# PERFORMANCE ASSESSMENT OF A THYROID COUNTER


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## Abstract

*Routine assessment of internal contamination for potential exposed radiation workers is essential to be carried to ensure dose received by the workers are adhered the annual dose limits of 20 mSv as stated in the Basic Safety Radiation Protection (BSRP) 2010 as well as to verify the applications of radiation protection principles in the work place. For monitoring intake of $^{131}$I radionuclide by the workers, a direct measurement technique using Captus 3000 Thyroid Counter System could be used. In Medical Physics Group, this equipment is calibrated and maintained with two types of gamma emitter radionuclides; $^{137}$Cs and $^{152}$Eu. In order to ensure consistent and reliable measurement, a quality assurance consists of linearity, constancy and chi-square tests have been implemented on weekly basis to the thyroid system. In addition, annual checks on minimum detectable activity (MDA) and efficiency for several radionuclides also have been performed. The results shows that all QA tests were complied the tolerance limits given the manufacturer. The MDA value for $^{131}$I radionuclide was determined to be 149.2 ± 35.4 Bq and the efficiency values for the selected radionuclides were comparable with thyroid counters in other institutions. As a conclusion, the equipment now is fully operational and could be used for routine internal monitoring of exposed personnel.*

## Abstrak

*Penilaian cemaran dalaman secara berkala ke atas pekerja sinaran yang berpotensi untuk menerima dos dalaman perlu dilakukan bagi memastikan dedahan sinaran yang diterima adalah tidak melebihi had dos tahunan 20 mSv seperti yang ditetapkan dalam Keselamatan Perlindungan Sinaran Asas 2010. Penilaian ini juga penting untuk mengesahkan pematuhan kepada prinsip-prinsip perlindungan sinaran di tempat kerja. Bagi tujuan pemantauan pengambilan $^{131}$I oleh pekerja, teknik pengukuran secara terus menggunakan pembilang tiroid boleh dijalankan. Di Kumpulan Fizik Perubatan, alat ini telah ditentukur dan diselenggara menggunakan dua jenis radionuklid pemancar gamma iaitu $^{137}$Cs dan $^{152}$Eu. Untuk memastikan kebolehpercayaan pengukuran, kawalan mutu yang melibatkan ujian kelelurusan, kekonstanan dan keberulangan telah dilakukan secara mingguan ke atas alat ini. Selain itu, penentuan aktiviti minimum boleh dikesan (MDA) dan ujian kecekapan turut dijalankan setiap tahun. Keputusan menunjukkan bahawa semua ujian kawalan mutu adalah mematuhi had toleransi yang ditetapkan. Nilai MDA untuk radionuklid $^{131}$I adalah 149.2 ± 35.4 Bq dan nilai kecekapan untuk beberapa radionuklid adalah sebanding dengan nilai kecekapan pembilang tiroid di institusi-institusi lain. Kesimpulannya, pembilang tiroid ini dapat beroperasi sepenuhnya dan dapat digunakan untuk kerja-kerja pemantauan dos dalaman kepada pekerja sinaran.*


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***Keywords:*** *Thyroid counter, quality assurance, minimum detectable activity, efficiency calibration*

***Kata kunci:*** *Pembilang tiroid, kawalan mutu, aktiviti minimum dikesan, tentukuran kecekapan*

## 1. INTRODUCTION

The routine assessment of doses to workers is a part of radiation protection programme that must be carried out to ensure that the dose received by the workers do not exceed the limit of 20 millisieverts (mSv) in a calendar year as recommended by the Atomic Energy Licensing Board (AELB). From the Basic Safety Radiation Protection (BSRP), the annual dose limit for radiation workers includes the occupational doses from external exposures and the committed doses from intakes of radionuclides (BSRP, 2010). Currently in Malaysia, there are almost 20,000 radiation workers who dealing with various types of radiation sources for medical, industrial, agricultural and research & development (R&D) applications. For external dose monitoring, each radiation worker is mandatory to wear an approved personal monitoring device such as a film badge or a Thermoluminescent dosimeter (TLD) badge which are evaluated by authorised bodies on monthly basis. However, workers involved in nuclear activities from research reactor and nuclear medicine are highly potential to be exposed to the internal radiation especially from $^{131}I$ radioactive source. Therefore, a special monitoring is needed for estimating intakes of this radionuclide and finally determining committed effective doses that contribute to annual dose limit.

The $^{131}I$ is categorized as a short lived radioisotope with physical half-life of 8 days. This radioisotope decays with the emission of both beta particles and gamma radiation with average energy for main emission are 0.19 MeV and 364 keV, respectively. Without proper handling, this radionuclide can be easily absorbed into the blood circulation either via inhalation or ingestion.

Bio-assay is a technique used to determine the internal doses. There are two techniques of bioassay: (i) Direct bioassay using whole body counter, lung counter and thyroid counter to detect and count emitted gamma radiation from internal human organs; and (ii) In-direct bioassay by counting radioactivity from the samples of human fluid such as urines, faeces and sweats. In this paper, we only focused on the thyroid counter which is a dedicated counter used for *in vivo* detection of radiation emitted from the $^{131}I$.

The thyroid counter system consists of a scintillation detector, a high-voltage supply, an amplifier, an analog to digital converter, a multi-channel analyser and data acquisition system (Fig. 1). A crystal of thallium-activated sodium iodide (NaI(Tl)) is commonly used for thyroid counter due to its ability to detect energetic photons above 100 keV. It does not require crystal cooling thus featuring better feasibility for fast monitoring of internal contamination. This detector is usually mounted in lead shielding in order to reduce radiation interference from external sources. A simple lead collimator is placed in front of detector to: (i) increase efficiency of intake of radionuclide measurement; and (ii) minimize background radiation during thyroid monitoring. This probe (collimator and detector) is mounted on an adjustable supporting frame in order to get proper alignment with the thyroid, assuring correct geometrical configuration and the comfort of monitored person.

A routine maintenance of thyroid counter system is needed prior measurement of intake of radionuclide in order to ensure the consistency, reliability and precision of reading. The routine works includes: (i) Test of energy calibration using $^{137}Cs$ standard source; (ii) Test of energy resolution in term of percentage of Full Width half maximum (FWHM); (iii) Test of linearity of energy response; (iv) Test of sensitivity; and (v) Test of counting precision (IAEA, 1991). Moreover, the constancy test using a long half live radionuclide such as $^{137}Cs$ and check for Minimum Detectable Activity (MDA) for appropriate radionuclide must be carried out in regular basis in order to maintain the system stability and to ensure the great performance of the counter.

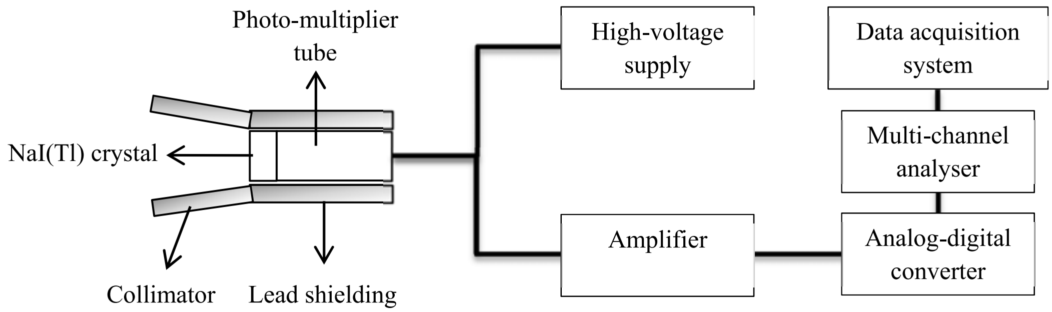


Fig. 1: Schematic diagram of thyroid counter system.

The objectives of this study are:

a) To check the performance of thyroid counter system for energy calibration, energy resolution, linearity, sensitivity and precision tests are complied with tolerance limits given by the manufacturer;
b) To determine the minimum detectable activity of thyroid counter system for $^{131}$I radioisotope; and
c) To study the fluctuation of background radiation in the Nuclear Medicine Standard Laboratory.

## 2. MATERIALS AND METHODS

### 2.1 Instrumentation

The thyroid counter used in this study was a Captus 3000 Thyroid Uptake System (Captus 3000, Capintec Inc., USA). The system consists of 2 in. x 2 in. Thallium-activated Sodium Iodide (NaI(TI)) flat face crystal detector mounted on a shielded lead collimator and data acquisition system equipped with a Captus 3000 software Rev. 1.27. The detector was placed in the drilled well with 1 in. lead shielding and brass liner for reducing its response to environmental radiation. The measurements energies of this NaI(Tl) scintillation detector is up to 2MeV. The Captus 3000 software was used for data acquisition and spectra analysis. The software was provided with an auto calibration module for adjusting high voltage (HV), zero offset and automatic gain; as well as linearity correction and constancy test. The quality assurance test for chi-square, minimum detectable activity (MDA) and efficiency also can be performed automatically using this software.

Two types of standards radioactive sources were used for the quality control of the thyroid counter; $^{137}$Cs (33 and 662) keV and $^{152}$Eu (32.9, 40.8, 121.8, 344.8 and 661.7) keV. The sources were manufactured by Ezkert & Ziegler analytics, USA. Both sources were rod type with 5 mm diameter of active area. The reference activities of the sources are 500 nCi at 1 July 2010 and 1 April 2011, respectively. The $^{137}$Cs source was used for energy peak channel calibration, full width half maximum (FWHM) determination, constancy and chi-square test while the $^{152}$Eu source was used for the linearity test.

### 2.2 Quality Control of Thyroid Counter

The thyroid counter was maintained on the weekly basis for the auto calibration and constancy test. The auto calibration includes low energy peak channel (LEPC), high energy peak channel (HEPC), voltage, auto zero, FWHM and linearity test. All measurements were carried out with a fixed detector-collimator aperture distance at 15 cm. To ensure the reproducibility of the measurement set-up, the source was inserted into the source holder before placing into the collimator (Fig. 2). The end of the source was ensured to just touching the detector window to avoid any damage to the aluminium coating at the scintillation detector. The measurements for constancy test were carried out for two geometrical set-ups to study the effect of detector positioning during calibration: 1) detector at horizontal position; and 2) detector at vertical position. The results for all tests were compared with the calibration results carried out by the manufacturer on 23 Mac 2011 and must comply with their tolerance limits. The results with outside the tolerance limits were repeated until the detector's performances are satisfied.

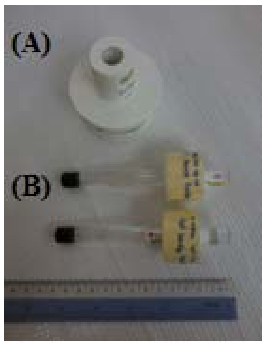


Fig. 1: (A) Source holder. (B) $^{137}$Cs and $^{152}$Eu standard sources, rod type.

### 2.3 Chi-square test

The chi-square ($\chi^2$) test was performed using a $^{137}$Cs standard source to check the counting precision and reliability of the detector. The test was carried out on weekly basis with counting time of 60 s and 10 times repetitions. The value of $\chi^2$ was calculated using equation (1). The tolerance limit of 4.1-14.7 as recommended by the manufacturer is followed. . If result falls outside these limits, the test was repeated.

$$\chi^2 = \frac{\Sigma\left(C_i - \overline{C}\right)^2}{\overline{C}} \qquad \text{(Equation 1)}$$

Where $C_i$ is an individual count and $\overline{C}$ is the mean of 10 counts.

### 2.4 Minimum Detectable Activity

The MDA determination for the $^{131}$I was performed using a neck phantom as a blank, positioning as close as possible to the detector collimator (Fig. 2). The neck phantom is made of 0.96 g/cm3 density polyethylene with weight of 1.5 kg was used. The phantom consists of 11 cm diameter and 5.8 cm height of cylinder bored with a 2.9 cm diameter and 5.1 cm depth of hole at 1.1 cm distance from the phantom surface. The hole was designed to accommodate a 20ml vial representing the thyroid glands. The regions of interest (ROIs) for the $^{131}$I were automatically set to 334-395 keV, 597-677 keV and 258-311 keV. The counting time was set at 900 s. The MDA was automatically calculated by the software using equation 2.

$$MDA = \frac{\left(4.65\sqrt{N} + 2.71\right)}{\left(\varepsilon \times T\right)} \qquad \text{(Equation 2)}$$

Where $N$ is background counts in the region of interest, Ɛ is counting efficiency (cps $Bq^{-1}$) for $^{131}I$ = 0.19% and $T$ is counting time (s). The formula is based on the NCRP Report 58 (NCRP, 1984).

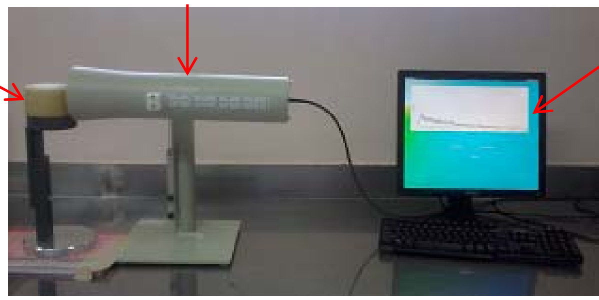


Fig. 2: Captus 3000 Thyroid Counter System.

### 2.5 Environmental conditions

All measurements were carried out in the controlled ambient conditions with the temperature within a range of 20 $^0$C to 24 $^0$C, the maximum relative humidity within 60% to 70% and barometric pressure of 100 ±1 kPa. The level of the background radiation was monitored to ensure its low and as constant as possible during the measurements. Although the detector was shielded with lead and brass, the existing of radioactive in the nearby area still can affect the readings. The thyroid counter was used to study the background radiations in the Nuclear Medicine Standard Laboratory where the thyroid counter is storage and operating. The monitoring was involved two conditions: 1) laboratory door closed and; 2) laboratory door opened. The monitoring was performed from 9.30am to 5.30 pm for three consecutive days. Result of the background radiations monitoring was presented in Fig. 7.

## 3. RESULTS AND DISCUSSION

### 3.1 Quality Control of the Thyroid Counter

The auto calibration using $^{137}Cs$ and $^{152}Eu$ standard sources for the thyroid counter was monitored every week. The results show that the LEPC and HEPC give consistent readings of 16.50 ± 0.16 keV and 331.0 ± 0.6 keV, respectively. The high voltage supplied to the detector was maintained at 1000 V and the auto zero was deviated within the range of 0.051 ± 0.017%. The FWHM values are varies within 6.67 ± 0.22% and linearity correction for energies range within 32.9 to 661.7 keV is 5.17 ± 0.25%. These results demonstrate that all tests performed are satisfied with the manufacturer's tolerance limits.

The results of constancy test for the thyroid detector at horizontal and vertical positions are shown in Fig. 3. The results are expressed as percentage deviation between the measured activity using the counter and calculated activity using decay formula. The mean of the distribution for detector at horizontal position is -0.09% and the standard deviation is 1.86%. The deviations vary between a minimum percentage relative deviation of -3.90% and a maximum of 2.20%. Meanwhile, the mean of the distribution for detector at vertical position is 0.05% and the standard deviation is 1.09%. The deviations vary between a minimum percentage relative deviation of –1.40% and a maximum of 1.60%. All data fall within the tolerance limit of ± 5%. The result shows that the detector positioning during measurement is not affect the result of constancy test. Therefore, the test could be done either at horizontal or vertical position although the manufacturer is recommended that the detector is positioning vertically during measurement. However, the horizontal position is selected for this test in order to maintain its measurement set-up.

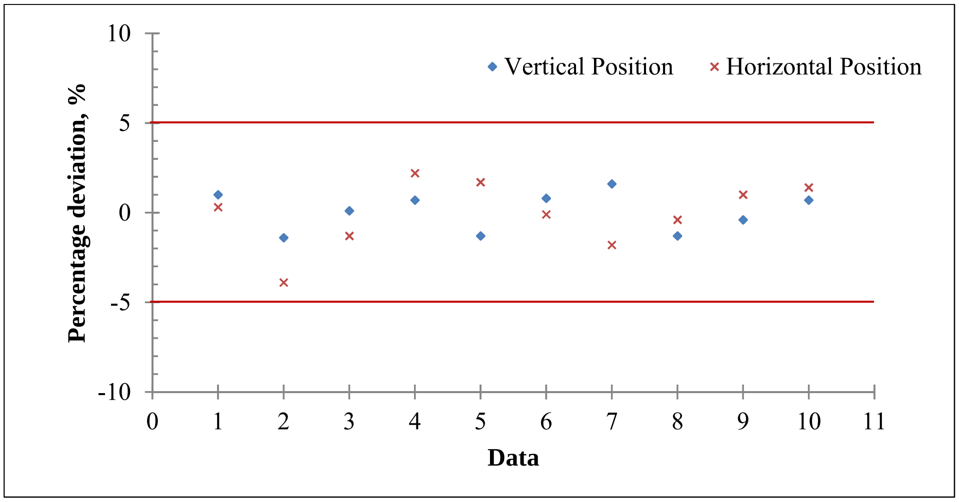


Fig. 3: Comparison of constancy test of Captus 3000 Thyroid Counter System for horizontal and vertical detector positioning.

Fig. 4 shows the weekly results of constancy test of Captus 3000 Thyroid Counter using $^{137}Cs$. The mean of the distribution for constancy test is 5.17% and the standard deviation is 0.25%. The deviations vary between a minimum percentage relative deviation of -5.7% and a maximum of 7.4%. Out of 100 measurements, only nine data were fall outside the tolerance limit of ± 5%. The source of error was identified due to present of other radioactive sources surrounding the detector that contribute to fluctuation of background radiation. The measurement then was repeated until the tolerance limit is complied.

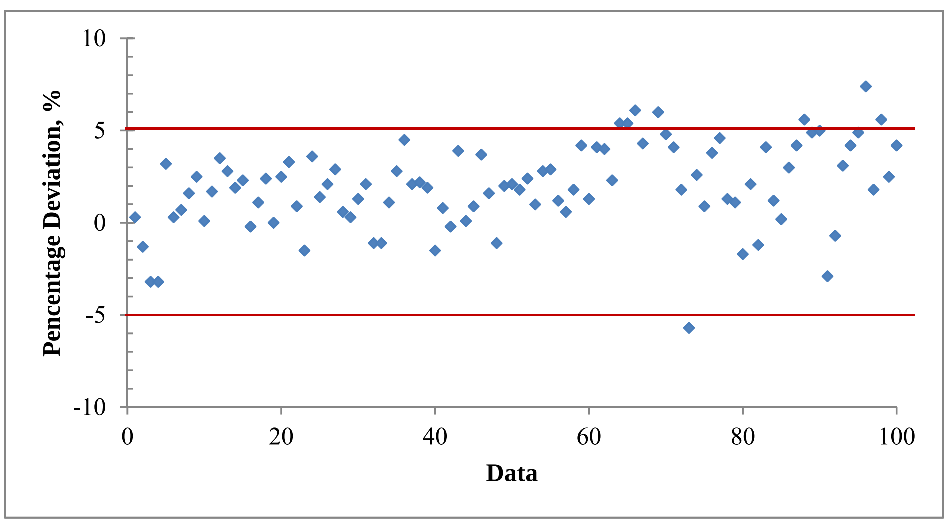


Fig. 4: Results of constancy test of Captus 3000 Thyroid Counter System.

### 3.2 Chi-square Test

The results of chi-square test for the thyroid counter are shown in Fig. 5. The results are expressed as percentage deviation between 10 readings of $^{137}$Cs source. The mean of the distribution for chi-square test is 8.09% and the standard deviation is 3.17%. The deviations vary between a minimum percentage relative deviation of 3.4% and a maximum of 18.2%. Out of 100 measurements, only ten data were fall outside the tolerance limit of 4.1-14.7. The results of greater than 14.7 might be due to electrical noise, unstable detector and temperature changes especially when the test was carried in every Monday morning. The results of less than 4.1 might be due to counting losses because of high count rate. Therefore, the detector should be warm-up for at least one hour before starting the measurement to ensure its stability. To ensure the detector gives consistent and reliable readings, it is recommended to keep the system in stand-by mode for 24 hours. If not, it takes more than 3 days to stabilise the system.

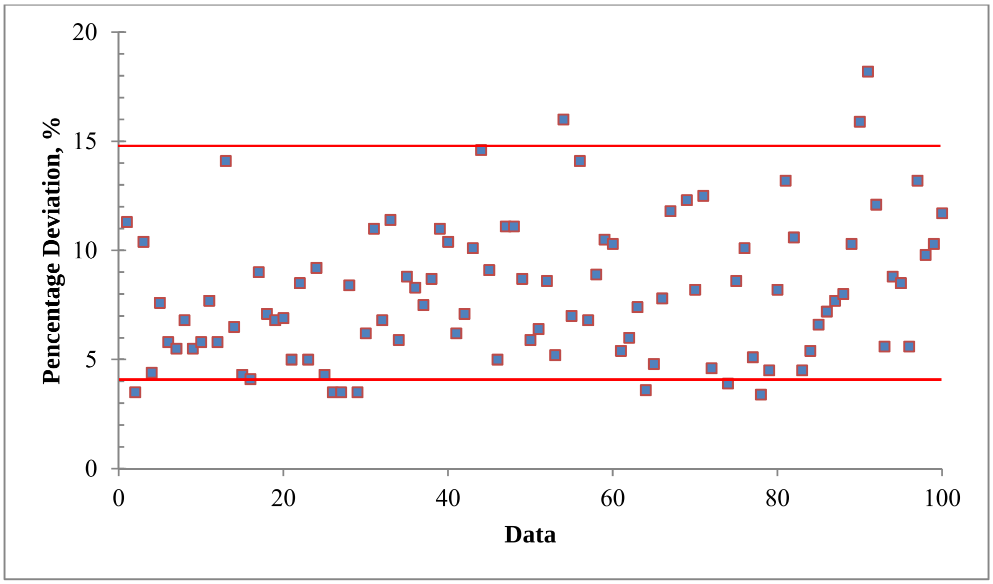


Fig. 5: Percentage deviation of chi-square test for Captus 3000 Thyroid Counter.

### 3.3 MDA

Since the $^{131}$I is an interest radionuclide for thyroid monitoring, the MDA for this radionuclide was determined. The MDA values were estimated by measuring a blank phantom for 900 s. From 100 measurements, the obtained MDA for $^{131}$I was 158.9 ± 39.5 Bq. The values vary between a minimum MDA of 144.8 Bq and a maximum of 203.2 Bq. This result was compared with the MDA values of Ba-133 obtained by the other institutions participated in the IAEA's intercomparison programme for thyroid counter. In the intercomparison programme, $^{133}$Ba radionuclide is used as a mock source for $^{131}$I due to its long-lived and having gamma energy of 356 keV which corresponded with $^{131}$I gamma energy. The IAEA's results show wide variation of MDA for $^{133}$Ba standard source from 3Bq to 1.3 kBq (Kramer,G., 2006 and Dantas, BM, 2011).

The results of weekly monitoring of MDA for this radionuclide are shown in Fig. 6. The linear line functions as a guide for the eyes. From the graph, the MDA values increased with gradient about 0.5Bq every week. This condition is expected because the Nuclear Medicine Standard Laboratory also was used as a storage room for all radioactive materials in the Medical Physics Group. Since the MDA value is depended on the background radiation, the existing of other sources in the room will contribute to higher MDA value of the thyroid counter. However, this situation is still under control where all sources were stored in lead lined in order to ensure the background radiation is as constant as possible during thyroid monitoring.

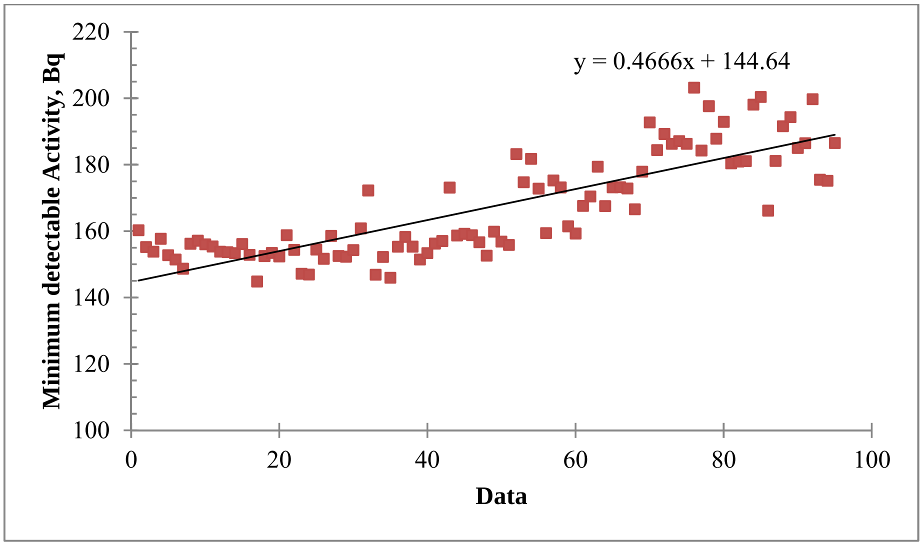


Fig. 6: Monitoring of minimum detectable activity (MDA) of $^{131}$I for Captus 3000 Thyroid Counter System.

### 3.4 Background radiations monitoring

Results of the background radiation in the Nuclear Medicine Standard Laboratory obtained using a Captus 3000 Thyroid Counter is presented in Fig.7. The results show that the background radiation in the laboratory was maintained within 1069 ± 2 cpm and 947 ± 2 cpm for close and open door, respectively. The background monitoring for close door condition gives 13% higher readings compared to open door condition. This condition might due to the occurrence of accumulative radon gas within the laboratory when the door is closed within a long period. Therefore, it is advisable to measure background radiation as close as possible in time to the measurement of subject, ideally just before or just after in order to reduce uncertainty of thyroid monitoring.

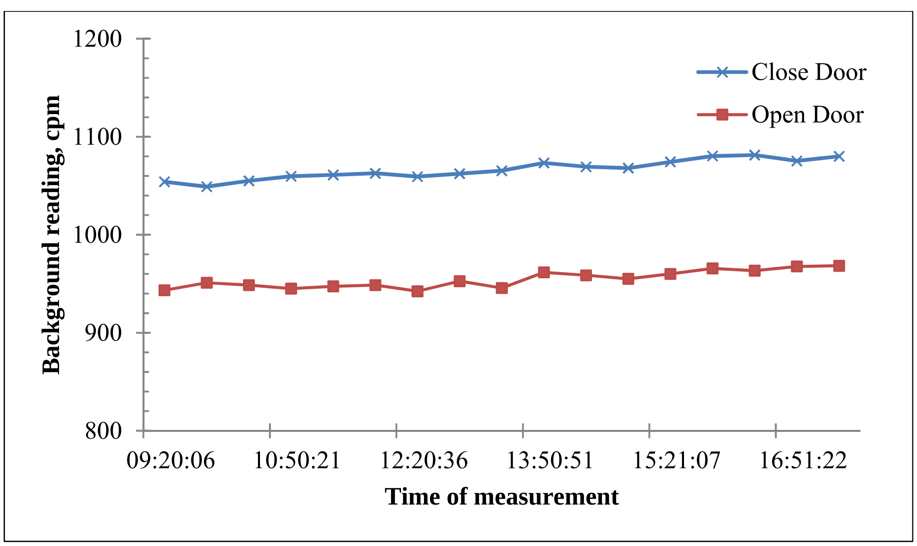

Fig. 7: Comparison of background radiations in the Nuclear Medicine Standard Laboratory using Captus 3000 Thyroid Counter for close door and open door conditions.

## 4. CONCLUSION

The performance assessment for the Captus 3000 Thyroid Counter System using standard radioactive sources of $^{137}Cs$ and $^{152}Eu$ has been carried out. We found that all tests include constancy, linearity and chi-square tests were complied with the tolerance limits given by the manufacturer. The MDA of $^{131}I$ for this counter is 149.2 ± 35.4 Bq; this value is comparable with other unit of thyroid counter in the world. From these findings, we are sure that this counter system is consistent, reliable and suitable to be used for the thyroid monitoring.

## REFERENCES


Atomic Energy Licensing Board (AELB). (2010). Basic Safety Radiation Protection. *AELB, Malaysia*.

Bento, J, Martins, B, Teles, P, Neves, M, Colarinha, P, Alves, F. Zankl, M. (2012). Performance assessment and uncertainty evaluation of a portable NaI-based detection system used for thyroid monitoring. *Radiation protection dosimetry, 151*(2), 252-261.

Bento, J, Teles, P, Silva, L, Nogueira, P, Neves, M, & Vaz, P. (2010). Performance parameters of a whole body counter. *Radiation Measurements, 45*(2), 190-195.

Damet, J, Bochud, FO, Bailat, C, Laedermann, JP, & Baechler, S. (2011). Variability of radioiodine measurements in the thyroid. *Radiation protection dosimetry, 144*(1-4), 326-329.

Dantas, BM, Dantas, ALA, Santos, DS, & Cruz-Suárez, R. (2011). IAEA regional intercomparison of in vivo measurements of 131I in the thyroid: the Latin American and Caribbean experience. *Radiation protection dosimetry, 144*(1-4), 291-294.

Ghare, VP, Patni, HK, Akar, DK, & Rao, DD. (2013). Counting Efficiency of Whole-Body Monitoring System Using BOMAB And ANSI/IAEA Thyroid Phantom Due To Internal Contamination of $^{131}I$. *Radiation protection dosimetry*, nct269.

Kramer, G, & Bureau, Radiation Protection. (2006). Measurement of the quantity 'activity'of radionuclides in simulated human organs: an international intercomparison. *IAEA, Vienna*.

National Council on Radiation Protection and Measurements (NCRP) Report No 58. (1984). A Handbook of Radioactivity Measurement Procedures. *NCRP Publications, USA.*