

The efficiency calibration for local manufacturing gamma scanning systems of radioactive waste drums

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Abstract

The Local manufacturing scanning gamma system designed in Tuwaitha site for nondestructive assay method of radioactive waste drums, where it consist of two main parts with their belongings for controlling the of detector and drum movements up-down and rotation respectively. The volume of the used drum is 220 L with 85 cm height. The drum filled with Portland cement. Six cylindrical holes were made within cement drum and distributed in radial arrangement. The ^{152}Eu source inserted in these holes individually, to measure the average angular count rate of gamma radiation. The full energy efficiency value for geometry of drum and detector is computed for thirteen photo peaks. The average efficiency represented by the curve of these peaks indicated the decreasing of efficiency value with increasing the cement thickness and the distance between the detector and the location of radioactive source inside the drum.

Key words

Gamma scanning system, radioactive waste (RW), nondestructive assay (NDA).

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معايرة الكفاءة لمنظومة مسح اشعة كاما المصنعة محليا لبراميل النفايات المشعة

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الخلاصة

تم تصنيع منظومة مسح اشعة كاما في موقع التوثيقة لأجل التحليل غير الإتلافي لبراميل النفايات المشعة، حيث ان هذه المنظومة تتكون من جزأين رئيسيين مع ملحقاتهما للسيطرة على حركة الكاشف للاسفل والاعلى وعلى حركة البرميل الدورانية. ان حجم البرميل المستخدم هو 220 لتر وبارتفاع 85 سم. ملئ البرميل بإسمنت بورتلاند. تم صنع ستة فجوات اسطوانية في برميل الاسمنت موزعة بشكل شعاعي. تم ادخال المصدر المشع ^{152}Eu في كل فجوة على حده لاجل قياس معدل نسبة العد الزاوي لاشعة كاما. ان قيمة الكفاءة للشكل الهندسي المؤلف من الكاشف والبرميل قد تم حسابها لثلاثة عشر ذروة ضوئية. لقد بين معدل الكفاءة المتمثل بمحني هذه الذروات النقصان في قيمة الكفاءة عند زيادة سمك الاسمنت والمسافة بين الكاشف وموقع المصدر المشع داخل البرميل.

Introduction

In Iraq the problem of nuclear radioactive waste (RW) aggravated because of many destroyed nuclear facilities, missiles remains of depleted uranium used by American army in addition to legacy of old nuclear activities. RW packaged in drums and being placed in drums then located in storage sites such as Al-Tuwaitha.

The RW which contains different radioactive materials should be characterized before disposal into an appropriate container or drum.

Because of the energy calibration can be done with common radioactive sources, the qualitative assay for radioactive materials is not difficult task to be done. The quantitative analysis to determine the activity of

each radionuclide is more difficult due to the efficiency calibration. In principle, it should be carried out with calibration standard which requires physical and chemical similarity with unknown sample. In fact the calibration standard is not needed if the detector efficiency is accurately known as a function of source position, the counting geometry and the sample size and shape are accurately known. Also, the exact energy peak and the counting rate of emitted gamma radiation can be determined for the isotope (s) and analyzed explicitly [1].

In spite of destructive assay method (DA) is more precise than nondestructive assay (NDA), the sampling in DA, required opening the drums and special procedures for safety and protection, that may make it more expensive than NDA, but in both of methods the quality and quantity assay can be achieved [2].

Number of researches relating to NDA had been done in the some of the calibration techniques of gamma spectrometry for the radioactive waste drums. The Monte Carlo codes FOTELP and spectrometry of gamma analysis used as a non-destructive methodologies to assay 200 liter drum of radioactive waste [3]. Haralambie, et al., achieved the experimental calibration curve of efficiency for waste drum system in addition to Monte Carlo Simulation by using the software of GESPECOR [4]. In the other hand, Savidou, et al. used numerical simulations technique to perform the measurement of the drum as a whole without opening the drum [5]. A methodology utilizing efficiencies calculated with reference sources consolidated with theoretical method is done for getting the efficiency curve for disc sources and measured with a NaI (Tl) detector [6]. Daniela and Octavian employed a simulation rely on toolkit of GEANT

3.21 so as to simulate the ISOCART response function for gamma spectrometry analysis system to characterize RW drum volume [7].

Depending on Fredholm integral equation, utilizing a little number of estimations, an approach in the basic scanning of gamma rotating waste drums achieved for linear reference ^{152}Eu radioactive source [8].

The new model product "Wide Range Segmented Gamma Scanner" assembled and devoted specially for the radioactive waste characterization of the Chinese nuclear industry. The device has the abilities of the earliest copy of scanning gamma system which advanced at Los Alamos National Laboratory [9].

In order to agree with the standard international system requirements, the present study is focused on the experimental efficiency calibration of the local designed and manufactured scanning system for characterization the radioactive waste drums which contain the solid radioactive with 220L size by NDA.

Experimental set up

The features of used drum depend on the purpose of use. The waste drums, which employed for storage and collecting solid radioactive waste in Al-Tuwaitha site, are with height is 85 cm and internal diameter equal to 57 cm. These drums are made from iron with wall thickness 0.7 mm. the capacity of the iron drum is 220L. For calibration standard a similar dimensions and features drum was used, in addition to get the efficiency curve for utilized detection system. The waste drum filled partially with wet Karasta Portland cement with density when dried equal to 1. Six parallel plastic pipes made 6 hollow of 2 cm diameter. The hollow cylindrical gaps were made in the calibration drum at different radial distances from

the drum centerline. Fig. 1 describes the drum filled with cement and cylindrical vacancies from two different visions sides. The plastic pipes removed after solidification of cement.

The hollow cement tubes are used to contain radioactive sources into the

drum to perform the efficiency calibration. During the efficiency calibration one tube at a time was individually filled with source leaving the others empty.

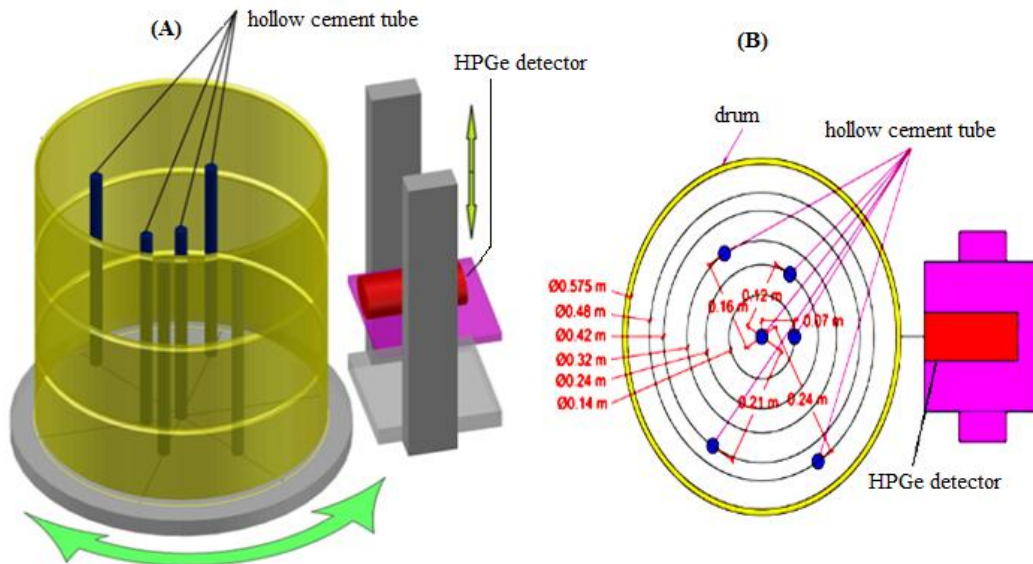


Fig.1: (A) The transparency view of drum with detector, (B): top view of drum with detector and holes locations.

In general the efficiency value for a specific detector depends upon several factors: the geometry arrangement for detector and radioactive source or sample, energy of incident photon, the content of detector material around the crystal and the parameter of the crystal of detector.

The experimental full energy peak efficiency can be calculated by equation:

$$\epsilon(E) = \frac{N}{T A I(E)} \quad (1)$$

where, $\epsilon(E)$ is a full energy peak efficiency of used detector (HPGe) for a gamma ray of energy E, N: is the net area under the specified photo peak, A: is the activity of radionuclide emitting gamma ray of energy E in Becquerel (Bq) units, I(E): is the yield of disintegration probability of radionuclide for specific photo peak

with energy E and T: is the time of the measurement in seconds [10, 11].

For the present local scanning system the distance is fixed at 5 cm from end cap of detector to out surface of waste drum. The collected count rate with respect to the radial distance for thirteen photo peaks and six holes can be represented by:

$$A_T = \sum_i^6 \frac{N_i V_i}{V} \quad (2)$$

where N_i is the net counts per second of specified photo peak of gamma (Bq), i is equal to 1, 2, ..., 6 numbers of cylindrical cement holes, S represents the drum base area, $S = \pi R^2$; $R = 28.5$ cm, L is the drum height, V is the drum volume drum, $V = SL$, V_i is the longitudinal volume section of drum, $V_i = S_i L$ and S_i is the base area for specific longitudinal volume section of drum.

The detectors of scanning system

Falcon 5000 portable, remote control and supplied with small computerized tablet High Purity Germanium spectrometer system has been interfaced and joined with local scanning gamma system for experimental measurements. The detector model is a Canberra with Falcon software interfaced with genie 2000 software.

The main features of this detector are as follows: Relative efficiency at 1332 keV ^{60}Co is 18.7%, full width at half maximum (FWHM) resolution is about 2 keV and 1 keV for 1332 keV and 122 keV respectively, and the peak-to-Compton ratio for ^{60}Co is 44.7:1. The crystal diameter is 61mm and the length is 25.5 mm. The cryostat window material is aluminum with 1.5 mm thickness and includes an electrical cooler, type: Pulse Tube Cooler, with time to cool 3 to 4 hours at 25 °C [12].

Scanning system

After putting the drum on rotating platform, which has the ability to

change the speed and direction of rotation, to minimize the effect of non-homogeneous matrix or hot spot distribution. The scanning of whole drum is fulfilled without opening it. While drum is rotating, simultaneously the detector is in up or down vertically motion to insure the scanning of all drum segments. In general, the scanning systems are devoted to assay the low and intermediate level RW. As illustrated in Fig. 2 the main parts of local scanning system with control system, sensors and timers are supplied and interacted altogether: (1) the drum of RW, (2) rotating platform :the location of the RW drum, (3) box of electrical control and motors, (4) iron rail to adjust the distance between the detector and the drum, (5) carrier and transporter system of detector, (6) a second iron rail to adjust the distance between the detector and the drum, (7) pillars of carrying and holding the detector, (8) the HPGGe FALCON type detector, (9) the carrier box of detector and (10) remote control tablet of the FALCON detector.



Fig.2 The local designed scanning system.

Results and discussion

The assay of acquired spectrum of gamma ray is achieved for characteristic energy peaks of presence radioisotope. The count rate distributions are generated as a function of the drum height and rotation angle depending on these energy peaks. The specific activity of the radioactive waste (radioisotopes content) is measured by assuming the homogeneous distribution for matrix and activity. The results of specific activity based on these assumptions are computed by use of the averaged count rate.

The count rates of ^{152}Eu radioactive source spectra are collected individually for each hollow cement tube. The spectra of radioactive source in Fig.3 illustrate the effect of attenuation factor and inverse square law. However, for all energies it is clear that the count rate of spectra in location H1 decreases relative to the level exist in H3 due to increase the thickness of the cement and the radial distance between detector and radionuclides location. Spectra in Fig.3 display without background subtraction.

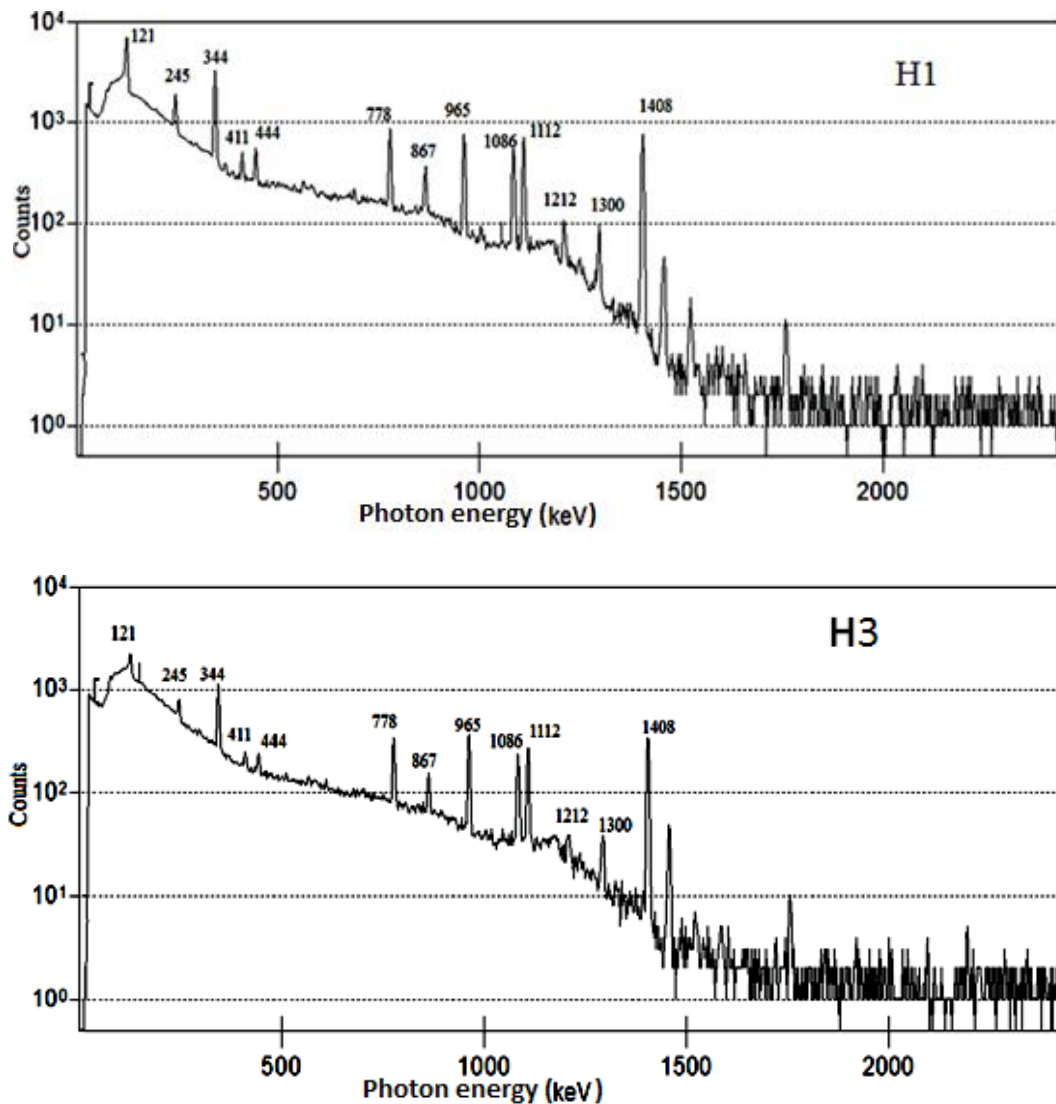


Fig.3: Spectra of ^{152}Eu in log scale from the hollow cement tube H1 and H3 collected by scanning system within 1800sec counting time.

The detector efficiency of the waste drum is not the same for every individual hollow cement tube according to the radial distance between the detector and the location of radionuclide in drum. The efficiency is increasing when the radionuclide become nearest to surface of drum. That means the distance of hollow cement tube to the detector is small.

From the solid angle point of view, the detector sees the radionuclide bigger for smaller distance between the detector and radio nuclide and vice versa. This behavior indicated in Fig. 4 for mentioned energies where $(R-R_i)$ represents the distance between hollow cement tube to the surface of the waste drum, which is one of dimensions of specified active volume in cm units.

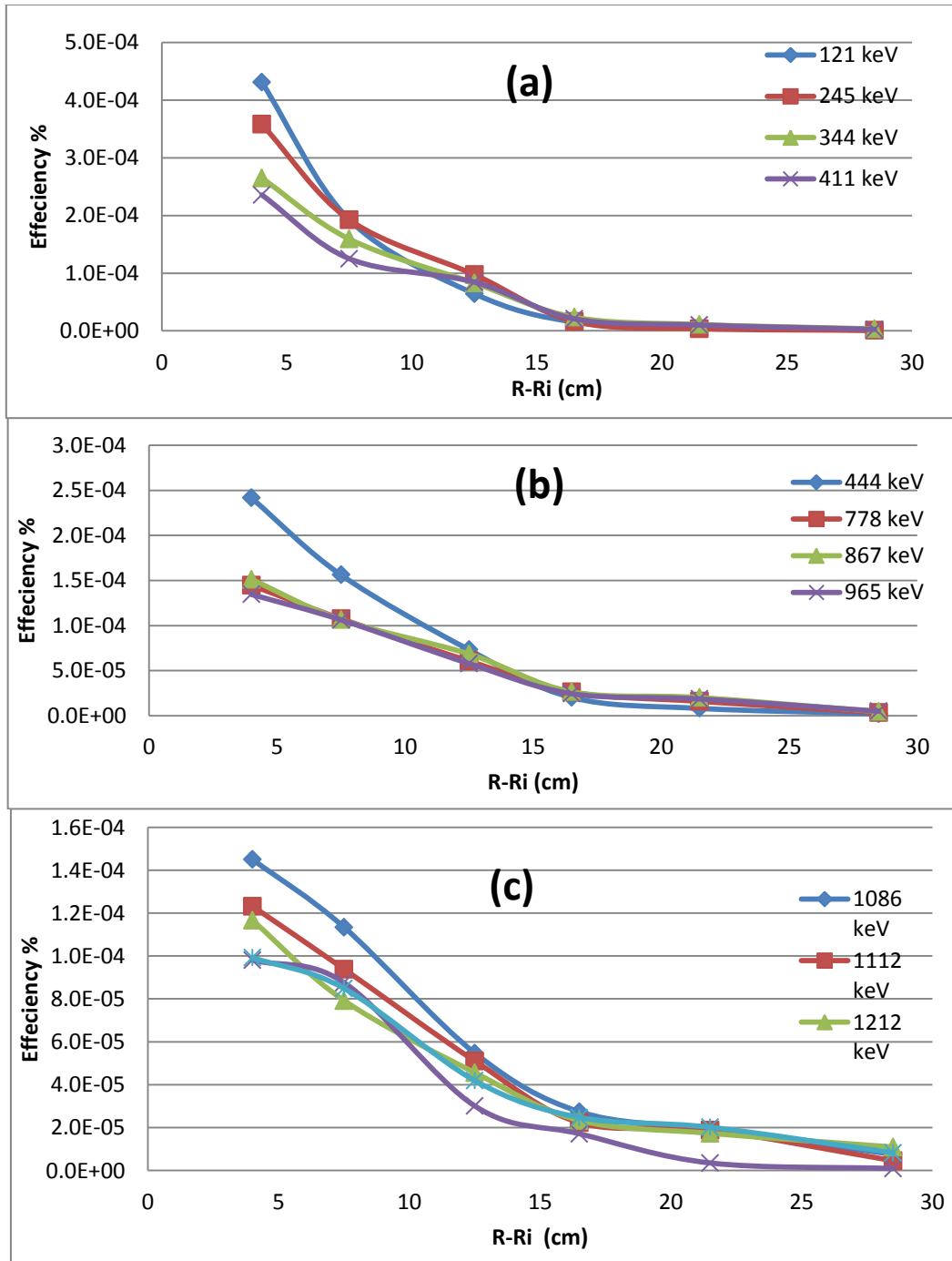


Fig.4: Changing the average efficiency for each of thirteen studied gamma energy of ¹⁵²Eu (a, b and c) at specified volume with radius $(R- R_i)$, (without fitting).

In general the expected response of FALCON HPGe detector in the range of used radioisotope photo peaks energy is shown in Fig. 5. This indicates changing the average

efficiency curve relative to varying the radial distance between detector and active waste inside the whole volume of drum.

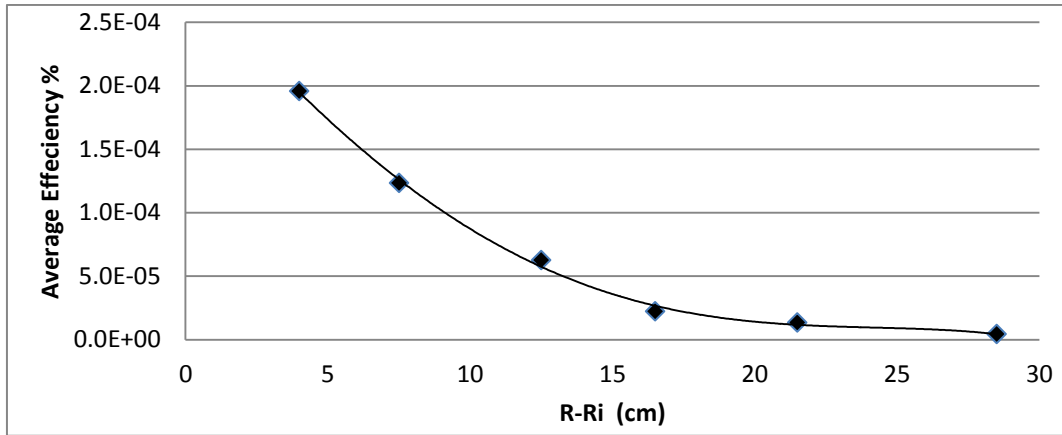


Fig. 5: Changing the average efficiency of specified energy relative to whole volume of drum in polynomial fitting order 4.

From another point of view, the efficiency curves in Fig. 6 indicate thirteen gamma photo peaks for each position of every single hollow cement tubes in whole volume of cement drum. It illustrates the effects of attenuation factor and inverse square law on the value of efficiency due to changing the distance between detector and the hot spot inside cement drum, which represents the location of

radionuclide in one of six hollow cement tube. As a result the geometry will change successively so as shown and the efficiency curves gradually decrease from H1, which is the nearest location of cement tube, to the detector. While H6 is the greater distance of cement tube to the detector location and represents the location of radionuclide in the center of the cement tube.

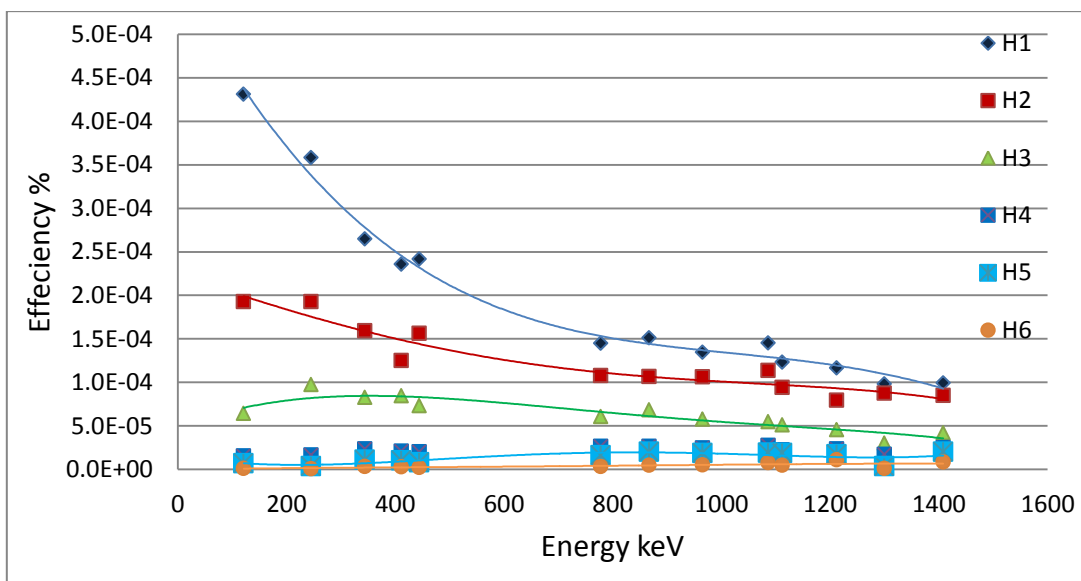


Fig.6: Efficiency curves for six holes (positions) individually for twelve photo peak in polynomial fitting of order 4.

The efficiency curve was illustrated in Fig. 7, for spectrum of thirteen gamma photo peak energies, is the average value of each these photo

peaks that emitted from ^{152}Eu , where it's distributed in a whole volume waste drum content.

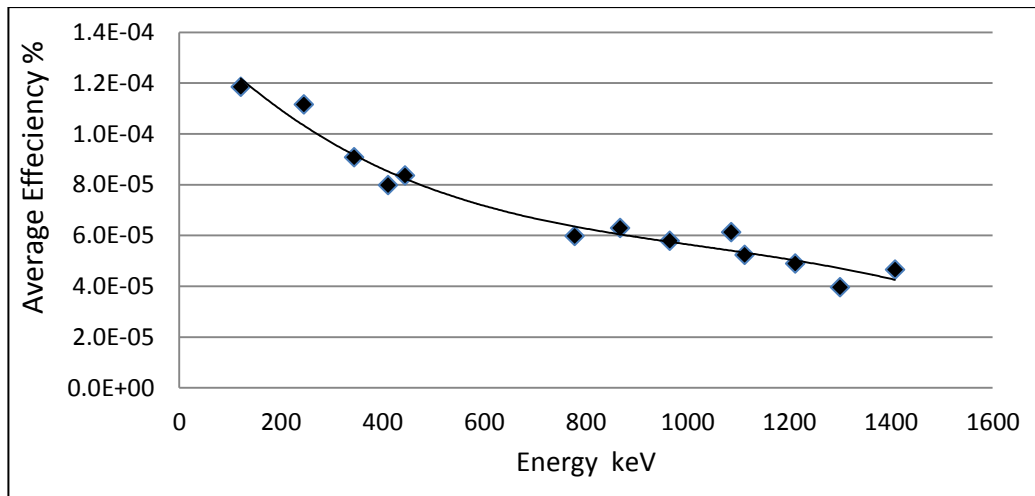


Fig.7: The average efficiency curve of spectrum energy of ^{152}Eu relative to whole volume of drum in polynomial fitting of order 4.

Conclusions

From results we can conclude that present local designed scanning gamma system is suitable for nondestructive radioactive waste assay technique and practically preferred rather than destructive assay technique. The efficiencies are measured for energies of radioactive source that located in the six holes of the drum. From these measurements, one can find that efficiency depends upon several factors: the geometry arrangement for detector and radioactive source, energy of incident photon, where it is decreased when the distance between the detector and location of radio nuclide in the drum. The radio nuclides spectra illustrated the effect of attenuation factor and inverse square law on the value of efficiency for a specific gamma photon energy.

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