. Estep, K. B. Sherwood, "Prototype Tomographic Gamma Scanner for assaying 208 l Drums", *Transactions of the American Nuclear Society*., 63, 1991.
10. H.E Martz, G.P Roberson, D.C Camp, D.J Decman, J.A Jackson and G.K Becker (1998), Active and Passive Computed Tomography Mixed Waste Focus Area, *Final Report. Lawrence Livermore National Laboratory*, UCRL-ID-131695.
11. J. K. Sprinkle and S. T. Hsue (1987), "Recent Advantage in Segmented Gamma Scanner Analysis*", Proceeding of. 3rd International. Conference on Facility Operation Safeguards Interface, San-Diego*, California.

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