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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. Four locations on the transfer phantom were considered to calculate the mean photo peak efficiency of the standard mixed gamma source. Photo peak efficiency of the HPGe detector at static, thyroid, diagnostic, and screening whole-body configurations for 88– 1836 KeV was carried out. The minimum detectable activity values for some radionuclides such as ^{131}I, ^{137}Cs and ^{60}Co were calculated. The energy resolution of the HpGe whole-body counter for the energy range 88–1836 KeV was recorded as the mean value of 1%. The effective dose for volunteers contaminated with ^{131}I ranged from 13 µSv to 66 µSv. The efficiency for four compartments of fixed screening whole-body configuration was higher than the corresponding value at diagnostic whole-body geometry by a factor of three. This makes the HPGe detector configuration suitable for monitoring the low activity of internal contamination radionuclides.

KEYWORDS

Transfer phantom, MDA, HPGe, Efficiency.

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INTRODUCTION

The Whole-body counters are used for the in vivo detection of radiation emitted by radionuclides internally incorporated during occupational exposure. The determination of the in-vivo activity for each radionuclide requires a prior knowledge of the full energy peak efficiency at each photon energy for a given measuring geometry. The accuracy of the measurement highly depends on the various system detectors performance, one of the well-known and popular types of detectors used being the High-Purity Germanium (HPGe) detector**.** Several authors have been interested in the calibration of whole-body counters. In the late 1970s and early 1980s, new types of semiconductor detectors such as germanium, came into use for whole-body counters. The use of germanium (Ge) detectors has improved the performance of whole-body counters, especially the ability to distinguish among and between gamma rays that have similar energies. The first whole body counter at Inshass-NRC consists of NaI (Tl) crystal (20 cm diameter x 10 cm thick). **Morsy *et al*. (1973)** studied optimum operational conditions of the Inshass whole body counter**. Abdel-Wahab *et al*. (1992)** carried out a simple calibration of a whole body counter for the measurement of total body potassium in humans. A few years ago, however, another two whole-body counters were installed. The second Fastscan whole-body counter uses two large NaI(TI) detectors (10 cm x 16 cm x 40 cm) configured in a linear array on a common vertical axis. The third Accuscan II whole-body counter installed in NRC in 1999 uses a single high-purity germanium detector. **Bento *et al*. (2010)** observed that the HPGe detector is able to detect and quantify several radionuclides with gamma emissions between 60 and 1900 keV**. MinSeok *et al*. (2021)** used the NaI (Tl)-based stand-up and HPGe-based bed-type commercial whole-body counters for calculating the counting efficiencies. **Taha *et al*. (2022)** carried out a study to estimate the total body burden for some individuals using a whole-body counter. The current research study aims to calibrate the photo peak energy efficiency of the whole body counter in static, thyroid, (lung, total body, TB and Gastrointestinal Tract, GIT) whole body in diagnostic and screening modes.

MATERIALS AND METHODS

The whole body counter (WBC) consists of three parts; detector(s) connected with electronic circuits, shield, and phantom.

Detector and software.

Canberra WBC System was used in this study. The system comprises a Canberra High Purity Germanium Detector with a relative efficiency of 25% for detecting gamma emitters from 88 keV to 1800 keV. The detector was shielded in the steel frame and lead-lined to minimize the influence of background radiation. The standard ACCUSCAN II system includes a shield and scanning detector mechanism, a 25% coaxial germanium detector and cryostat assembly, a digital spectrum analyzer, as well as the Mirion Apex-InVivo whole body counting and Genie™ spectroscopy software packages. The ACCUSCAN II counter uses a shadow shield to shield against the elevated ambient background. The system's shadow shield is composed of two major assemblies, a low background steel personnel enclosure and a scanning tower assembly with a lead detector shield assembly. The personnel shield or enclosure provides shielding from the back and sides of the person and the lead detector shadow shield shields the detectors from the front.

Whole body counter phantom

Canberra WBC Phantom consists of two basic components: a "torso" section, and a "neck" section. The torso section is constructed from flat sheets of cast acrylic material (e.g., Lexan or Plexiglas), with the front sheet thickness chosen to provide the proper amount of absorber between the calibration source

and WBC system detector (s). Three interior source cavities provide lung equivalent and G.I. region-equivalent configurations. The neck section is a cast acrylic cylinder with a thyroid-equivalent source cavity, of dimensions specified in ANSI N44.3. The source master solution is Eckert and Ziegler Analytics, EZAs eight isotopes mixture which is calibrated quarterly and consists of ^{109}cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{114}Sn, ^{137}Cs, ^{88}Y and ^{60}Co. It covers the energy range from 88 keV to 1836.1keV. A standard mixed gamma radiation source is used for the efficiency calibration of high purity germanium, whole body counter. The calibration was performed in three geometries static, thyroid, and whole body (lung, TB and GIT) in screening and diagnostic modes as shown in Fig. (1. a, b & c). In the case of static geometry, the source-to-detector distance was 15 cm (Fig. 1.c); for fixed screening geometry, the source-to-phantom distance was 10 cm (Fig. 1.b); for diagnostic configuration, the source-to-detector distance was 25 cm (Fig. 1.a).

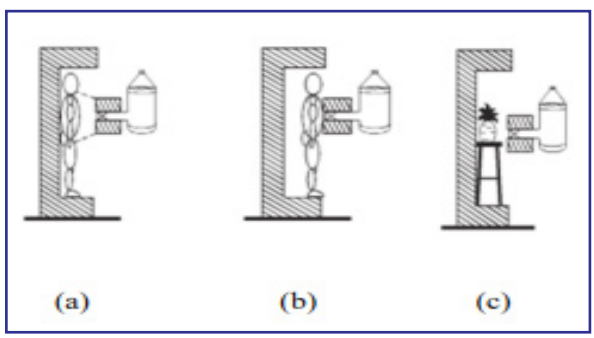

Fig. (1): Fixed diagnostics, screening, and static positions. (a): Diagnostic mode at SDD 25 cm. (b): Screening mode at SDD 10 cm. (c): Static mode at 15 cm.

The photo peak efficiency of the High Purity Germanium can be calculated using the equation (2) **(Alnour *et al., 2014*).**

$$\varepsilon = \frac{N}{A\,p} \quad (2)$$

where:

ε: efficiency (%)

N: net full peak counting rate estimated from the summed spectrum after subtracting the background.

A: activity of radionuclides (Bq)

p: photon emission probability of the considered emission line (%).

Committed Dose equivalent Calculation

Intake of radionuclide is calculated using equation (1).

$$Intake\ (Bq) = \frac{Measured\ Activity}{IRF} \quad (1)$$

Where:

Intake: Activity at time of intake, Bq

IRF: Intake Retention Fraction that represents the fraction of radioactive material that remains in a given organ at a specific time after the intake.

The committed dose equivalent (CDE) of some individuals after diagnosis of the thyroid gland has been calculated as presented in equation (2) **(ICRP-68)**.

$$CED = Intake\ (Bq)\ x\ H_{inh} \quad (2)$$

Where:

CED= Committed dose equivalent, Sv

Intake: Activity at time of intake, Bq

H_{inh}: Committed dose equivalent conversion factors due to inhalation, Sv/Bq for radionuclides.

The minimum detectable activity (MDA) was calculated for ^{131}I, ^{137}Cs and ^{60}Co using equation (3) (**Ha, 2018)** as follows:

$$MDA = (3 \pm 4.65 S_b)/(t.\varepsilon) \quad (3)$$

Where: S_b is the square root of background counts, t is the acquisition time (s) and ε is photo peak efficiency for the energy peak.

RESULTS

For the static geometry, the energy calibration was carried out at 15 cm source to detector distance (SDD). The mixed gamma source consists of the foll-

lowing radionuclides: ^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{114}Sn, ^{137}Cs, ^{88}Y and ^{60}Co, respectively. The full width at half maximum (FWHM) for Eckert and Ziegler Analytics, EZA,s eight isotopes mixture ranged from 1.065 to 1.87 keV. The peak shape at the diagnostic configuration for ^{60}Co was 1.84. The peak-to-Compton ratio at a fixed diagnostic configuration using transfer phantom for ^{60}Co was 36 to 1. The energy calibration for HPGe gamma-ray spectrometer presented the relation chip between channel number and energy was presented in (Fig. 2).

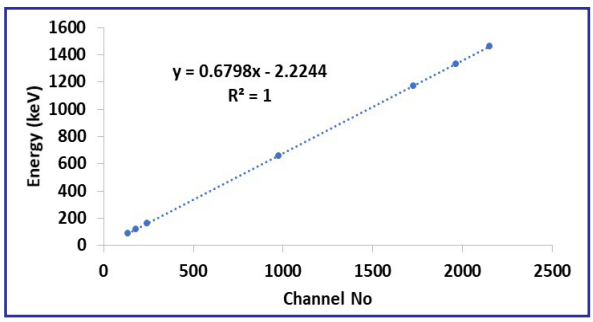

Fig. (2): Efficiency Calibration of HPGe detector (Static, thyroid, fixed screening and diagnostic modes.

The photo peak efficiency for radionuclides in the range from 88 keV to 1332 keV is presented as shown in (Fig. 3), in static, thyroid, screening and diagnostic mode. Fig. (4) indicates that the photo peak efficiency of the whole-body counter in screening mode is higher than the corresponding value in the diagnostic mode by a factor of three.

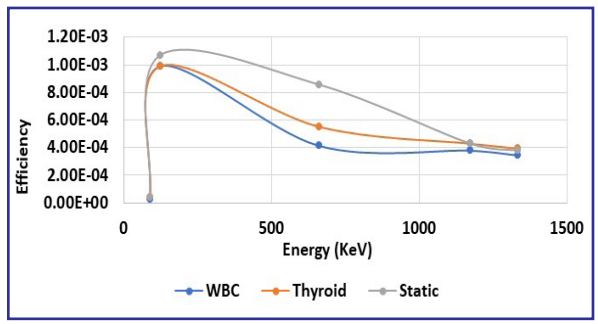

Fig. (3): Photopeak Energy efficiency using mixed gamma source for static, thyroid and whole body in Diagnostic Mode.

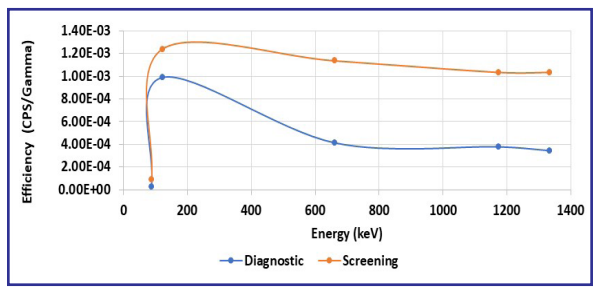

Fig. (4): Calibration of HPGe WBC in Screening and Diagnostic Modes.

The minimum detectable activity for some radionuclides such as ^{131}I, ^{137}Cs and ^{60}Co are presented in Table 1.

Table (1) : *Efficiency and MDA for ^{131}I , ^{137}Cs and ^{60}Co.*

Radionuclides	E (KeV)	Efficiency	MDA
^{131}I	365	1.55E-04	172
^{137}Cs	661	4.13E-04	28
^{60}Co	1332	3.44E-04	33

The decayed activities of volunteers contaminated with ^{131}I in the thyroid and the corresponding committed dose equivalent (CDE) of some individuals after diagnosis of the thyroid gland has been calculated using the conversion factor h (ing) (Sv Bq^{-1}) and h(inh) (Sv Bq^{-1}) for ingestion and inhaled ^{131}I of the occupational workers quoted from Commission of Radiological Protection, **(ICRP, 1994)** as 1.1E-08 (Sv Bq^{-1}) and 2.2E-08 (Sv Bq^{-1}) respectively **(ICRP-68)** and mentioned in equations (1-2). The activity intake and committed dose equivalents for ^{131}I are presented as shown in Table 2.

Table (2) : *The activities and committed dose equivalents of ^{131}I in the thyroid gland..*

Thyroid compartment	E (Kev)	Activity at time of intake (Bq)	Committed Dose Equivalent (μSv)
Subject 1	365	1200	13
Subject 2	365	2000	22
Subject 3	365	5000	55
Subject 4	365	6000	66
Subject 5	365	590	13
Subject 6	365	1051	23
Subject 7	365	592	13
Subject 8	365	1585	35
Subject 9	365	1197	26
Subject 10	365	2638	58

DISCUSSION

The photopeak efficiency for HPGe at a static position was higher than the corresponding value at the thyroid and diagnostic whole body counter due to there is no attenuation material. So static geometry may be applied for environmental monitoring. The photopeak efficiency for HPGe at the thyroid location was higher than the corresponding value at the diagnostic whole-body counter due to the decreased source-to-detector distance according to the inverse square law. The mean photopeak efficiency for HPGe at screening whole-body configurations is higher than the corresponding value in diagnostic configurations by a factor of three because efficiency depends on source-to-detector distance. The committed effective dose was calculated using internal dose coefficients **(ICRP-68, 1995).** The conversion factor h(g) (Sv Bq− 1) and h(inh) (Sv Bq− 1) for ingested and inhaled ^{131}I of the occupational workers quoted from Commission of Radiological Protection as 1.1E-08 (Sv Bq^{-1}) and 2.2E-08 (Sv Bq^{-1}) respectively. The effective doses for occupational workers contaminated with iodine ^{131}I ranged from 0.06 mSv to 0.43 mSv as presented 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, 2007**). The bio kinetic model of ^{131}I. Iodine is rapidly absorbed in the blood following intake, where about 70% is excreted in the urine and about 30% concentrates in the thyroid.

CONCLUSION

The HPGe detector whole body counter configuration is suitable for monitoring the low activity of internal contamination radionuclides. The results obtained for individuals exposed to ^{131}I as shown in Table (2) indicate that the internal dose to that contaminated with ^{131}I individuals varied from 13 μSv to 66 μSv. Hence contaminated individuals were exposed internally to less than the average annual dose limit.

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