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Study of Performance of Thyroid Counter for Monitoring of Intake of Iodine-131 among Radiation Workers in Malaysia

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ABSTRACT

Background: 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 AELB's Basic Safety Radiation Protection (BSRP) 2010. In the Medical Physics Group, Nuclear Malaysia, the intake of ^{131}I radionuclide by the workers could be monitored using a Captus 3000 Thyroid Counter System. In order to ensure the consistency and reliability of measurements, this thyroid counter system is calibrated and maintained using two types of gamma emitter radionuclides; ^{137}Cs and ^{152}Eu. A weekly check on the system performances including energy calibration, constancy and chi-square tests are performed. In addition, checks on minimum detectable activities (MDA) and efficiencies detection for this radionuclide are also carried out. **Objective:** The objectives of this paper are: (i) To assess the performance of thyroid counter includes energy calibration, constancy and precision tests; (ii) To investigate the effect of neck-collimator distance on efficiency detection of ^{131}I; (iii) To determine the MDA of ^{131}I at various neck-collimator distances and several counting times; and (iv) To study the fluctuation of background radiation in the Nuclear Medicine Standard Laboratory. **Results:** The results of energy calibration, constancy and precision tests of the thyroid counter are complied with the IAEA's tolerance limits. We found that the efficiency detection is inversely proportional with neck-collimator distance. The MDAs of ^{131}I at 0-7 cm neck-collimator distances for 300 s, 600 s, 900 s and 1800 s were determined to be within 129.92 Bq to 547.12 Bq. **Conclusion:** As a conclusion, the Captus 3000 Thyroid Counter System now is fully operational and could be used for routine internal monitoring of contaminated personnel.

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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 more than 20,000 radiation workers who are 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, Thermoluminescent dosimeter (TLD) or Radiophotoluminescent dosimeter (RPL) badges which are evaluated by the 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

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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 thus contributes to the internal doses.

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 radionuclide that accumulated at thyroid organ.

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 assessment; 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, ensure correct geometrical configuration and provide comfort of monitored person.

A routine maintenance of thyroid counter system is needed prior measurement of intake of radionuclide in order to confirm the consistency, reliability and precision of readings. 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.

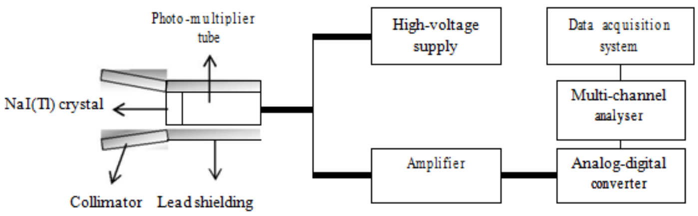

Fig. 1: Schematic diagram of thyroid counter system.

MATERIALS AND METHODS

Instrumentation:

The thyroid counter used in this study was a Captus 3000 Thyroid Uptake System (Captus 3000, Capintec Inc., USA). The system consists of: (i) 2 in. x 2 in. Thallium-activated Sodium Iodide (NaI(TI)) flat face crystal detector mounted in the drilled well with 1 in. lead shielding and brass liner for reducing its response to environmental radiation; and (ii) data acquisition system equipped with a Captus 3000 software Version 1.27 Rev. V used for spectra analysis. The software was provided with an auto calibration module for adjusting high voltage (HV), zero offset and automatic gain; as well as for performing linearity correction and constancy test. The quality assurance tests 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 weekly 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 (Fig. 2). 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 tests while the ^{152}Eu source was used for the linearity correction.

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), high voltage, auto zero, FWHM and linearity correction. All measurements were carried out at a fixed detector-collimator aperture distance of 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 must be placed against the detector window carefully to avoid any damage to the aluminum coating. Damage of aluminum coating may results to deterioration of detector measurement capabilities. The results for all tests must comply with the IAEA's tolerance limits. The results with outside the tolerance limits were repeated until the detector's performances are satisfied.

The thyroid counter was also checked for the effect of detector positioning on the constancy test using ^{137}Cs source at two geometrical set-ups: 1) detector at horizontal position; and 2) detector at vertical position. This is study was carried out to identify the suitable position of detector during routine QC of thyroid counter. The result of constancy test at two different detector positioning was compared as shown in Fig. 4.

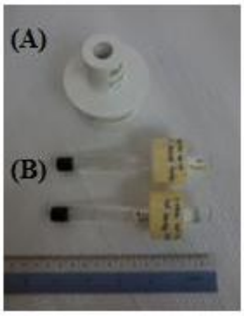

Fig. 2: (A) Source holder. (B) ^{137}Cs and ^{152}Eu standard sources, rod type.

Chi-square test:

The chi-square (χ^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 once a week. The software was set to collect ten readings of ^{137}Cs in 60 s counting time for each reading. The value of χ^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 until the tolerance limit is complied.

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

Where C_i is an individual count and C is the mean of 10 counts.

Measurement of Detection Efficiency:

The efficiencies of ^{131}I radionuclide at 0-7 cm neck-collimator distances for 300 s was determined prior the study of MDA and background radiation measurements. The ^{131}I radionuclide contains in a 20 ml glass vial with a volume of 5 ml is placed in the neck phantom for the measurement. The reference activity of the source is 521 µCi at 4 April 2015. The neck phantom used is made of 0.96 g/cm3 density polyethylene with weight of 1.5 kg. 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 20 ml vial representing the thyroid glands (Fig. 3). The regions of interest (ROIs) for the ^{131}I were automatically set to 334-395 keV, 597-677 keV and 258-311 keV. Results of efficiencies detection for ^{131}I are shown in Fig. 9.

Fig. 3: Neck phantom and ^{131}I for measurement of efficiency detection.

Measurement of Minimum Detectable Activity:

The MDA determination for the ^{131}I was performed using a neck phantom as a blank, positioning at 0-7 cm to the detector collimator with 1 cm interval (Fig. 4). For each neck-collimator distance, the MDA for 300 s, 600 s, 900 s and 1800 s were obtained. The MDA was automatically calculated by the software using equation 2. Results of MDA were demonstrated in Fig. 10.

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

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

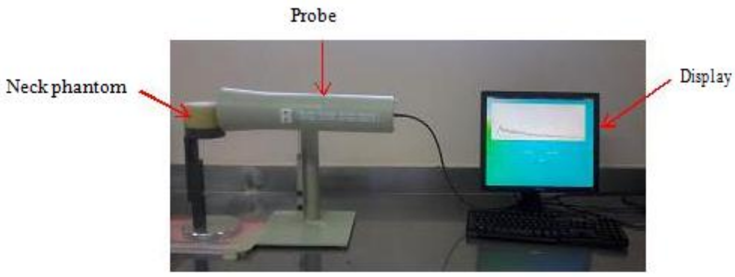

Fig. 4: Measurement set-up for MDA determination. The neck phantom is moved from the collimator at 1 cm interval, starting at 0 cm to 7 cm neck-collimator distance for each MDA measurement.

Measurement of Background Radiation:

The level of background radiation in the Nuclear Medicine Standard Laboratory was monitored to ensure its low and as constant as possible during the thyroid monitoring. Large fluctuation of background radiation during thyroid monitoring may result to inaccurate estimation of internal dose assessment. Although the thyroid detector was shielded with lead and brass, existence of radioactive materials in the nearby area of detector still can affect the readings of measurement. Therefore, the background radiation for ^{131}I in the Nuclear Medicine Standard Laboratory must be monitored using this thyroid counter. The background radiation monitoring was carried out for 72 hours at 30 minutes intervals for three consecutive days. Result of the background radiations monitoring for this radionuclide was presented in Fig. 11.

RESULTS AND DISCUSSION

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%. These results demonstrate that all tests performed are satisfied with the tolerance limits. Fig. 5 shows the result of linearity correction for energies range within 32.9 to 661.7 keV using ^{152}Eu. The gamma energies of ^{152}Eu are linearly dependent with channel of the thyroid counter with determination coefficient of 0.9998. The maximum different percentage between gamma energy and channel for this radionuclide was recorded at 121.8 keV with 5.1 % while the minimum different percentage of -0.1 % was obtained at 661.7 keV.

The results of constancy test for the thyroid detector at horizontal and vertical positions are shown in Fig. 6. 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 of constancy test at horizontal position 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 of constancy test at vertical position 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 does not affect the result of constancy test. Therefore, the test could be done either at horizontal or vertical position although the manufacturer recommended positioning of the detector vertically during constancy test. However, positioning of the detector horizontally is selected due to easy to maintain its measurement set-up.

Fig. 7 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: (i) present of other radioactive sources near the detector that affect the counting of ^{137}Cs activity; (ii) wrong input of efficiency value for ^{137}Cs in the isotope library thus results to high error of reading; and (iii) present of electronic device near to the detector which may cause the electromagnetic interference (EMI) to the detector. Therefore, the following action should be taken to avoid this error:

(i) any sources must be kept further from the detector or in shielded place in order to maintain a constancy of background radiation during the measurement; (ii) User must ensure the correct value of efficiency is input in the isotope library; and (iii) Any electronic devices such as hand phone and laptop should be kept further from the detector during measurement. The results fall outside the limit then was repeated until the tolerance limit is complied. By rejecting the nine outliers, the mean of the distribution and standard deviation of constancy test are given by 1.76 % and 1.913 %, respectively. The deviations vary between a minimum percentage relative deviation of –3.20% and a maximum of 5.00%.

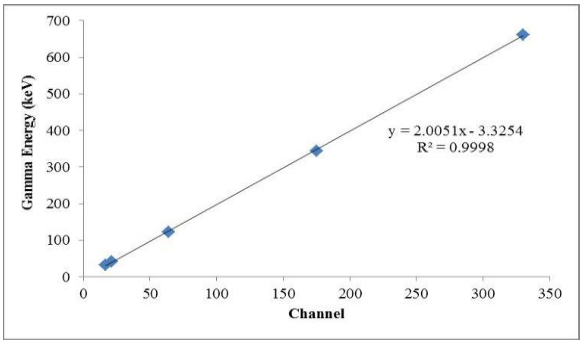

Fig. 5: Linerity correction of Captus 3000 thyroid counter using ^{152}Eu.

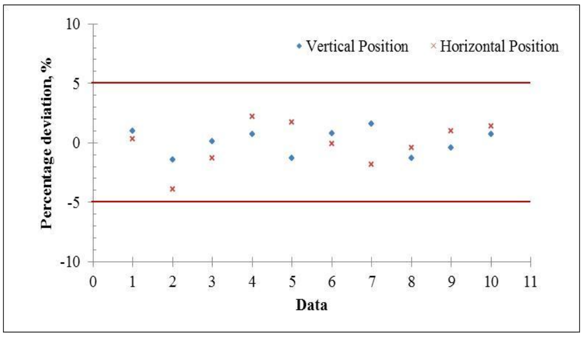

Fig. 6: Comparison of constancy test of Captus 3000 Thyroid Counter System for horizontal and vertical detector positioning.

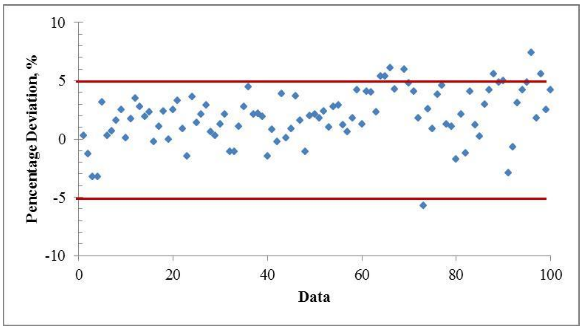

Fig. 7: Results of constancy test of Captus 3000 Thyroid Counter System.

Chi-square Test:

The results of chi-square test for the thyroid counter are shown in Fig. 8. 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 the first working day of the week. The results of less than 4.1 might be due to counting losses because of high count rate. The results fall outside the limit then was repeated until the tolerance limit is complied. By rejecting the ten outliers, the mean of the distribution and standard deviation of chi- square test are given by 8.15 % and 2.64 %, respectively. The deviations vary between a minimum percentage relative deviation of 4.1% and a maximum of 14.6%. In order to maintain the detector performance, it is recommended to keep the counter system in stand-by mode for 24 hours. If not, it takes more than 3 days to stabilize the system.

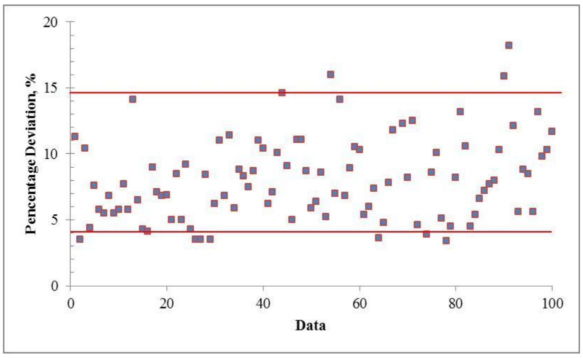

Fig. 8: Percentage deviation of chi-square test for Captus 3000 Thyroid Counter.

Efficiency of Thyroid Counter:

The results of efficiency of ^{131}I radionuclide for 300 s counting time at 0-7 cm neck-collimator distances were presented in Fig. 9. The line is plotted at least polynomial order and functioned as a guide for the eyes. The efficiency detection for ^{131}I radionuclide reduces with the increasing of distance between neck phantom and collimator. Taking into account the inverse square law concept, this reduction is due to absorption of weak energy radiation in air thus contribute to decreasing of amount of photon counted by the detector at further distance. The efficiency detection of ^{131}I reduces by approximately of 39% for phantom-collimator distances from 0 cm to 7 cm. Therefore, the monitored person should be positioned as close as to the detector in order to increase the reliability of reading thus more accurate results of internal dose will be obtained.

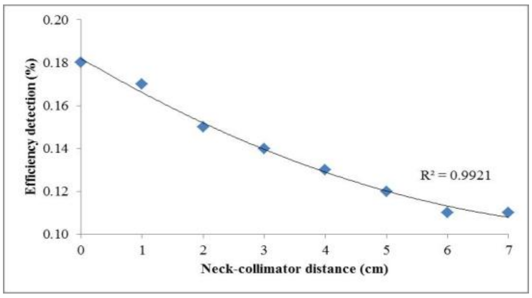

Fig. 9: Efficiency detection for ^{131}I for various neck-collimator distances at 300 s counting time.

Minimum Detectable Activity:

Since the ^{131}I is an interest radionuclide for thyroid monitoring, the MDA for this radionuclide was determined. The results of MDA of ^{131}I radionuclide for 300 s, 600 s, 900 s and 1800 s counting time at 0-7 cm neck-collimator distance were presented in Fig. 10. The linear lines are plotted and function as the guide for the eyes. The graphs show that the values of MDAs are linearly dependent with neck-collimator distance between 0- 7 cm with determination coefficient of 0.9886, 0.94, 0.9657 and 0.9897 for counting time of 300 s, 600 s, 900 s and 1800 s, respectively. The highest MDA value is given by 300 s counting time where the MDA vary between a minimum of 320.42 Bq and a maximum of 547.12 Bq. The smallest MDA value is given by 1800 s counting time where the MDA vary between a minimum of 129.92 Bq and a maximum of 215.88 Bq. Therefore, the longer counting time is better for the counter in order to detect smaller radioactivity of accumulated ^{131}I in the thyroid organ. This result was then 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, 2006 and Dantas, 2011). Therefore, we can conclude that the performance of Captus 3000 Thyroid Counter is equivalent with thyroid counters used by the other institutions in the world.

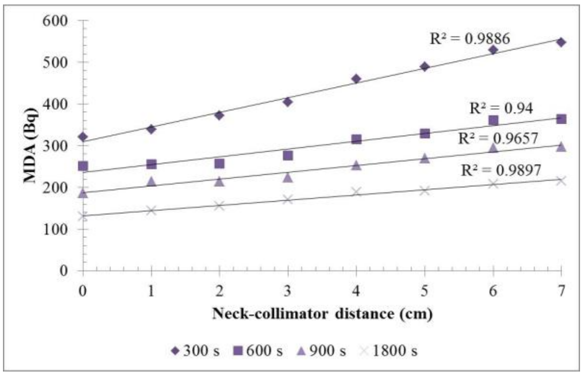

Fig. 10: Monitoring of minimum detectable activity (MDA) of ^{131}I for Captus 3000 Thyroid Counter System.

Monitoring of Background Radiations:

Monitoring of background radiation for ^{131}I using Captus 3000 Thyroid counter was carried out for three consecutive days to observe the fluctuation of background reading in the laboratory as shown in Fig. 11. Total of 135 data were collected for every 1800 s (30 minutes) interval with 5 s elapsed time. Results show that the background radiations were distributed within the mean of distribution of 4.62 Bq and standard deviation of the mean of 1.1%. The background radiation varies between the minimum value of 4.50 Bq and the maximum value of 4.77 Bq. These results demonstrate that the background radiations in the Nuclear Medicine Standard Laboratory are constant throughout the day thus the thyroid monitoring could be performed anytime. However, it is advisable to check of background radiation just before or after the thyroid monitoring in order to avoid any uncertainty in the result of internal contamination.

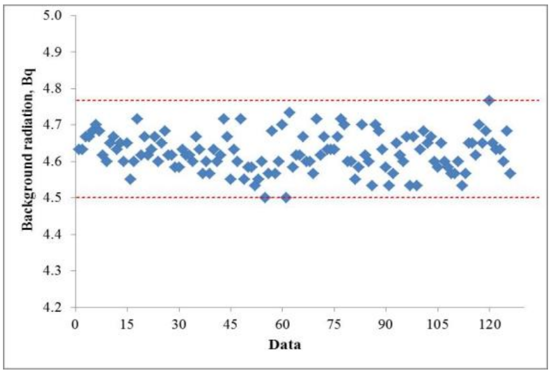

Fig. 11: Background monitoring of ^{131}I using Captus 3000 Thyroid Counter.

Conclusion:

The performance assessment of the Captus 3000 Thyroid Counter System has been carried out. We found that all quality control tests include energy calibration, constancy and precision tests were complied with the tolerance limits given by the manufacturer. The efficiency detection of ^{131}I reduces with the increasing of neck-collimator distance. The MDAs of ^{131}I at 0-7 cm neck-collimator distances increase with the increasing of counting time. The background radiation in the laboratory is stable and constant throughout the day. 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., B. Martins, P. Teles, M. Neves, P. Colarinha, F. Alves, M. Zankl, 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., P. Teles, L. Silva, P. Nogueira, M. Neves, P. Vaz, 2010. Performance parameters of a whole body counter. *Radiation Measurements, 45*(2): 190-195.

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

Dantas, B., E. Lucena, A. Dantas, M. Santos, L. Juliao, D. Melo, W. Sousa, P. Fernandes, S. Mesquita, 2010. A mobile bioassay laboratory for the assessment of internal doses based on in vivo and in vitro measurements. Health physics, 99: 449-452.

Dantas, B.M., A.L.A. Dantas, D.S. Santos, R. Cruz-Suárez, 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, V.P., H.K. Patni, D.K. Akar, D.D. Rao, 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*.

Kramer, G.H., 1997. Considerations in assigning dose based on uncertainties from in vivo counting. Environmental health perspectives, 105: 1393.

National Council on Radiation Protection and Measurements (NCRP), 1984. Report, 58. A Handbook of Radioactivity Measurement Procedures. *NCRP Publications, USA.*