# Calibration of Whole-Body Counter in Diagnostic and Screening Modes

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**Abstract:** The current study aims to calibrate High Purity Germanium (HPGe) Whole-Body Counter. Material and Method: The standard mixed gamma source is located at four locations of the transfer phantom and the mean photo peak efficiency is calculated. Results: The efficiency for four compartments of fixed screening whole body configuration was higher than the corresponding value at diagnostic of the whole-body geometry by a factor of three. This makes the HPGe detector configuration suitable for monitoring low activity of internal contamination of radionuclides.

[T. M. Taha, T. M. Morsi**. Calibration of Whole-Body Counter in Diagnostic and Screening Modes.** *Biomedicine and Nursing* 2024;10(3):68-73]. ISSN 2379-8211 (print); ISSN 2379-8203 (online). http://www.nbmedicine.org. 07. doi:10.7537/marsbnj100324.07

**KEYWORDS:** Transfer phantom, MDA, HPGe, Efficiency

## Introduction

The Whole-body counters (WBCs) are used for the in vivo detection of radiation emitted by radionuclides incorporated during occupational exposure, as well as for the preparedness of response in the case of Radiological Emergencies (IAEA, 1999a). The determination of the activity for each radionuclide requires a prior knowledge of the full energy peak efficiency at each photon energy for a given measuring geometry (Vargas et al. , 2002). The accuracy of the measurement depends highly on the performance of the various system detectors and one of those well-known and popular types of detectors is the High-Purity Germanium (HPGe) detector. Several authors have been interested in calibration of whole-body counters. T.M. Taha et al. (2009) assessed individual counting efficiencies for organ compartments such as thyroid, lung, upper and lower gastrointestinal tract using transfer phantom in fixed diagnostic and screening positions respectively. They found that the organ compartment efficiencies in screening geometry were higher than the value of diagnostic geometry by a factor of three. J. Bento et al. (2010) calibrated HPGe detector (GC 2520, Canberra) – a coaxial germanium detector (2.8 cm diameter and 4.75 lengths) for energy and efficiency with a calibration source, and they observed that it is able to detect and quantify several radionuclides with gamma emissions between 60 and 1900 keV. MinSeok Park et al. (2021) used the NaI(Tl)-based stand-up and HPGe-based bed type commercial whole-body counters for calculating the counting efficiencies. The counting efficiencies were obtained from 19 computational phantoms representing various shapes and sizes of the measured individuals. The discrepancies in the counting efficiencies obtained using the computational and physical phantoms range from 2% to 33%, and the results indicate that the counting efficiency depends on the size of the measured individual. Thaer, (2018) performed a calibration of a scanning whole-body counter for measurements of the activity of gamma-emitting radionuclides in the human body.

### 1.1 Testing parameters

The factors affecting the performance whole body counter include the resolution, peak shape, the minimum detectable activity, and photo peak efficiency, and peak to Compton of a HPGe detector for 88– 1836 keV at static, thyroid, and whole body configurations. Resolution is defined as the capability of a gamma spectrometer to distinguish between two adjacent energies. Peak-to-Compton ratio. In the case of 60Co the measurement of the peak-to-Compton ratio is based on the same energy peak (1332.5 keV) used for the 60Co resolution measurement. The ratio as described in the ANSI/IEEE standard is the number of counts in the biggest channel of the 1332.5 keV60Co peak to the average number of counts in the channels representing the range from 1040 through 1096 keV, which is part of the Compton region associated with the 1332.5 keV. Peak shape is determined by calculating the ratio of FWTM over FWHM to check if there is broadening of peak over time. The ideal and acceptable resolution ratio for FWTM/FWHM is 1.82 for the Gaussian peak Gilmore et al. (1998). The current study aims to estimate factors affecting the performance of whol- body counter such as the resolution, peak-to-Compton ratio, peak shape, the minimum detectable activity, and photo peak efficiency of a HPGe detector for 88–1836 KeV at static, thyroid, screening, and diagnostic whole-body modes.

**Materials and Methods**

HPGe detector (GC 2520, Canberra) – a coaxial germanium detector (2.8 cm diameter and 4.75 length) with a relative efficiency of 25%; aluminum endcap with 1.5 mm thickness was calibrated via two steps; energy calibration for a detector and efficiency calibration for a whole-body counting system. In the first step, the energy calibration for the detector was carried out using mixed gamma sources. The source master solution is Eckert and Ziegler Analytics, EZA, s eight isotopes mixture which is calibrated quarterly and found to consist of 109cd, 57Co, 139Ce, 203Hg, 114Sn, 137Cs, 88Y and 60Co. It covers the energy from 88 keV to 1836.1keV. In the second step, the efficiency calibration was carried out for wide energy using a standard mixed gamma radiation source in static, thyroid, screening and diagnostic configuration .In the case of static geometry , the source to detector distance was 15 cm, for fixed screening geometry, the source to phantom distance was 10 cm and for diagnostic configuration, the source to detector distance was 24-28 cm as shown in Figure. (1.a, 1.b, 1.c).

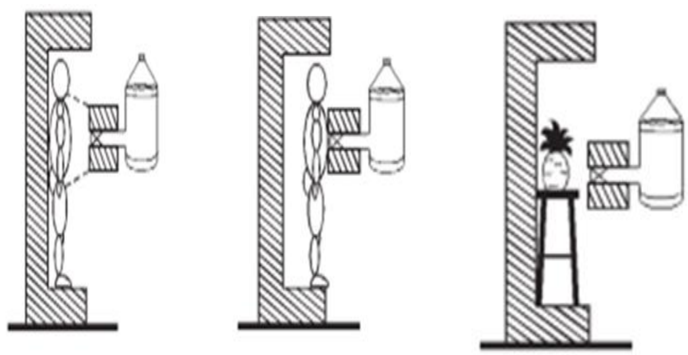

Fig.(1a) Fig. (1.b) Fig.(1.c)

Fig.1. Fixed diagnostics position at SDD 30 cm (a), Fixed screening position at SDD 10 cm (b). and Fixed static position at 10 cm (c)

The photo peak efficiency of The High Purity Germanium Whole-Body Counter can be predicted using the following fitted equation and sample formula (1). (Siria Medici et al., 2020).

$$\varepsilon = \frac{C}{A \times P} (100) \qquad (1)$$

Where

$\varepsilon$: is the photo peak efficiency percentage

C: is the net full energy peak counting rate estimated from the summed spectrum after subtracting the background.

A: is the activity of radionuclides in Bq.

P%: is the photon emission probability of the considered emission line.

The sum of the four different spectra obtained in the four different available cavities (Thyroid, lung, whole-body and GIT) was taken into account for the whole-body configurations to reduce statistical uncertainty.

**2.1 Minimum Detectable Activity, MDA**

The minimum detectable activity was calculated using acquisition time of 300 sec and equation (3), (Battisti et al., 2000), **as follows:**

$$\boldsymbol{MDA = \frac{3 \pm 4.65\sqrt{B}}{t.\varepsilon}} \qquad (3)$$

Where: B is the background counts, t is the acquisition time, 300 (s) and $\varepsilon$ is photo peak efficiency for the energy peak.

**Results**

The mixed gamma source ,Eckert and Ziegler Analytics , EZA,s eight isotopes mixture was used to check the energy calibration of the Canberra Accuscan II whole-body counter with a single HPGe detector (model Canberra) as shown in Figure 1. It reveals the correlation between energy to channel number that was estimated to be 0.60 keV/ch. The energy calibration was carried out at static geometry was found to be 15 cm source to detector distance, SDD. The mixed gamma source consists of $^{109}$cd, $^{57}$Co, $^{139}$Ce, $^{203}$Hg, $^{114}$Sn, $^{137}$Cs, $^{88}$Y and $^{60}$Co. It covers the energy from 88 keV to 1836.1 keV.The full width at half maximum, (FWHM) for EZA,s eight isotopes mixture ranged from 1.065 to 1.87 KeV. The peak shape at the diagnostic configuration for 60Co was 1.84. The peak to Compton ratio at a fixed diagnostic configuration and mixed gamma source inserted in total-body geometry using transfer phantom for 60Co was 36 to 1.

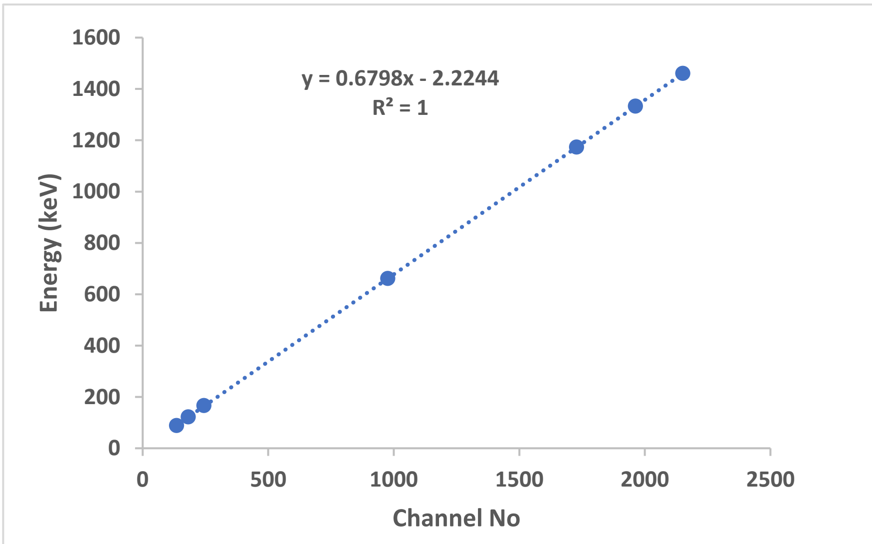


Fig.(2.) Linearity of High Purity Germanium detector

1.1 **Efficiency Calibration of HPGe detector (Static, fixed screening and diagnostic configurations)**

The photo peak efficiency was studied for four cases; at static, thyroid and diagnostic mode. The standard source is located at different positions of organ compartments such as the thyroid, lung, and upper and lower gastrointestinal tract as shown in Figure 2. Figures 2-3 present the efficiency calibration curves obtained using in built ABACOS-2000 algorithm, which fits a polynomial function to the measured values. In static, thyroid, screening, and diagnostic configurations, the geometric efficiency is constant and maximized because the source is horizontally aligned with the detector throughout the entire counting time. The phantom is farthest from the the detector and backed against the shielding, which also reducesreducing the geometric efficiency. Figure 43 shows the efficiency curve for screening the whole-body configuration is higher than the corresponding value in the diagnostic configuration by a factor of three.

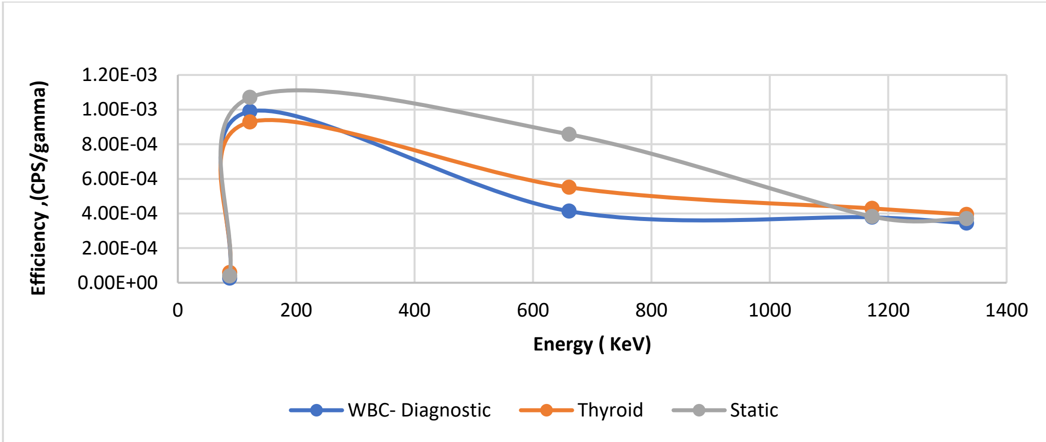


Fig. 3. Photo peak Energy Efficiency using mixed gamma source at Static, Thyroid and Diagnostic WBC configurations

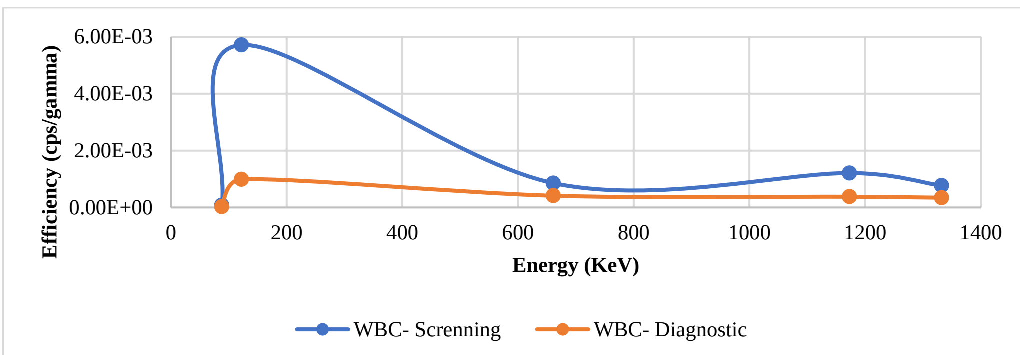


Fig. 4. Photo peak Energy Efficiency using mixed gamma source in Screening and Diagnostic WBC configurations

**3.2 Minimum detectable activity, MDA**

Minimum detectable activity and minimum detectable effective dose for 57Co, 99mTc, 131I, 137Cs, 60Co and 40K respectively was calculated as presented in Table (1). Minimum detectable effective dose, MDED for the mentioned radionuclides was calculated based on effective dose coefficient (SvBq-1) for intake of radionuclides inhaled and ingested by workers (ICRP-68, 1995).

Table (1): Efficiency and MDA and MEED for some isotopes

| Isotopes | E (KeV) | Efficiency | Sv/Bq | MDA,Bq | MDED (µSv)) |
|---|---|---|---|---|---|
| $^{57}$Co | 122 | 9.89E-04 | 3.9E-10 | 16 | 0.00624 |
| $^{99m}$Tc | 140 | 3.3 E-04 | 2.0E-11 | 178 | 0.00034 |
| $^{131}$I | 365 | 2.5 E-04 | 1.1E-08 | 172 | 0.187 |
| $^{137}$Cs | 661 | 4.13E-04 | 3E-08 | 28 | 0.84 |
| $^{60}$Co | 1332 | 3.44E-04 | 7.1E-09 | 33 | 0.234 |
| $^{40}$K | 1460 | 1.8 E-04 | 6.2E-09 | 204 | 1.265 |

### 3.3 Internal Dosimetry for Inhaled of $^{131}I$

The remainder of activities of $^{131}I$ in the thyroid of post-treatment individuals with $^{131}I$ and their committed dose equivalent (CDE) of some individuals due to ingestion of radioiodine have been calculated using committed dose equivalent conversion factors of 2.23E-08 Sv/Bq for $^{131}I$ (ICRP-68) as shown in the table 2.

***Table 2. The remainder activities and committed dose equivalents of $^{131}I$ in thyroid gland .***

| *Thyroid Organ Cases* | *E (Kev)* | *Activity (Bq)* | *Committed Dose Equivalent uSv* |
|---|---|---|---|
| Subject 1 | 365 | 300 | 7 |
| Subject 2 | 365 | 2000 | 45 |
| Subject 3 | 365 | 5000 | 112 |
| Subject 4 | 365 | 6000 | 138 |

*The committed dose equivalents for four post-treatment with $^{131}I$ was ranged from 7 to 138 µSv.*

### 4. discussion

In the current study, the resolution of the HpGe whole-body counter for energy range 88– 1836 KeV was recorded as mean value of 1%. It means that the HpGe detector has the capability to distinguish between two adjacent energies by 1%. Peak shape calculated for 60Co and it was 1.84 similar to acceptable practice value recommended by Gilmore et al., (1998). Low peak to Compton ratio for 60Co was 36 to 1. This ratio means that a signal-to-noise ratio was 36:1. The minimum detectable activity and the minimum detectable effective dose for 57Co, 99mTc, 131I, 137Cs, 60Co and 40K are shown in Table (1). The minimum detectable amount for 99mTc, 131I, 137Cs, 60Co and 40K was 178, 172, 33, 28 and 204 Bq respectively, applying a measurement time of 300 sec. Photo peak efficiency of the HPGe detector at static, thyroid and diagnostic whole-body configurations for 88– 1836 KeV was calculated as shown in Fig. (2). The photo peak efficiency decreases with increasing the gamma ray energy and source to detector distance too, the HPGe detector offers a very good resolution. Fig.(3) reveals that the efficiency curve for mean screening whole-body configurations is higher than the corresponding value in diagnostic configurations by a factor of three. This value is in good agreement with the comparative study conducted by Taha et al., (2009). This result makes the HPGe detector whole-body counter is suitable for monitoring low activity of internal contamination with radio nuclides. The committed effective dose was calculated using internal dose coefficients (ICRP-68, 1995). The conversion factor h(g) 2.23E-08 Sv/Bq for $^{131}I$ (ICRP-68) of the individuals quoted from Commission of Radiological Protection, (ICRP-68, 1995) as 2.23E-08 SvBq-1 respectively. The committed effective doses for contamination for four volunteers post-treatment with $^{131}I$ was ranged from 7 to 138 µSv as presented as shown in Table (2). The concentration of $^{131}I$ in the thyroid depends on the location of the subject during inhalation and the biokinetic model of $^{131}I$. Hence contaminated individuals were exposed internally to less than the average annual dose limit (ICRP-103, 2007). Iodine is rapidly absorbed in the blood following intake, where about 70% is excreted in the urine and about 30% concentrates in the thyroid (ICRP-68) and (ICRP, 1979).

### 5.Conclusion

For low level radioactivity measurements in man, it is essential to reduce the background count and increase the detection efficiency. The efficiency depends on the source-detector geometry. Screening configuration detector provides a resolution that is considered the best choice to assess low internal activity due to the high detection efficiency, low MDA and high energy. Hence contaminated individuals were exposed internally to less than the average annual dose limit.

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**Acknowledgment**

The authors acknowledge with thanks the support of the the head and staff members of the Radiation Protection Department, Nuclear Research Center, and Atomic Energy Authority of Egypt.

**Funding**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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7/6/2024