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Assessment of the Body Radioactivity of I-131 Using Two Techniques

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ABSTRACT

Iodine-131 has become an essential radionuclide used in nuclear medicine for clinical and research purposes. The increase use of this radionuclide in medicine for diagnostic and treatment of thyroid diseases creates a demand to obtain a feasible methodology for occupational or accidental monitoring of internal contamination. In this study, two techniques were employed to find an appropriate one of in vivo bioassay for evaluating Iodine-131 body content. A scanning Whole Body Counter (WBC) equipped with 6NaI (Tl) scintillation detector, an anthropomorphic phantom and point source were used. The results showed that the counter sensitivity, as a first approach (conventional method), had a logarithmic and significant correlation with neck weight. On the other hand, the counting rate in the Compton band was considered, which is a measure of gamma ray attenuation, and found to have a direct relationship with body weight. The new technique, which is considered the variation of the counter sensitivity with the Compton to photopeak counting rate ratio, had the same regression but less uncertainty than the conventional approach. Finally, the theoretical MDA with neck weight was calculated for all the phantom configurations.

Keywords: I-131, whole body counter, Compton/peak counting ratio, phantom

حساب نشاط اليود-131الإشعاعي للجسم باستخدام تقنيتين

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الخلاصه

لقد أصبحت نويدات اليود-131 المشعة من الأساسيات المتستخدمة في الطب النووي للأغراض السريرية والبحثية. إن زيادة استخدام هذه النويدات المشعة في الطب لتشخيص وعلاج أمراض الغدة الدرقية تفرض حاجة للحصول على منهجية مجدية للرصد المهني أو العرضي للتلوث الداخلي. في هذه الدراسة ، تم استخدام طريقتين لإيجاد اختبار حيوي مناسب في الجسم الحي لتقييم محتوى الجسم للايود-131. تم استخدام عداد المسح الكامل للجسم (WBC) مزود بستة كواشف وميضية (NaI Tl) وشبح مجسم ومصدر نقطي للاشعاع. أوضحت النتائج أن حساسية العداد كطريقة أولى (الطريقة التقليدية) لها علاقة لوغاريتمية مهمة مع وزن الرقبة. من ناحية أخرى ، تم النظر في معدل العد في نطاق كومبتون ، وهو مقياس لتوهين أشعة جاما ، ووجد أن له علاقة مباشرة بوزن الجسم. التقنية الجديدة ، التي تاخذ بنظر الاعتبار تباين حساسية العداد مع نسبة كومبتون إلى معدل عد الذروة ، لها نفس الانحدار ولكن بدقة أقل من الطريقة التقليدية. أخيرًا ، تم حساب الحد الأدنى من النشاط القابل للكشف النظري مع وزن الرقبة لجميع التراكيب الشبحية.

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2- INTRODUCTION

Iodine-131 has been widely used in nuclear medicine for imaging and treating thyroid cancer and other abnormal conditions of the thyroid gland such as hyperthyroidism [1].Iodine can enter the human body via several natural sources such as food, water and air and it is needed to produce thyroid hormones. The gland is considered healthy if the amount of iodine in the body around 10–15 mg, otherwise it is unhealthy and can influence the entire body [2].

In spite of being a strong gamma emitter, Iodine-131 is used for beta therapy [3]. According to UNSCEAR, 90% of therapeutic purposes use the Iodine-131 in nuclear medicine [4]. Iodine-131 with 8-day half-life is a beta particle emitter of 606 keV with a relative intensity of 89.98%, and several gamma emissions, the main one is 364 keV. The emission of beta particles and gamma rays by Iodine-131 has a great damage effect when they are incorporated, due to their high ionization power [5]. The biological effects of I-131 come from the exposure to both beta and gamma rays. Iodine-131 is absorbed by the body and ultimately accumulates in the thyroid gland and surrounding tissues that takes the highest dose of radiation. The amount of absorbed dose and its biological effects depends on the isotope and its radiation type and energy and effective half-life. The probability of thyroid cancer to be occurred among people is more common cancer which is associated with radioiodine exposure. Exposure to high levels of radioiodine increases the risk of hypothyroidism or hyperthyroidism and could affect reproductive function [6].

The amount of radioiodine inside human body can be determined via in vivo and in vitro measurements. For in vivo measurements, radioiodine can directly be quantified using radiation counters such as whole body counter (WBC) or thyroid uptake counter. These measurements are commonly adopted to determine body burden of radioiodine but not the stable ones. Calibration of such systems can be done using a neck phantom or full-body phantom with radioiodine standard either as point sources [7] or dissolved within water-filled phantoms [8][9]. Radiation counters can monitor radioactive iodine inside human body by measuring the 346 keV photopeak gamma rays coming from the thyroid gland in the neck [10].In addition to the peak, Compton region scattered photons, due to the activity distribution in the source and scattering materials, has a great influence on the counter measurement accuracy especially at low energies of gamma photons[11].The sensitivity of the counting technique is calculated from comparing the photopeak actual counting rates to the known activity of the source. The counter sensitivity with the body weight provides the basis to evaluate a body content of radioiodine. In the present study, in addition to the counter sensitivity which was corrected from Compton region effect, radioiodine content determination was considered in two ways; neck weight as a conventional technique and Compton to photopeak count rate ratio rather than neck weight as a new one.

3- Methodology

Counting system and phantom

A scanning whole body counter, located at the University Hospital of Wales, was employed for this study. The counter is composed of six uncollimated sodium iodide detectors, each with diameter of 15.2 cm and 10.2 cm thickness. The detectors are placed in a shielded room which has dimensions of 182 cm in height, 152 cm in width and 213 cm in length, and its walls are made from 15 cm uncontaminated steel plates and 0.3 cm aged lead. The system can measure activities within a range 370 Bq - 370 kBq, and gamma energies within 50 keV to 2 MeV. It works in static and in scanning geometry with variable scan speed (Figure 1-a). Software Genie 2000 by Canberra is assigned for the counter.

Anthropomorphic phantom (BOMAB phantom) was used to determine radioiodine neck content (Figure 1-b). The phantom of height 170 cm is composed of torso, head and neck, arms and legs used for determining absorbed dose in radiotherapy [12]. Three sets of the phantom were employed to construct five different configurations of heights and weights; this was achieved by adding/removing other compartments to/from the standard phantom height. The phantom configurations are 150, 160, 170, 180, and 190 cm height.

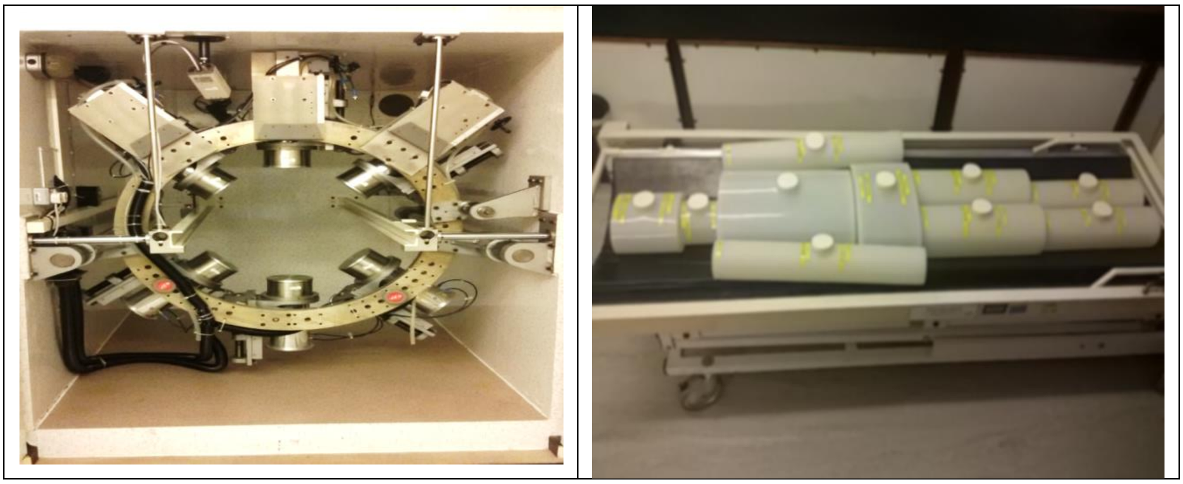

Figure 1: (a) the counting system and (b) the anthropomorphic phantom, used in this study

Radioiodine source and scanning procedure

For thyroid monitoring, it is preferable that the phantom mimics the monitored persons and this can be achieved simply by a point source as a practical consideration [13]. Therefore, liquid radioiodine of activity 3.076 kBq was put in a schott vial, as point source, and hung in the center of neck compartment of the phantom, to simulate a contaminated thyroid (Figure 2). Six different weights for the neck compartment were employed, while the phantom mass was fixed (full water capacity). The weight of the neck compartment in term of water volume was 60% (0.648 kg), 80% (0.864 kg), and full water capacity 100% (1.080 kg). Three other layers of water bags (0.5 liter capacity each) were placed consecutively above the compartment. The bags were placed so that one bag over the compartment to represent layer one (1.580 kg), one bag under and another over the compartment to represent layer two (2.080 kg), and two bags in both sides of the compartment in addition to the two bags of the layer two to represent layer three (3.080 kg). The phantom was scanned once in supine position with a live time of 962 s (scan speed 0.3 cm/sec). This speed was chosen to ensure a total counts over 10000 and consequently reduce the counting uncertainty less than 1%. Net counting rate was determined by subtracting background counting rate, which was measured at the same scan speed (962 sec live time) with empty bed i.e. without phantom, from gross counting rate. The detected counts were corrected for Compton region overlapping.

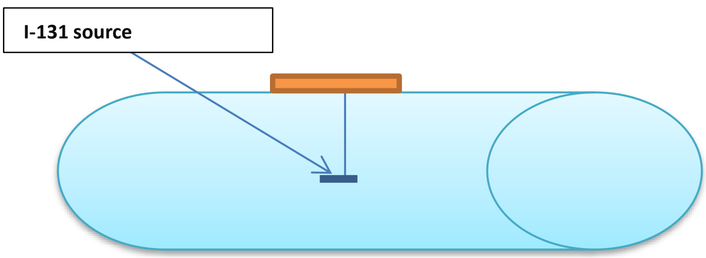

Figure 2: The schematic diagram of the neck compartment with the I-131 point source

Counting window

The spectral windows of interest for I-131 spectra were 346 keV for the photopeak and 160-230 keV for the Compton band. The net counting rate in these two windows with neck weight was determined.

Twice FWHM method was used to calculate the counting window as it provides good counting statistics [9]. The sensitivity of the counter which is defined as a net counting rate per unit activity (counts per sec/ Becquerel) was determined as follows:

$$\text{Sensitivity (S)}= \frac{\text{net count rate}}{\text{source activity (Bq)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Body content of radioactivity is normally derived from counter sensitivity by subject size. In this study, body burden of radioiodine was expressed in term of detector sensitivity with neck weight. The weight of the neck was estimated as a volume by assuming water density is 1.0 g/cm^3. By considering the neck as a cylinder and measuring its height (h) and circumference (c), the volume (v) of the cylinder can be calculated as follows:

$$V= \pi h r^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

By substituting the radius of the cylinder (r)=$\frac{C}{2\pi}$, the volume will be,

$$V= \frac{hC^2}{4\pi}\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Microsoft excel was employed as a statistical tool to analyze the collected data and the mean and the standard deviation (SD) were calculated and the T-test was used to determine the statistical significance ($p < 0.001$ was considered as a confidence value) of the data sets. The statistical measurements of coefficient of correlation (R^2), standard error of estimate (S.E.E) and p-value were taken as criteria to select the best technique.

Corrections for Compton overlap effect

The attenuation of a gamma beam inside human body has an exponential relationship with the body thickness weather the radioisotope is distributed uniformly or a point source. Moreover, the relative Compton counting rate becomes greater with body weight [15].Therefore, in this study, the counting rate was corrected for the effect of the overlap of Compton region with the peak. The correction was achieved by taking counts of 10 channels from either sides of the window, beginning from channel five under the low energy side of the window toward lower energies and from channel five above the high energy toward higher energies, then the relative counts per channel for 20 channels was determined (Figure 3). The net counts were then multiplied by the number of channels in the peak to obtain the net counts of that portion of the Compton band lying inside the peak region. Compton band sensitivity was calculated from the counting rate per activity. Then the sensitivity value (eq.1) is corrected by the factor resulting from the Compton band overlap.

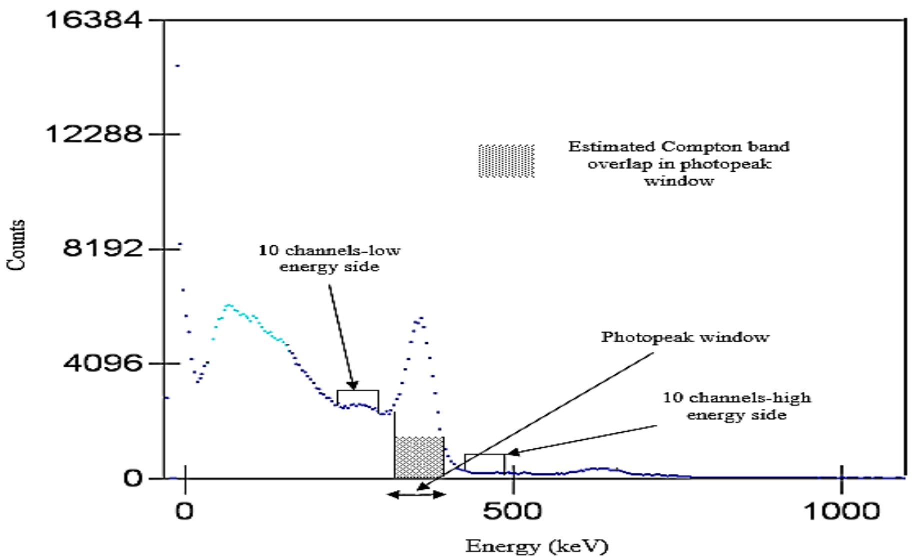

Figure 3: The method of correcting I-131 peak for the Compton region overlap

Minimum detectable activity

The theoretical MDA for the neck content of the radioiodine was calculated according to equation 4, for the five phantom height sat a live time of 962 s (0.3 cm/sec scan speed). Linear regression was the best fitness used to show the relationship between the theoretical MDA and neck weight.

$$\text{Theoretical MDA (Bq)}= \frac{\frac{3\sqrt{B}}{t}}{Detector\ sensitivity} \quad \ldots\ldots\ldots\ldots(4)$$

where $\sqrt{B}$ is the standard deviation of background measurements (B) estimated from Poisson distribution[16].

4-Results

Counter sensitivity Vs neck weight

Figure (4) shows a family of logarithmic regressions of the counter sensitivity with neck weight for the five phantom heights in one graph. These values were corrected for Compton overlapping effect on the photopeak values.

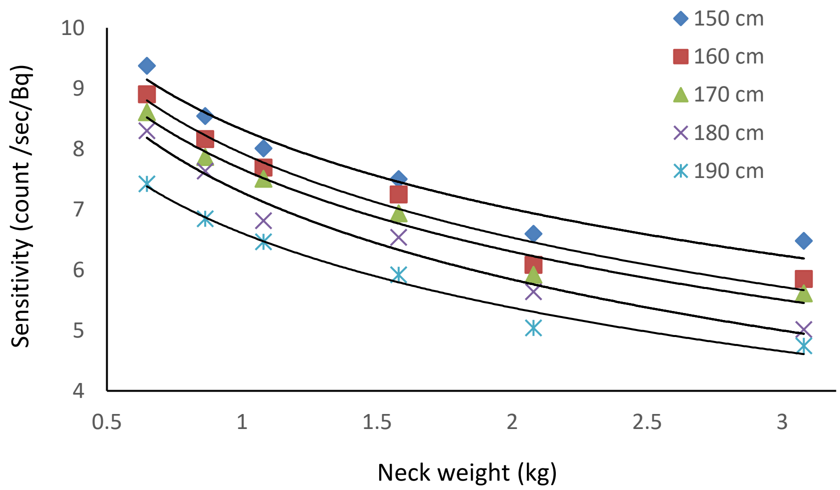

Figure 4: The variation of the counter sensitivity with the neck weight for the five individual heights.

Compton to peak count rate ratio

The number of the counting rate in the Compton band due to the influence of neck weight on the gamma photon attenuation for the neck content of I-131was considered.

Figure (5) shows the variation of the counting rate in Compton region to peak ratio with the neck weight for the five phantom heights. The results were corrected for the Compton band overlap.

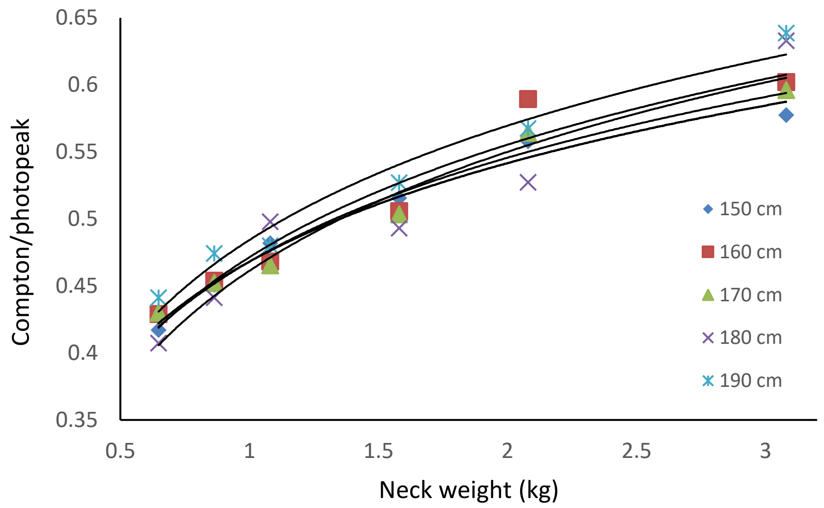

Figure 5: The relationship between the Compton to peak count rate ratio with neck weight for the different phantom heights.

Counter sensitivity Vs Compton to photopeak count rate ratio

Since both the sensitivity of the counter and Compton to peak count rate ratio were depended on the subject weight, the variation of the counter sensitivity with the ratio of Compton to peak count rate can be used as a new technique to investigate the neck content of I-131. This alternative approach may be used when person neck's measurements are not available for some reason.

Figure (6) shows the variation of the counter sensitivity with the ratio of Compton to peak counting rate for the phantom heights, while Table (1) shows the statistical measurements for both approaches.

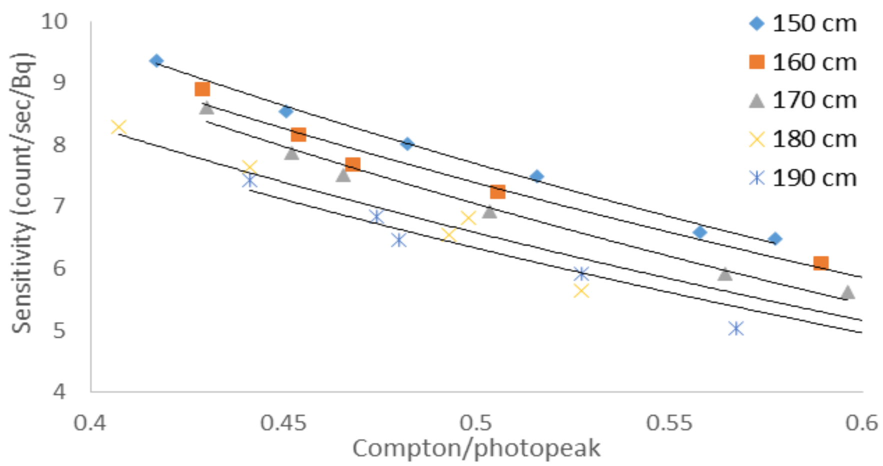

Figure 6: The counter sensitivity Vs Compton to photopeak count rate ratio for the phantom heights.

Table 1 shows the coefficient of determination (R^2), standard error of estimate and p values for the counter sensitivity once with the neck weight (derived by the first method-Figure 4) and the other with Compton to peak count rate ratio (derived by the alternative method-Figure 6), for the five phantom configurations.

Table 1: The statistical analysis of the counter sensitivity using the two techniques

	First technique			Second technique		
Phantom height (cm)	R^2	S.E.E (cps/kBq)	P value	R^2	S.E.E (cps/kBq)	P value
150	0.955	0.265	<0.001	0.994	0.094	<0.001
160	0.964	0.251	<0.001	0.982	0.178	<0.001
170	0.975	0.202	<0.001	0.984	0.164	<0.001
180	0.977	0.209	<0.001	0.942	0.330	<0.001
190	0.980	0.164	<0.001	0.954	0.246	<0.001

Minimum detectable activity

Figure 7 shows the variation of the theoretical MDA with neck weight for the body content of radioiodine for the five phantom heights.

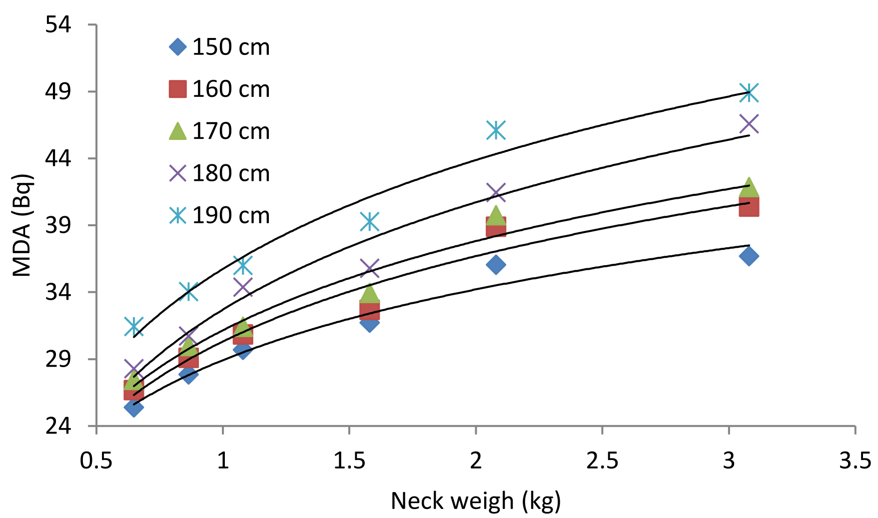

Figure 7: The variation of MDA with neck weight using the five phantom heights

6- Discussion

Iodine enters the body and is absorbed by the thyroid gland to produce hormones which regulate body's energy and metabolism, but this eventually exposes the gland to risk of radiation and potentially increasing the probability for thyroid cancer or other thyroid problems.

In this study, two techniques for estimating neck content of I-131 using whole body counter, anthropomorphic phantom and radioiodine point source. The first technique depends on the counter sensitivity with neck weight calculation, and the second one adopts the fact that photopeak counting rate is influenced by counting rate of the Compton region. The second technique uses the dependence of both counter sensitivity and the ratio of Compton to photopeak count rate on the subject weight as a new approach. In the beginning of the calculations, the counting rate in the photopeak region ware corrected for the effect of the Compton region with the photopeak overlap.

Figure 4 shows that the counter sensitivity had a significant decrease ($P<0.001$) with the phantom's weight, while the height had only a slight influence on the sensitivity ($P>0.05$). On the other hand, the variation of the I-131 Compton band to the photopeak count rate ratio with neck weight was calculated as a measure of gamma photon attenuation. Figure 5 shows that this ratio had a significant increase ($P<0.001$) with neck weight for the phantom heights, while the height had also a slight influence on the ratio ($P>0.05$). These results confirm that whether a radionuclide is concentrated in a small volume or is uniformly distributed throughout the body, the attenuation of gamma rays from that source increases exponentially with subject thickness. Additionally, with increasing body weight, the relative count rate in the Compton area rises (15). On the other hand, the strong relationship between the neck weight and the Compton to count rate ratio, pushed to develop a new method. This method utilizes the ratio as a substitute index of the neck weight with the counter sensitivity to determine radioiodine body content. The results of the new approach showed that the counter sensitivity had nearly the same regression, with a significant difference ($P<0.001$), with the Compton to peak count rate ratio (Figure 6). In spite of that the statistical analysis (R^2, S.E.E and P-value) of the counter sensitivity for the both techniques showed a relatively slight difference, the new one would give better results (Table 1). The new technique (second method) can be easily used when subject's neck measurements are not available for some reason. This can be achieved by taking one scan for a person; the neck content of I-131 can be determined by calculating the Compton to photopeak counting rate ratio and the corresponding value of the sensitivity.
Lastly in this study, the theoretical MDA of the counter for I-131 neck content was calculated and found that it increased logarithmically with neck weight for all the five phantom heights (Figure 7). The results were very close to those in the literature [17].

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