EXPERIMENTAL STUDY OF SYSTEMATIC ERRORS OF GAMMA TECHNIQUE FOR ASSAY OF RADIOACTIVE WASTE DRUMS

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ABSTRACT

A measuring technique using two identical detectors has been studied for assay of the drums containing low density waste, mainly consisting of organic materials such as contaminated paper, rags, protective clothing, shoes, etc.

In order to develop the technique to measure the activity of the radioactive waste drums released during operation of Dalat Research Reactor, Dalat City, Vietnam, the experimental study are carried out to confirm the calculation results of the systematic errors and evaluate the performance of this technique in practice.In this paper, the results of uniform matrix and point source in different positions in the drum are presented. The results are also basic for establishment of measuring procedure for assay the radwaste drums.

I- INTRODUCTION

The operation of nuclear reactors results in the production of a considerable amount of radioactive low density waste, mainly consisting of organic materials which are usually stored in large sealed drums (208 l). The drums must be checked to satisfy regulations of radioactive waste management.

The Segmented Gamma Scanner (SGS) is a traditional tool for the isotopic composition measurement and for determination of the activity level in gamma contaminated waste drums [1, 2]. The systematic error of this technique is still large because of: non-uniform distribution of radioactive source within the drums frequently causes the largest error [3,4]; non-uniform distribution of non-radioactive materials (matrix) [4,5]; particles size of the nuclear material, the lump effect, specially for uranium and plutonium assay [2,6,7,8]; the drum-to-detector distance [4].

The other measuring technique has been studied by Cesana [9] for assay of the drums containing low density waste, mainly consisting of organic materials such as contaminated paper, rags, protective clothing, shoes, etc. The measuring arrangement consists two identical detectors set at equal distances from two bases of drum. This technique was developed because of the reasons: first, the measure is usually limited to rather hard gamma rays emitted by Cs-137, Cs-134, Co-60..., the mass-absorption coefficients are nearly independent of the atomic number of matrix, and the linear attenuation coefficients are very low (typically 0.01-0.03 cm^{-2}) because of the low waste density (0.2-0.4 g/cm^3). Therefore, the gamma attenuation in whole drum can be considered by means of on average linear attenuation coefficient, independent of the position in a drum; second, the number of drums to be examined is supposed to be very large, so that a detailed scanning by SGS is practically impossible; third, the measuring arrangement is very simple, so it can be used for any situation. However, in this measurement the drum must lie down. Thus, it spends time and is not convenient for use in practice. Moreover, the error is still very large (223 %) if the activity is distributed in the vertical large region.

A modification to the measurement arrangement with the geometric coefficient for cylindrical sample was proposed to overcome the disadvantages [10]. In order to develop the technique to measure the activity of the radioactive waste drums released during operation of Dalat Research Reactor, Dalat City, Vietnam, the experimental study are carried out to confirm the calculation results of the systematic errors and evaluate the performance of this technique in practice. The affect of the factors, such as distribution of sources, attenuation coefficients and homogeneity of matrix, on the measuring results were investigated. In this paper, the results of homogenous matrix and point source in different positions in the drum are presented.

II) STUDY AND RESULTS

The measuring principle is given in Figure 1. A detector is set perpendicularly to the drum axis at the middle point.

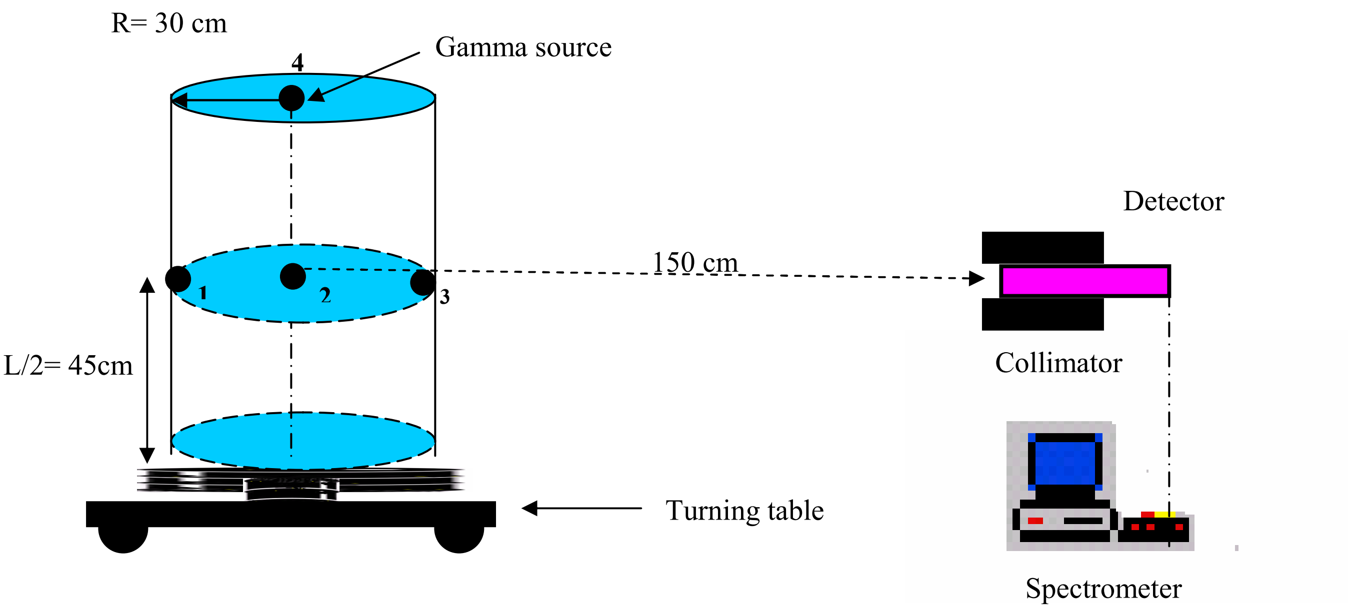

Figure 1: Waste drum counting geometry. The drum is measured two times. In the second measurement the drum is rotated 180^0.

The activity I in the drum can be determined as

$$I = \frac{(C_1 C_2)^{1/2}}{G} \quad (1)$$

With

$$G = \frac{\alpha}{S^2} \exp -(\mu_1 \times 0.832 \times R) \quad (2)$$

Where C_1, C_2- the count rates of the detector in two measurements; S=K-0.823.R; K- distance from detector to the drum. This distance is larger the diameter of the drum several times; α-coefficient, that is a function of the gamma-ray energy, intrinsic efficiency of detector and the effective distance K. $\mu_1=2/S+\mu$; μ - the linear attenuation coefficient in the waste mixture. Rradius of drum; The values of α/S^2 versus gamma ray energy can be determined by using appropriate standard source.

The proposed coefficient G in formula (2) is based on the some approximations [9, 10]. The distance between the centre of the drum and the detectors is about four times the half of the height of the drum. Thus, the geometric mean of the efficiencies of the sources at different positions of vertical axis can be considered as the same. When the height of the drum is 86 cm, K= 120 cm the maximum variation is less than 6 %. Therefore, the vertical count rate variation can be ignored. The systematic errors are caused mainly by the horizontal inhomogeneity of the source in the drum because the important assumption of this technique is that the activity is distributed in a small region of the drum volume.

In the experiments, a standard drum was used. Two point sources Co-60 of 0.36 MBq and two point sources Cs-137 of 0.64 MBq were located at four specified radial positions in the different measurements as in Fig. 1. Many pieces of matrix with various shapes and densities are made from clothing materials. The linear attenuation coefficients are in range 0.011- 0.031 cm^{-1} corresponding to gamma rays emitted by Cs-137 and Co-60 sources. A High-purity germanium detector- Gem 50P4, and a standard digital spectrometer, model DSPEC.JR-312-Ortec, with GAMMAVISION 32 version 6.1 and COLEGRAM version 2.01 were used for detection and analysis of gamma spectra. The results are given in Table I. Here the experimental and calculated values of errors are presented as ratio of the experimental and calculated to true value of activity.

The experimental results confirm prediction of the theoretical results of systematic errors of this technique. When the activity concentrates as a point source the systematic errors are minimum and independent on the attenuation coefficient of matrix as given in Table I.a. In these cases the errors depend only on the position of the sources. The distance between the centre of the drum and the detectors is equal to many times the half of the height of the drum. Thus, the geometric mean of the efficiencies of the sources at different positions of vertical axis can be considered as the same. When the height of drum is 86 cm and detector- to –drum is 120 cm the maximum variation is less than 6 %. This is proved in case of the source in position 5. Therefore, the vertical count rate variation can be ignored. The errors are caused mainly by the horizontal inhomogeneity of the source in the drum as case of two sources with the same activity in position 1 and 3 (see Table I.).

TABLE I

a) Comparison of the experimental and calculated values for estimation of the systematic error when a point source in different positions.

Case of study		*One source in position 1*		*One source in position 2*	
Gamma Energy (kev)	Linear attenuation coefficient (cm^{-1})	Experimental value of error	Calculated value of error	Experimental value of error	Calculated value of error
661	0.016	0.97 ± 0.01	0.99	0.91 ± 0.02	0.95
661	0.024	0.92 ± 0.01	0.95	1.04 ± 0.02	0.91
661	0.031	0.92 ± 0.02	0.91	1.01 ± 0.02	0.87
1173	0.013	0.99 ± 0.01	1.00	0.90 ± 0.02	0.96
1173	0.014	0.99 ± 0.01	1.00	0.88 ± 0.02	0.96
1173	0.023	0.96 ± 0.01	0.95	0.91 ± 0.02	0.91
1332	0.011	0.99 ±0.01	1.01	0.90 ± 0.02	0.97
1332	0.013	1.00 ± 0.01	1.00	0.91 ± 0.02	0.96
1332	0.019	0.97 ± 0.01	0.97	0.91 ± 0.02	0.93
1332	0.021	0.96 ± 0.02	0.96	0.93 ± 0.02	0.92

TABLE I (continued)

b) Comparison of the experimental and calculated values for cases of large systematic errors.

Case of study		*One source in position 5*		*Two sources in position 1 and 3*	
Gamma Energy (kev)	Linear attenuation coefficient (cm^{-1})	Experimental value of error	Calculated value of error	Experimental Value of error	Calculated value of error
661	0.016	0.81 ± 0.02	0.85	1.15 ± 0.02	1.21
661	0.024	0.87 ± 0.02	0.81	1.27 ± 0.03	1.30
661	0.031	0.76 ± 0.02	0.77	1.38 ± 0.03	1.41
1173	0.013	0.82 ± 0.02	0.87	1.16 ± 0.02	1.18
1173	0.014	0.81 ± 0.02	0.86	1.15 ± 0.03	1.19
1173	0.023	0.78 ± 0.02	0.81	1.31 ± 0.03	1.29
1332	0.011	0.80 ± 0.02	0.88	1.14 ± 0.02	1.17
1332	0.013	0.81±0.02	0.87	1.25 ± 0.03	1.18
1332	0.019	0.90 ± 0.02	0.83	1.17 ± 0.03	1.24
1332	0.021	0.88 ± 0.02	0.82	1.30 ± 0.03	1.26

The experiment is aimed at verifying the calculation model. The experimental results show that the calculation model is satisfactory in view of the approaches for application.

When distance between the centre of the drum and the detectors is equal to about four times the half of the height of the drum, the maximum variation is less than 10 % as shown in the case of the source in position 5**.** As a result, the sources at different positions of vertical axis can be considered as the same.

The results demonstrate that generally the proposed expression (2) satisfies the characteristic of the method: the more the total activity is distributed in a small range the higher the measurement accuracy is. They are about 3-12 % for almost cases. The large errors (maximum value ~ 41%) happen when two sources with the same activity are in opposite positions as 1 and 3 positions (see Table I.b).

3. Conclusion

The experimental results confirm performance of this gamma technique for assay of radioactive waste in practice. The maximum systematic errors are not larger than about 50% when the attenuation coefficients of matrix are in the range of 0.01-0.03 cm^{-1}. The maximum error (~ 41%) of this method is larger than that (~ 30%) of SGS techniques. However its measurement apparatus is very simple, perform of measurement is faster, and it can be used for most of the situations encountered in practice.

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