Member's Paper

From IRPS Bulletin Vol 24 No 3, October 2010

Internal Dosimetry of ^{40}K and ^{131}I in Egyptian Radiation Workers

M.I. Gohary [1], M.A. Gomaa, Samia M. Rashad, Eid M.A. and T.M. Morsi [2]

[1] Physics Department, Faculty of Science, Al Azhar University, Cairo, Egypt
[2] Atomic Energy Authority, Cairo, Egypt

Abstract

The aim of the present work is to review experience gained in the field of radiation internal dosimetry of Egyptian workers who deal with unsealed radioactive sources (e.g. as in nuclear medicine). Radioactivity levels for ^{40}K and ^{131}I were measured for both males and females using a whole body counter (WBC). This study includes the calibration of the WBC using several radionuclides. The activity of ^{40}K in males ranged from 2724 to 7529 Bq with an average of 5196 ±7.05 % Bq. The activity of ^{40}K in females ranged from 2984 to 6159 Bq with an average of 4118.5 ±7.7 % Bq. The measured activity of ^{131}I due to inhalation for some individuals varied from 201 to 51248 Bq, corresponding to a range of estimated initial activity of 2946 to 212523 Bq. The obtained dosimetric results are compared with dose limits to individuals recommended by 2007 ICRP recommendations.

Key word: whole body counter- ^{40}K- ^{131}I

Introduction

Following 2007 ICRP recommendations and its new terminology - internationally known as ***ICRP-103*** [(1)] - exposure to radioactivity is categorized according to the following situations: planned exposure situations, existing exposure situations or emergency exposure situations. The present study focuses on planned exposure situations involving individual workers, public or private. Occupational radiation workers are exposed to natural and man-made sources by external exposure and/or internal contamination. Internal exposure arises when radiation is emitted from radioactive materials present within the body. The internal dose is directly related to the intake of radioactive materials, which are introduced into the body by inhalation, ingestion or through the skin (absorption, injection, etc.) ***(IAEA, safety standard series 1999)*** [(2)]. Internal contamination continues until the radioactive material is cleared from the body by natural processes or is removed by medical countermeasures.

All forms of radiation can cause internal radiation exposures. Occupational exposure to ^{131}I occurs in the nuclear industry, in research and in nuclear medicine, in both diagnostic and therapeutic settings.[(3, 4)] (In treatment facilities throughout Egypt, diagnostic use involves smaller quantities, of order MBq, compared to quantities required for treatment of patients, which which may exceed 10 GBq per week.) Generally, with ^{131}I, an individual is exposed to beta particles (average energy for main emission is 0.19 MeV) and gamma rays (main emission 0.36 MeV) [(5)].

^{131}I is produced by the irradiation of ^{130}Te in a nuclear reactor [(n, gamma) reaction] and has a half-life of 8.04 days, but its effective half life in the body is reduced to 7.3 days because of physiological processes. Iodine is rapidly absorbed in the blood following intake, where about 70% is excreted in the urine and about 30% concentrates in the thyroid.(6, 7) The biological half life of iodine in the blood is quite short, about 6 hours, because of these two mechanisms; the much longer 80 day biological half life in the thyroid, where it is incorporated into thyroid hormones that subsequently enter other tissues **(8)**, accounts for the overall effective half life in the body of 7.3 days. ^{131}I may be detected directly in the thyroid or indirectly in urine samples.

Direct measurement of body radioactivity using the whole body counter (WBC), a type of gamma-ray spectrometer used for in vivo measurements, is the most reliable method of monitoring such internal exposure to an individual. It has been used on a routine basis for radiation workers and for the public in case of an emergency (*e.g.* it was also used in the late 1950s and early 1960s to detect global fallout that had contaminated the general population) **(9)**. It is capable of both qualitative and quantitative measurement of natural and artificial radioactivity within the human body, and, in the present study, was used to conduct measurements of ^{40}K – as a continuation of earlier studies on Egyptian individuals – and of ^{131}I, in connection with contamination incidents at nuclear medicine facilities.

Materials and methods

The FASTSCAN whole-body counter, in use at the Egyptian Atomic Energy Authority since 1999, is designed to quickly and accurately monitor individuals for internal contamination of radionuclides that emit energies between 300 KeV and 1.8 MeV. It consists of two large sodium iodide detectors, configured in a linear array on a common vertical axis. The detectors are each 3x5x16 inch, and are each viewed by a single photomultiplier tube. In addition, it uses a shadow shield to minimize spectral background interference. The shield is constructed of 10 cm thick low background steel. Steel was chosen over lead because of its structural properties and because it does not contain ^{226}Ra which is always present in lead. The low background steel is manufactured for Canberra using a special cobalt-free process. This special process guarantees that the steel will be free of the ^{60}Co contamination found in normal steel. The FASTSCAN's steel shield is covered with painted sheet metal and lined with moulded plastic for ease of decontamination.

The electronic system and computer are straightforward. The two NaI (TI) detectors are biased by Canberra high voltage power supplies. Each detector signal goes through a pre-amplifier and an amplifier. The signals are routed into an appropriate multi-channel analyzer.

System operation

Each test subject enters the counting shield and leans against the back wall. There are molded positioning devices on the back wall that make it natural for the individual to stand in the correct location. The operator starts the count using the ABACOS software included with the system. The software starts the data collection and brings up a subject demographics screen.

For direct measurements, individuals should be free from external contamination and in fresh clothing. Usually, this will involve taking a shower, washing the hair, and donning disposable paper garments before entering the monitoring area. Accessories such as jewelry, watches and spectacles should be removed. Such precautions help to avoid false identification of internal activity, and also prevent the transfer of contamination to the counting equipment.

Results and discussion

Factors Affecting WBC performance

The following factors were studied: linearity, efficiency and absolute efficiency for ^{40}K and ^{131}I, and energy resolution. Linearity between channel number and energy in KeV was verified by using multi-gamma sources covering a range of energy from 300 KeV to 1600 KeV. Figure (1) shows the energy calibration for WBC.

The counting efficiency of the FASTSCAN WBC, defined as the measured count rate per unit activity, varies with energy and, hence, is one of the most important physical parameters affecting the performance of the whole body counter. It is determined experimentally by using calibrated mixed gamma-ray sources, which were, in the present case, placed inside a Canberra transfer phantom. The counting efficiency (observed count rate per Bq, divided by the associated branching fraction 0.817 for ^{131}I and 0.11 for ^{40}K), and consequently the statistical accuracy of measurements, depends on the crystal dimensions, geometry and the energy of incident photons. Figure (2) shows the efficiency calibration curve for the FASTSCAN WBC.

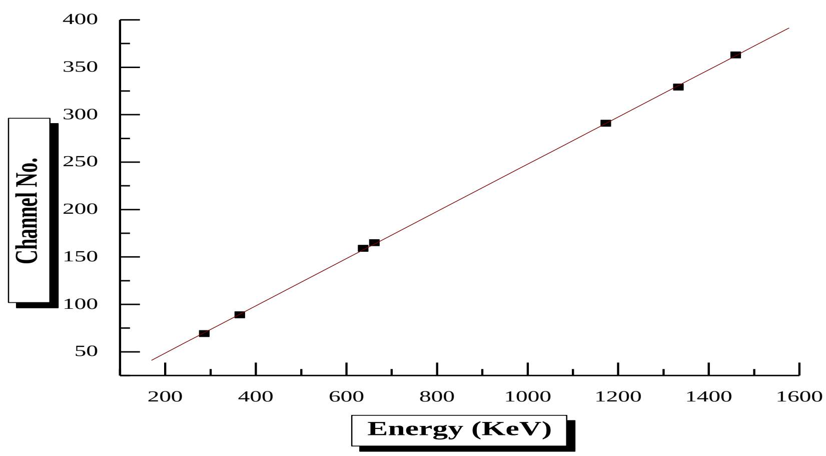

Figure (1) Energy Calibration for WBC.

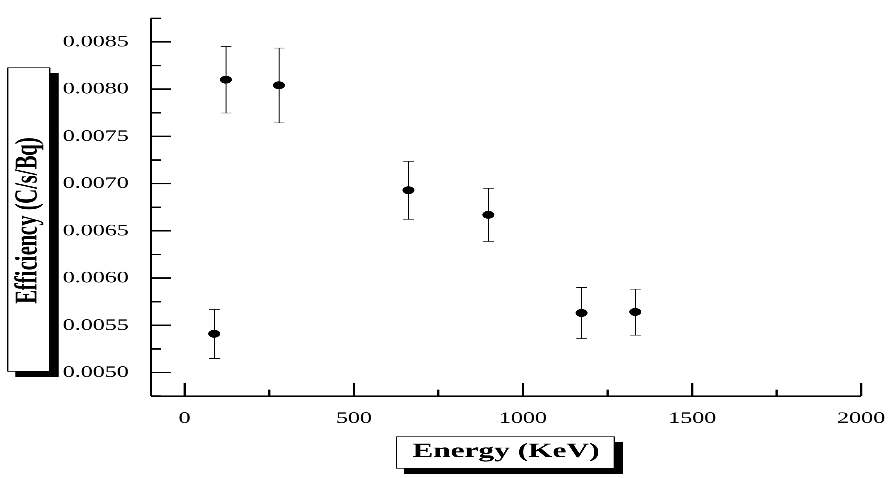

Figure (2) Efficiency Calibration Curve for 2 vertical NaI(Tl) detectors

Absolute efficiencies for counting gamma rays from ^{40}K and ^{131}I – with energies of 1.46 MeV and 364.5 KeV, respectively – were then determined by placing solutions with various, known concentrations of each radionuclide within a Bottle Mannequin Absorber (BOMAB) phantom and measuring the count rate as a function of the calculated activity. The obtained data of count rate vs. activity are plotted in Figures (3) and (4), respectively for ^{40}K and ^{131}I. The average absolute efficiency at ^{40}K was found to be 5.24×10^{-3} C/s/Bq, (Table 1). The latter showed that the average efficiency calibration for our two-vertical-NaI(Tl) WBC was 7.22×10^{-3} counts per second per Bq at 364.5 KeV (Table.2).

Table (1) Count rates of ^{40}K versus Efficiency for WBC.

Activity of ^{40}K (Bq)	Counts /s	Efficiency C/s/ Bq
2512.44	1.45	5.25×10^{-3}
2677.65	1.54	5.23×10^{-3}
3184.11	1.83	5.22×10^{-3}
3584.08	2.07	5.26×10^{-3}
3994.98	2.30	5.23×10^{-3}
4395.49	2.54	5.25×10^{-3}
5166.60	2.98	5.24×10^{-3}

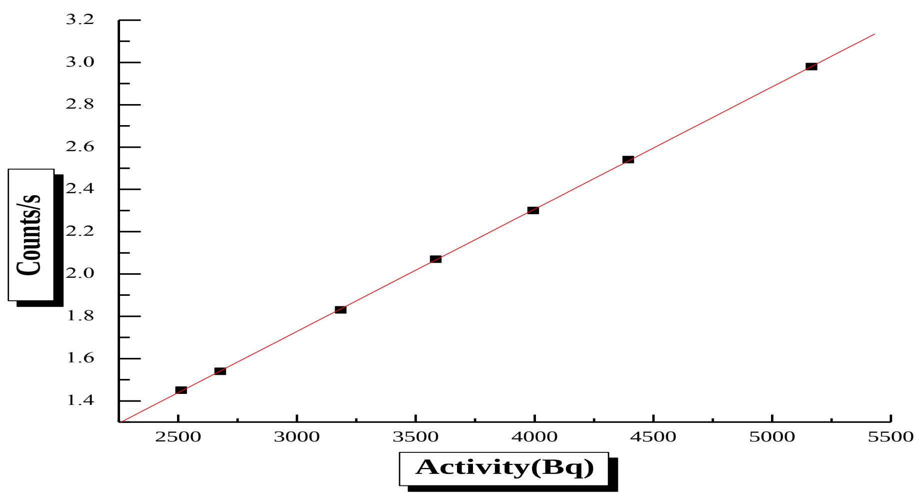

Figure (3) Count rate as a function of ^{40}K concentrations for 2 vertical NaI(Tl) in a FASTSCAN WBC.

Table (2) Count rates of ^{131}I versus Efficiency for WBC.

Activity of ^{131}I (Bq)	Counts /s	Efficiency C/s/ Bq
16197	96.47	7.29×10^{-3}
43923	262.34	7.31×10^{-3}
74524	440.30	7.23×10^{-3}
134754	783. 70	7.12×10^{-3}
245370	1437.65	7.17×10^{-3}

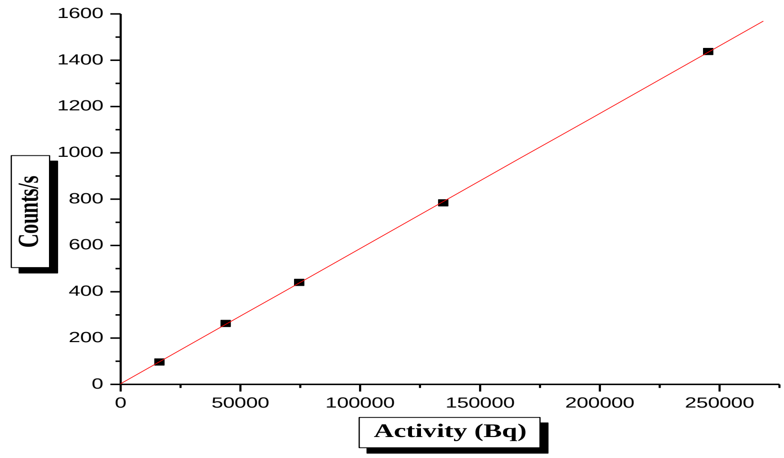

Figure (4) Count rate versus activity for FASTSCAN (WBC) using ^{131}I.

Experimental results

The energy resolution of the detector is conventionally defined as the full width at half maximum (FWHM) divided by the location of the peak energy. Resolution was calculated using different sources such as ^{60}Co and ^{137}Cs. The obtained result showed that the resolution for FASTSCAN (WBC) ranged from 5.80 % to 8.95 %.

The minimum significant activity (MSA) and minimum detectable activity (MDA) was evaluated in the region of interest at 1.46 MeV and 364.5 KeV. The *MSA and MDA* [10] are expressed in terms of:

$$MSA = \frac{1.64}{F}\sqrt{\frac{n_b}{t_s}\left(1+\frac{t_s}{t_b}\right)} \qquad (1)$$

$$MDA = \frac{2.71}{F\,t_s} + 2MSA \qquad (2)$$

where n_b is the background count rate; t_s and t_b are respectively the count times for the sample and for an associated measurement of the background; F is calibration efficiency. The MDA for NaI (Tl) FASTSCAN are equal to 14 Bq at 364.5 keV and 41 Bq at 1460 keV.

1. ^{40}K Measurements

Natural potassium is a mixture of three isotopes: ^{39}K, ^{40}K and ^{41}K with mass percentages of 93.08 %, 0.0118 % and 6.91 % respectively (***Carinou, E., et al, 2007***) [11] A typical 70 kg human body contains about 140 g of potassium with about 4400 Bq of ^{40}K (***T.Ishikawa, 2000***) [12]. The 1.46 MeV gamma rays emitted from ^{40}K in the body can be detected with a whole body counter FASTSCAN.

239 male individuals aged from 25 up to 65 years old and 47 female individuals aged from 25 up to 50 years old were selected for the study. The ^{40}K activity in males ranged from 2724 Bq to 7529 Bq with an average of 5196 Bq ±7.05 %. The ^{40}K activity in females ranged from 2984 Bq to 6159 Bq with an average of 4118 Bq ±7.7%. The present work results are in agreement with previously measured results (Table 3), where stand up geometry was used.

../Table 3

Table (3) Average ^{40}K activity measured compared to the present results for males and females.

Author	N_0 of Individual		^{40}K (Bq)	
	Male	Female	Male	Female
T.M.Taha, et al, 1996 [13]	42	22	4835	3818
W.M.Badawy, et al, 2005 [14]	17		4425	
The present work , 2010	192	47	5196 ± 7.05 %	4118.5 ± 7.7 %

The average total body potassium (TBK) content in males is 2.12 ± 0.44 g K/kg. The average total body potassium (TBK) content in females is 1.96 ± 0.51 g K/kg. The obtained results showed that the data of ^{40}K are in agreement with previously measured Egyptian results [13-14], (Table 4). TBK is dependent on sex, age, body index, body fat, food system, and environment. This smaller TBK for females relative to that for males may be a consequence of their relatively smaller body index (the ratio of flesh to bone in case of females being slightly less than that of males).

Table (4) Average TBK determined by different authors compared to the present work for males and females.

Author	**N_0 of Individual**		**(g K/kg)**	
	Male	Female	Male	Female
M.T.Abass, et al, 1994 [15]	120 both sexes		2.65	2.42
T.M.Taha, et al, 1996	42	22	2.1	1.7
T.P.Lynch, et al, 2004 [16]	2037	248	1.68 ± 0.3	1.41 ± 0.3
The present work	192	47	2.12 ± 0.44	1.96 ± 0.51

The present work values (with these errors) of total body potassium for males and females per one kg are compatible with the internationally accepted recommended values (*e.g.* the recommended TBK is about 2 g of K/kg for reference man, 4400 Bq of ^{40}K [***ICRP 23, 1974***] [17]).

2. ^{131}I Estimation

In the present work, 239 individuals were monitored for ^{131}I, of whom 21 tested positive for contamination. Nine of the latter individuals were counted just after intake and 12 were counted later. Since all of these individuals were contaminated with ^{131}I through inhalation, a dose-activity conversion factor of 1.05×10^{-8} Sv/Bq [18] for inhalation of ^{131}I was used to estimate the committed effective dose (CED) for each individual.

In the first group, where individuals were monitored directly after intake, the estimated results of CED range between 2.11 μSv to 157.22 μSv. Results are shown in table (5) and Figure (5).

Table (5) Activities and committed equivalent dose due to ^{131}I for individuals monitored directly after intake.

Individual	Counts/ s	Activity (Bq)	σ%	CED (μSv)
1	01.18	201.0	± 29.8	2.11
2	01.56	264.0	± 18.8	2.77
3	01.96	332.0	± 19.5	3.49
4	02.02	343.0	± 16.8	3.60
5	02.17	368.0	± 14.5	3.86
6	04.07	690.0	± 8.7	7.24
7	08.53	1447.0	± 4.5	15.20
8	50.84	8619.0	± 1.5	90.50
9	88.32	14973.0	± 1.1	157.22

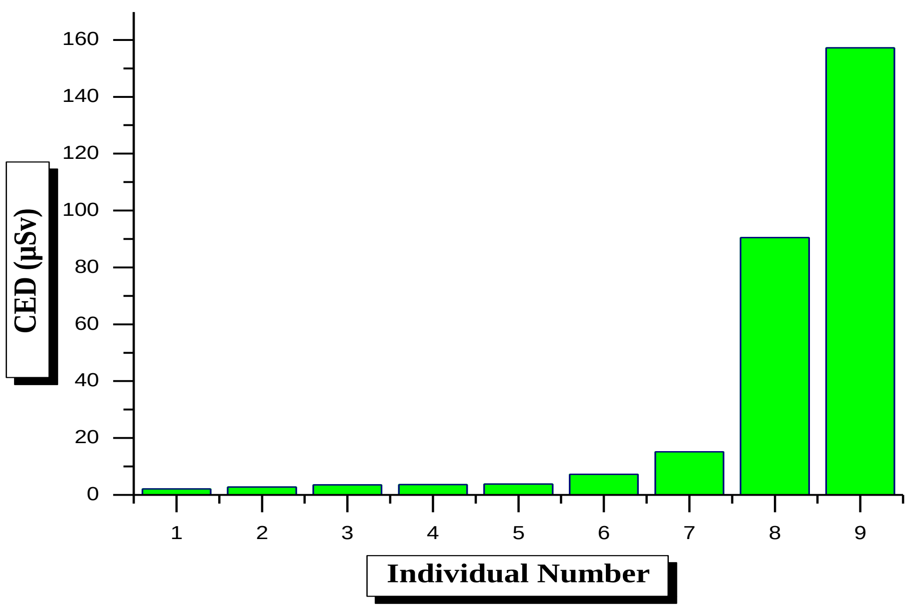

Figure (5) CED values measured after intake for individual workers at nuclear medicine unit.

For the second group, where individuals were counted several days after intake, CED at the measuring date varied between 5.25 μSv to 538.10 μSv as shown in Table 6a. Initial activities for all contaminated individuals were calculated [19] using the decay equation, $A = A_0 e^{-\Lambda t}$, and effective half life for ^{131}I. Hence, the initial dose due to inhalation was assessed and found to be in the range 7.85 μSv to 2231.50 μSv. Results are shown in Tables (6a and 6b).

Table (6a) Determination of activities measured and CED due to inhalation of ^{131}I, measured several days after intake.

Individual	Days after Intake	Counts/s	Activity (Bq)	σ%	CED (µSv)
1	6	002.950	500	± 16.80	5.25
2	30	003.672	623	± 10.40	6.54
3	23	007.188	1219	± 6.20	12.80
4	9	007.950	1348	± 7.50	14.15
5	35	008.350	1415	± 7.40	14.86
6	2	021.028	3565	± 2.40	37.43
7	30	021.850	3704	± 3.90	38.90
8	7	043.008	7291	± 1.90	76.56
9	7	043.222	7327	± 1.50	76.93
10	2	108.455	18386	± 0.95	193.05
11	2	105.233	17840	± 1.00	187.32
12	2	302.300	51248	± 0.90	538.10

Table (6b) Initial activities calculated and CED due to inhalation of ^{131}I for individuals registered in Table 6a.

Individual	Initial activity (Bq)	CED (µSv)
1	2946	7.85
2	35827	87.00
3	36003	378.03
4	10553	110.81
5	130493	1370.18
6	14367	150.85
7	212523	2231.50
8	47210	495.71
9	47443	498.15
10	74090	778.00
11	71890	754.85
12	206513	2168.39

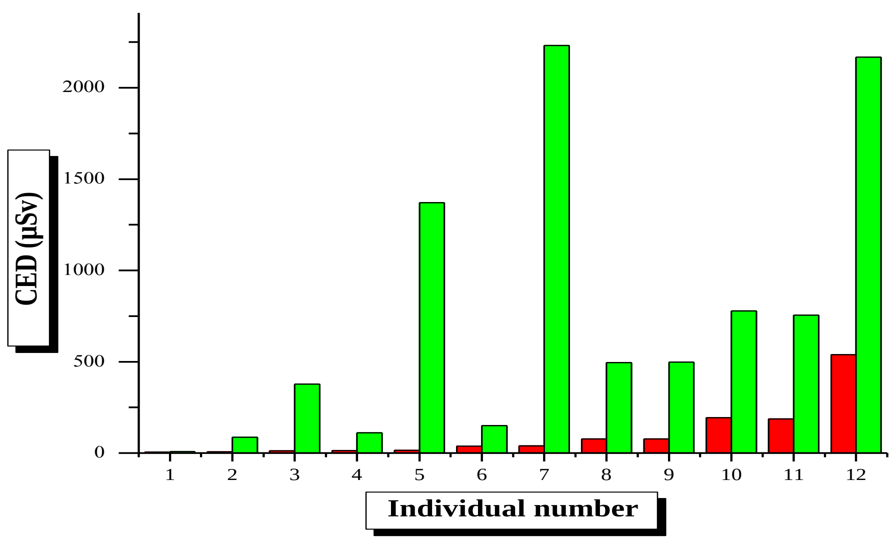

Figure (6) Initial dose were calculated (green column) and measured dose (red column) several days after intake of 131I

Conclusion

Experimental results for Egyptian individuals who participated in this study indicated that the average Total Body Potassium TBK is 2.12 ± 0.44 g K/kg for males and for females is 1.96 ± 0.51 g K/kg. The present ^{40}K results are in agreement with previously measured results. The results obtained for individualsexposed to ^{131}I as shown in tables 5 and 6 indicate that internal dose to individuals varied from 5.25 μSv to 2231.50μSv. Hence contaminated individuals were exposed internally to less than the average annual dose limit for workers; see ICRP-103, (2007).

References

1. 2007 ICRP Recommendations, Publication 103, 2007.
2. IAEA, Occupational Radiation Exposure, Safety Standard Series, 1999.
3. David C. Kocher, Radioactive decay data tables, p131, 1981.
4. MDS Nordion division. Nordion is a trademark of MDS (Canada) June 2008. *www.mds.nordion.com/documents/products/^{131}I- Solu_Can.pdf*
5. ICRP "Radionuclides Transformations: Energy and Intensity of Emissions", Publication-38, 1983.
6. ICRP, "Age dependent doses to members of the public from intake of radionuclides" part 1, publication 56, 1989.
7. ICRP, "Dose coefficients for intakes of radionuclides by workers" publication 68, 1994.
8. ICRP Publication 30, "Limits for Intakes of Radionuclides by Workers" part 1, 1979.
9. Gomaa, MA; M I Al-Gohary, S M Rashad, E M Ali and T M Morsi, Arab J of Nuclear Sciences and Applications, 42, pp (387-396), 2009.
10. AEA, Safety series 114, Direct Methods for Measuring Radionuclides in the Human Body, 1995.
11. E. Carinou, V. Koukouliou, M. Budayova, C. Potiriadis, V. Kamenopoulou; Nuclear Instrument and Methods in Physics Reasearch, A 580 , (197-200), 2007.
12. T. Ishikawa, Health Physics, 78, (420-433); 2000.
13. Taha.M.Taha, M.Sc.Thesis, (Investigation of certain factors affecting measurement of radioactivity in man), Cairo University, 1996.
14. Wael M. Badawy, MSc., (Radioactivity measurement in man, soil and drinking water), Minufiya University, 2005.
15. Abdel Wahab, M.S., S.K. Youssef, A.M. Ali, S.A. El-Fiki, N. El-Enany and Magda T. Abass, Applied Radiation and Isotopes, v. 43(10) p. 1285-1289, (1992), Pergamon Press Ltd.
16. Lynch, T. P. and Rivard, J. W. and Garcia, S., Radiation Protection Dosimetry, Oxford Journals, Published by Oxford University Press, June 2004.
17. International commission on radiological protection (ICRP), Reference Man, ICRP Publication 23, 1974, Pergamon Press, Oxford.
18. Integrated Modules for Bioassay Assessment, Gary Kramer, private communication, 2010.
19. Gomaa,M.A, Aziz.A, El-Assaly, F.M., El-Kolaly,M.A., Health Physics Vol.44, (405-409), 1983.