EFFICIENCY CALIBRATION STUDIES FOR GAMMA SPECTROMETRIC SYSTEMS: THE INFLUENCE OF DIFFERENT PARAMETERS*

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The radioactive waste containers, containing different radioactive materials, have to be characterized before their final disposal. Destructive methods, although being the most precise, are also the most expensive and not the easiest ones from the radioprotection point of view. In this situation, high resolution gamma spectrometry proved to be a reliable method for the non destructive assay method. However, the non-homogenous composition of the radioactive waste inside the drum makes the quantitative characterization of the radioactive waste drum a difficult task. The efficiency calibration procedure is difficult and dependent on different parameters such as: experimental set-up, the sources distribution inside the drum, and also on the nuclear data used for the calculations. The experimental studies complemented with the performed Monte Carlo calculations are presented in this paper.

Key words: gamma spectrometry, efficiency calibration, radioactive waste.

1. INTRODUCTION

Nuclear waste assay is an integral element of programs such as safeguards, waste management, and waste disposal. The radioactive waste containers, containing different radioactive materials, have to be characterized before their final disposal.

The majority of nuclear waste is packaged in drums and analyzed by various techniques to identify and quantify the radioactive content. Due to various regulations and the public interest in nuclear issues, the analytical results are required to be of high quality.

Destructive methods, although being the most precise, are also the most expensive and not the easiest ones from the radioprotection point of view. In this

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situation, high resolution gamma spectrometry proved to be a reliable method for the non destructive assay method. However, the non-homogenous composition of the radioactive waste inside the drum makes the quantitative characterization of the radioactive waste drum a difficult task. The calibration procedure is difficult [1] and dependent on different parameters such as: experimental set-up, the sources distribution inside the drum [2–5], and also on the nuclear data used for the calculations. The experimental studies and test cases with Monte Carlo calculations performed are presented in this paper.

In our country, the radioactive waste is generally packed in type A containers (220 l drums).

For the intermediate and final disposal of medium and low activity radioactive waste, the Romanian law authorizes this kind of packing.

2. EXPERIMENTAL SET-UP

For the experimental determinations, a calibration drum (similar with the one used in normal conditioning of the waste) and a linear reference source were used.

The drum is provided with 7 hollow parallel tubes of 20 mm diameter, the rest of the drum is filled with Portland cement similar with the one used for the drums. The tubes are placed in the calibration drum at different radial distances from the drum centerline as follows: 7 (center), 6 (7 cm), 5 (12 cm), 4 (16 cm), 3 (19 cm), 2 (21.5 cm), 1 (24.5 cm) from center, respectively. The drum has 82 cm length (Fig. 1).

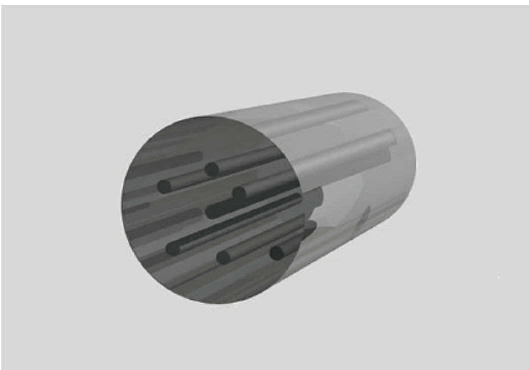
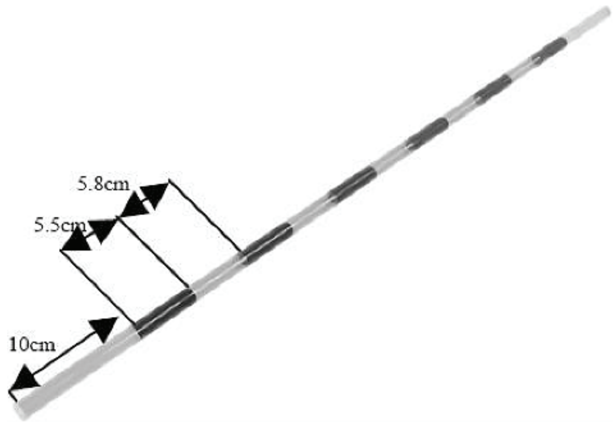


Fig. 1 – A schematic representation of the measurement geometry for the calibration drum.

The linear reference source is composed of six ^{152}Eu liquid sources of equal activity, each introduced in a glass ampoule with length $l = 55$ mm (Fig. 2). The ampoules were placed at equal distances in a plastic tube. The length of the linear source is 620 mm equal with the length of the active volume of the drum. In the normal conditioning of the waste both ends of the drum are

Fig. 2 – [152]Eu reference source.



filled with 10 cm of cement. In order to be in concordance with the active length of the drum, the source has 10 cm of its length inactive at both ends.

For the efficiency calculation the linear reference source is introduced in the hollow tubes from the calibration drum. During the efficiency calibration only one tube at a time was filled with the linear reference source leaving the others empty. The waste assay system [5] has a lead-collimated vertical HPGe detector, of 30% relative efficiency and 1.8 keV energy resolution (at 1332 keV). The rectangular collimator window has the length 10 cm and the width 4 cm. The lead shield has the interior diameter 9 cm and the wall thickness 4.4 cm. The detector was located at 32.5 cm in radial direction from the surface of the calibration drum

In order to minimize the effect of non-homogeneous matrix and sources distribution in typical measurements of waste drums, the drum is rotated and translated (a double translation) in front of an HPGe collimated detector, while the measurement is performed

3. RESULTS AND DISCUSSIONS

3.1. EXPERIMENTAL

The efficiency calibration for a uniformly distributed radioactive waste was performed using the shell-sources method [6–10]. This method provides the efficiency values for the case when only a part of the drum, namely a cylinder of radius x, coaxial with the drum, contains radioactive sources, the rest of the drum being filled with inactive concrete. In Table 1 the corresponding efficiencies are presented for several values of x.

It can be observed that for a source distributed in the entire volume of the drum (x = 28.5 cm), the calibration curve has a pattern approximately similar to a normal one.

Table 1

The detection efficiency for several values of *x* (cm)

E [keV]	Efficiency					
	28.5	**24.5**	**21.5**	**19.5·**	**16.5**	**12.5**
122	$1.250 \cdot 10^{-6}$	$5.540 \cdot 10^{-7}$	$2.190 \cdot 10^{-7}$	$9.930 \cdot 10^{-8}$	$2.530 \cdot 10^{-8}$	$3.570 \cdot 10^{-9}$
344	$1.470 \cdot 10^{-6}$	$7.760 \cdot 10^{-7}$	$4.020 \cdot 10^{-7}$	$2.370 \cdot 10^{-7}$	$9.920 \cdot 10^{-8}$	$3.230 \cdot 10^{-9}$
779	$1.330 \cdot 10^{-6}$	$8.010 \cdot 10^{-7}$	$4.960 \cdot 10^{-7}$	$3.430 \cdot 10^{-7}$	$1.860 \cdot 10^{-7}$	$7.730 \cdot 10^{-8}$
964	$1.350 \cdot 10^{-6}$	$8.270 \cdot 10^{-7}$	$5.250 \cdot 10^{-7}$	$3.710 \cdot 10^{-7}$	$2.090 \cdot 10^{-7}$	$9.070 \cdot 10^{-8}$
1112	$1.350 \cdot 10^{-6}$	$8.500 \cdot 10^{-7}$	$5.580 \cdot 10^{-7}$	$4.060 \cdot 10^{-7}$	$2.380 \cdot 10^{-7}$	$1.080 \cdot 10^{-7}$
1408	$1.420 \cdot 10^{-6}$	$9.180 \cdot 10^{-7}$	$6.190 \cdot 10^{-7}$	$4.590 \cdot 10^{-7}$	$2.780 \cdot 10^{-7}$	$1.310 \cdot 10^{-7}$

For a source distributed in smaller volumes (cylinders of the same length as the drum, but with the radius *x* smaller than the radius *R* of the drum, the rest of the drum being filled with inactive concrete), generally, the attenuation of gamma rays of low energy in cement layer is much stronger than that of the high-energy gammas. As a result, the efficiency curve presents a slowly increasing pattern with energy, though the relative efficiency of the detector decreases with gamma ray energy.

3.2. MONTE CARLO CALCULATION

In this work, also, the Monte Carlo based GESPECOR software was applied for the computation of the efficiency. The principles of the program and the extension for the measurement of high volume samples have been published elsewhere [7–9].

The efficiency values for different matrix densities (ρ = 1.6, 1.8, 2.0, 2.2, 2.3 and 2.4 g/cm^3) for two situations of interest were computed:

– in the cases of a point source placed at the half-distance between the drum's ends. As the point source, one of the six liquid ^{152}Eu sources, from the linear reference source, was used and

– the linear source with the drum only rotated.

The relative variation of these efficiencies with energy for $r = 0$ cm and $r = 24.5$ cm, for both linear source and point source are presented in Fig. 3.

As it can be observed, the effect of density variations is small for shell sources placed far from the center of the drum and increases as the shell source is displaced toward the center. Without proper knowledge of the source distribution it is impossible to apply accurate density corrections to the efficiency.

Monte-Carlo calculations can cover situations which experimentally can not be realized such as efficiency calibration for different matrix density, for different positions of a radioactive source inside the drum (experimental only for

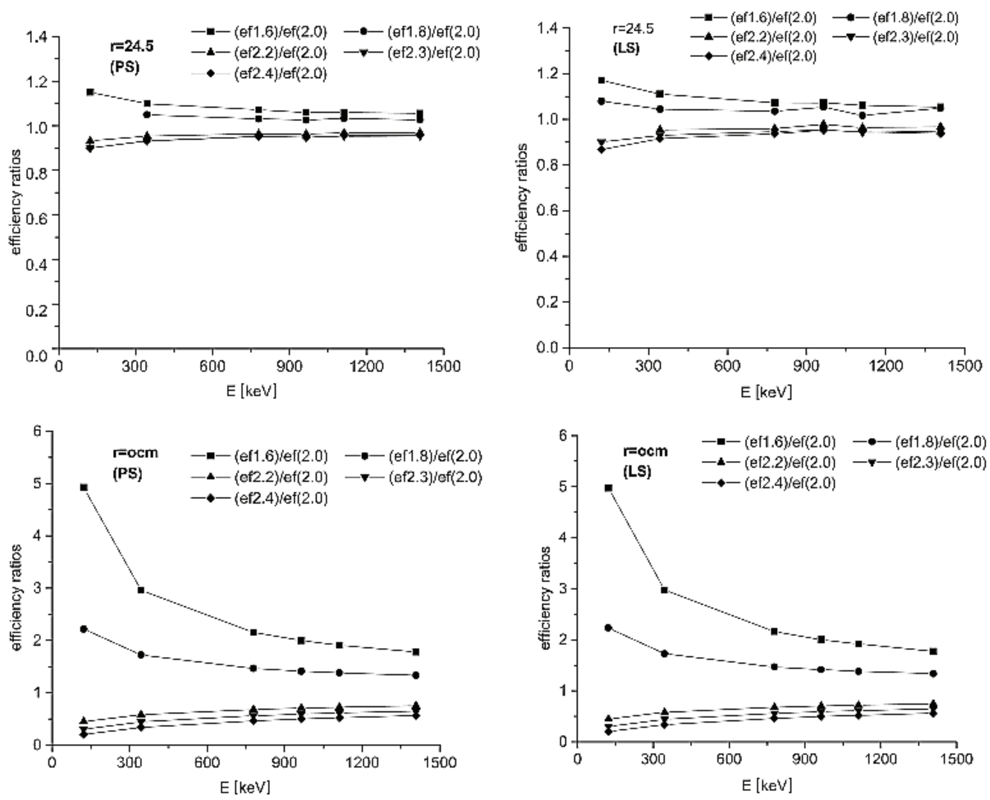


Fig. 3 – The relative variation of the computed efficiencies with energy for density variations. The point source (PS) and linear source (LS) are placed in two positions ($r = 24.5$ cm, $r = 0$ cm) inside the drum, the drum being only rotated.

the concrete density could be archived, as could be observed). In this situation, in order to be able to investigate the effect of the density variations of the efficiency a simulation technique is required. But other features of the experimental set-up are also important. For example, a change by 1 cm of the length of the collimator along the accepted photon paths results in a gradual change of the efficiency by approx. 20% for the linear source in position 7 to 4% for the linear source in position 1.

The work is in progress.

REFERENCES

1. Klaus Debertin, Richard G. Helmer, *Gamma and X-ray spectrometry with semiconductor detectors*, Elsevier Science Publishers B. V. (1988).
2. M. Bruggerman, J. Gerits, R. Carchon, *A minimum biased shell-source method for the calibration of rad waste assay system*, Applied Radiation and Isotopes 51, 255–259, 1999.

3. J. H. Liang, S. H. Jiang, G. T. Chou, *A Theoretical Investigation of Calibration for Radwaste Radioactivity Detection System,* Applied Radiation and Isotopes vol. 47. No. 7, 669–675, 1996.
4. J. H. Liang, S. H. Jiang, J. T. Chou, C. C. Chen, S. W. Lin, C. H. Lee, S. T. Chiou, *Parametric Study of Shell-source Method for Calibrating Radwaste Radioactivity Detection Systems*, Applied Radiation and Isotopes vol. 49, No. 4, 361–368, 1998.
5. M. Bruggerman, R. Carchon, *Solidang a computer code for the computation of the effective solid angle and correction factors for gamma spectroscopy-based waste assay*, Applied Radiation and Isotopes 52, 771–776, 2000.
6. P. Filb, *Relation between the activity of a High Density Waste Drum and its Gamma Count Rate Measured with an Unshielded Ge-detector*, Applied Radiation and Isotopes vol. 46, No. 8, 805–812, 1995.
7. L. Dinescu, I. Vata, I. L. Cazan, R. Macrin, Gh. Caraghergheopol, Gh. Rotarescu, *On the efficiency calibration of a drum waste assay system*, Nuclear Instruments and Methods in Physics Research A 487, 661–666, 2002.
8. O. Sima, C. Dovlete, *Matrix Effects in the Activity Measurement of Environmental Samples – Implementation of Specific Corrections in a Gamma-ray Spectrometry Analysis Program,* Applied Radiation and Isotopes 48, 59–69, 1997.
9. O. Sima, D. Arnold, C. Dovlete, *GESPECOR: a versatile tool in gamma ray spectrometry*, J. Radioanal. Nucl. Chem. 248 (2), (2001), 359–364.
10. M. Haralambie, L. Dinescu, O. Sima, *New data concerning the efficiency calibration of a drum waste assay system. Part I: Experimental calibration*. Romanian Reports in Physics, Vol. 56, No. 4, (2004) p. 711–720.