Appl. Radiat. Isot. Vol. 43, No. 10, pp. 1285–1289, 1992
Int. J. Radiat. Appl. Instrum. Part A
Printed in Great Britain

0883-2889/92 \$5.00 + 0.00
Pergamon Press Ltd

A Simple Calibration of a Whole-body Counter for the Measurement of Total Body Potassium in Humans

M. S. ABDEL-WAHAB[1], S. K. YOUSSEF[2], A. M. ALY[2] S. A. EL-FIKI[1], N. EL-ENANY[1] and MAGDA T. ABBAS[2]

[1]Physics Department, Faculty of Science, Ain Shams University, Cairo, Egypt and
[2]Radiation Protection Department, Nuclear Research Center, Atomic Energy Est., Cairo, Egypt

(Received 26 August 1991; in revised form 18 November 1991)

A simple calibration procedure for the Inshas whole body counter for evaluating total body potassium has been adopted. More than 120 Egyptian employees in the Nuclear Research Center (N.R.C.) were studied for their total body potassium (TBK). The potassium values were found to have an average of 2.85 ± 0.57 g K kg^{-1} body weight for males and 2.62 ± 0.52 g K kg^{-1} for females, which are higher than the recommended value given for reference man by ICRP. The TBK varied directly with body build index and is slightly sex dependent.

1. Introduction

Natural K is a mixture of three nuclides ^{39}K, ^{40}K and ^{41}K in the percentages of 93.08, 0.0118 and 6.91, respectively. It is of widespread presence in the environment and in the intracellular composition of the food chain as well as in the body burden of humans (Mitra, 1989). The body cell mass has been recognized as the core metabolically active portion of the body (Moore, 1963) and is that portion which consists of all hydrated cells. Since potassium is primarily intracellular, its determination would give a quantitative estimate of the body cell mass, provided its intracellular concentration is known. A typical 70 kg man contains about 140 g K with *ca* 3710 Bq of ^{40}K (Chao-Yeh Lan, 1989). As only 11% of the total disintegration results in the emission of 1.46 MeV γ-photons, a typical adult emits about 2.4×10^4 γ-photons per minute. Since potassium is primarily intracellular, the measurement of these γ-photons by external counting provides a method of total body K and ^{40}K estimation. The difficulties inherent in accurately measuring the potassium content of the human body have been reported earlier (Miller and Remenchit, 1963) and are generally related to the whole body counting system calibration factors. These factors mainly depend on the internal absorption and scattering of gamma-rays in subjects of different body size and shape as compared to calibration standards. They depend also on the geometrical dimensions of the subject for which whole-body counting is performed. However, many authors (Mitra *et al.*, 1989; Boddy *et al.*, 1971; Hawkins and Goode, 1976, Hughes and Williams, 1967) have assessed the sensitivity of whole body measuring systems for TBK using a reference man calibration phantom "by International Commission on Radiological Protection", ignoring the variance of the different subjects' geometrical sizes from that of the fitted standard man phantom. Mitra (1989) presented a detailed study on the calibration of a shadow shield whole body counter using two large detectors (up and down) with a mobile scanning bed for potassium. In the present article we followed a quite different technique for estimating K in subjects. Prediction of potassium calibration sensitivity using a stationary scanning chair is the concern of the present work. The calibration procedure also accounts for the deviation of the body size geometry from the committed reference man. Further, measurements of the TBK level in some selected examples of Nuclear Research Center (N.R.C.) occupational users (who work directly in the radiation laboratory) and non-users will be discussed.

2. Experimental

The whole-body counter used for measurements consists of a NaI(Tl) crystal (20 cm diameter × 10 cm thick). The whole-body scanning system used is the stationary chair geometry. The equipment was designed at the protection department of Nuclear Research Center at Inshas, Cairo, Egypt. The detector is fixed along the interior roof of a pre-1945 steel room of 240 cm long × 240 cm width × 195 cm high. The inside wall of the steel room is also bounded with 0.1 cm thick special sheets of low activity Pb shield in

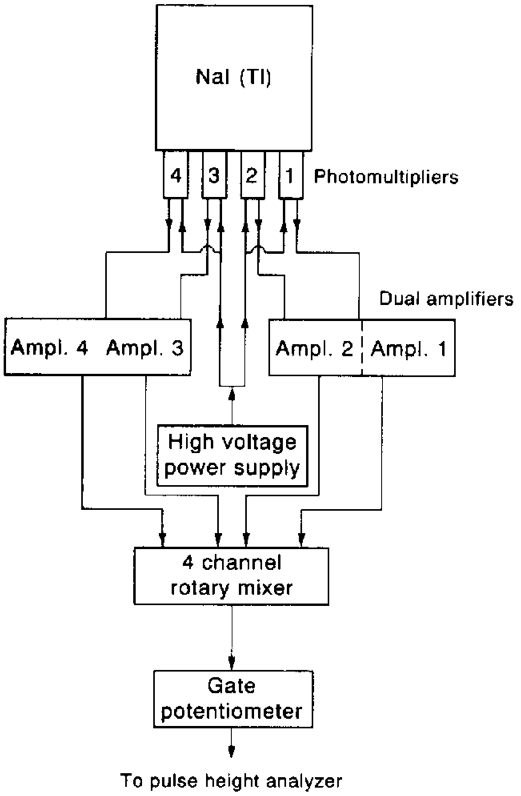

Fig. 1. Schematic diagram of whole body counting system.

order to reduce the side effects of environmental natural background on the detector. Figure 1 shows the general arrangement of the electronics. The four photomultipliers are supplied from a single high voltage power unit and the output from each is fed into two dual spectroscopic amplifiers. The output pulses of these amplifiers are further mixed using a four channel rotary mixer. The single output pulse is fed through a gate amplifier to an 8 K channel pulse height analyzer coupled to a computer system. The net counts are used for the determination of the total body potassium. To reduce the variable ^{40}K background, a similar humans phantom filled with distilled water was used before and after the subject measurement for 1 h. The daily average count-rate of the background level in the region of interest of potassium is found to be about 3000 ± 55 count h^{-1}. The electronic stability of the counting system was checked daily by using reference sources of ^{40}K, ^{60}Co and ^{137}Cs, and was found to be $<3.4\%$ for potassium and 1–2% for the other sources.

The whole body counting system is calibrated using the ^{40}K gamma rays from an aqueous solution containing different known concentrations of KCl. Several polyethylene bottles of identical dimensions were used for this purpose and were stacked close to each other to form the centrifugation shape of the committed reference man assembly phantom. A correction was also made for the changing of the phantom size.

The calibration sensitivity of the whole-body counter can be predicted using the following simple formula

$$X = AB$$

where: A represents the potassium activity in counts/g h for the committed reference man assembly phantom and B is a correction factor for the deviation of the body size from the fitted standard reference man size (30000 cc).

3. Results and Discussion

Figure 2 presents a linear plot of the measured counting activity of K against concentration for committed reference man phantom. The fitted line is a least square fit to the data using the formula

$$y = 31.799x - 0.1307 \text{ C/h}.$$

The calculated average counts per gram (A) is equal to 31.7 ± 2.5 C/g h.

The calibration scans were performed in the same way as those adopted for subjects regarding the body size. Furthermore, the Egyptian subjects are assumed to have the following specifications: width (22–40 cm), anterior posterior thickness (9–25 cm) and height (145–190 cm). The present whole body measurements using the chair geometry only scan the most condensed part of the humans (covering a volume extending from the neck down to the knees). Hence forth, a correction has been made for the deviation of the body size from the fitted standard reference man size. The phantoms are so constructed of widths varied between 22 and 40, anterior posterior thicknesses between 9 and 25 cm. The height of the phantom extending from the neck down to the knees varied between 85 and 130 cm.

Figure 3 shows the variation of the relative correction factor with the deviation of body size (volume index). It can be seen that the observed relative

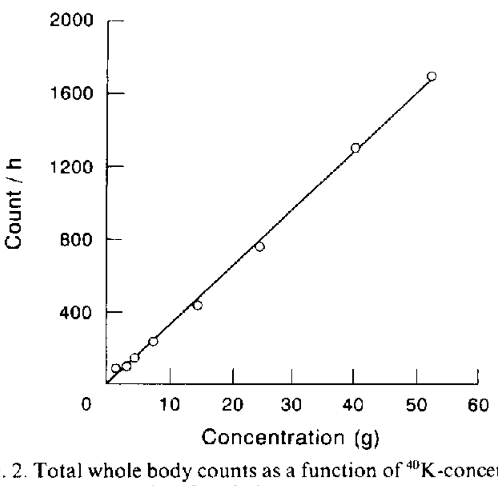

Fig. 2. Total whole body counts as a function of ^{40}K-concentration for chair geometry.

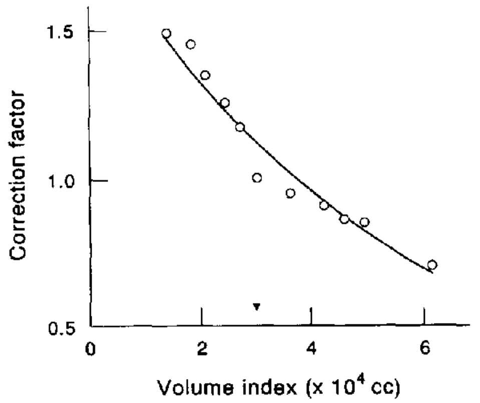

Fig. 3. Correction factor of body size.

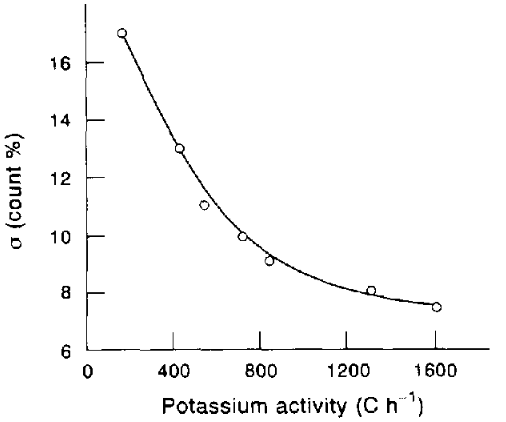

Fig. 4. Rate of change of ^{40}K activity as a function of experimental errors in the calibration sensitivity.

correction factor has an exponential form which can be predicted using the formula

$$B = 1.84\exp(-0.16x)$$

as indicated by the solid exponential line.

The minimum detected limit of the whole body counting system for ^{40}K was found to be in the range of 225 counts per hour which is equivalent to 10 ± 2 g of K $\simeq 265 \pm 53$ Bq per hour, beyond the measured values of background.

Figure 4 shows the estimated overall experimental statistical error σ in the calibration sensitivity X as a function of K activity in counts h^{-1}, which includes errors due to statistics of counting in the calibration, spectral shift and analytical errors in the fit. The background activity between scans has also been monitored to detect the occurrence of spectral shifts. The error due to background is found to be about 8% which consists of the daily background instability and the counting statistical errors.

An interlaboratory comparison of TBK has been made for about 120 occupational users and nonusers of the Egyptian N.R.C. for both sexes. TBK for these subjects were obtained from the equation: TBK (g) $= M/X$, where M is the ^{40}K counts per hour from the subject and X is the observed calibration sensitivity (C/g h). Errors involved in the estimation of TBK arise from the statistical error from counting the subject and from errors in the fitting of calibration data. The overall error in TBK has been determined to be 20%. The potassium values for subjects of both sexes as a function of body weight are shown in both Fig. 5 and Table 1. The results of TBK estimation showed an average K body burden values of

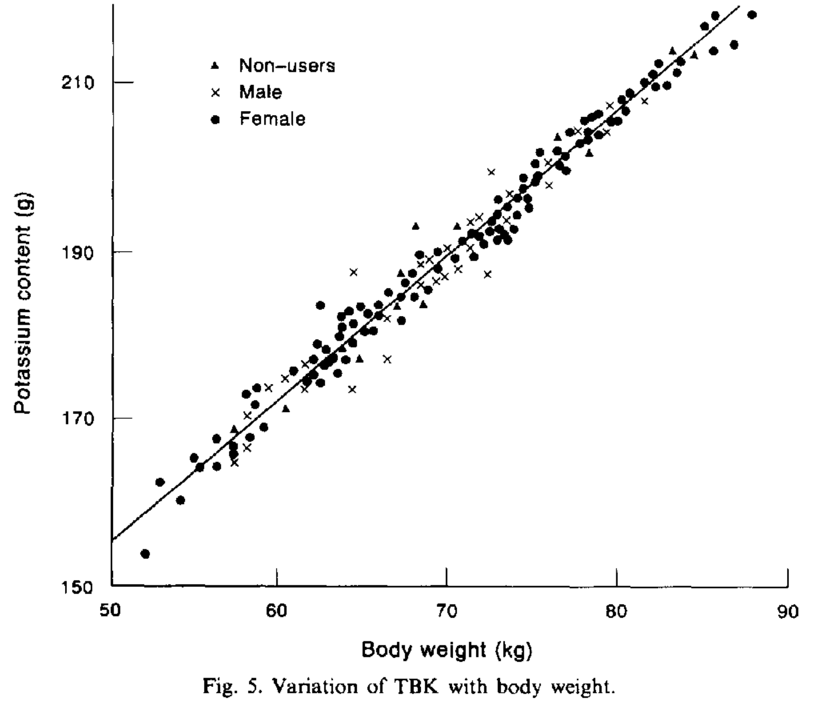

Fig. 5. Variation of TBK with body weight.

Table 1. Examples of measured body counting radioassay for composite sex-specific

Employment status	Sex type	Total No.	K body burden g K kg^{-1}	K body burden g K/1000 cc**
> 1 y*	Male	20	2.10–2.82	4.69–5.10
	Female		1.89–2.69	3.96–4.70
1–5 y	Male	10	2.35–2.99	4.86–4.84
	Female		2.12–2.67	4.25–5.06
5–10 y	Male	8	2.17–2.81	4.46–5.31
	Female		2.40–2.87	4.65–4.97
10–15 y	Male	20	2.41–2.94	4.72–5.62
	Female		2.29–2.86	4.34–4.82
15–20 y	Male	25	2.20–2.57	4.46–4.93
	Female		1.98–2.68	4.37–4.72
20–25 y	Male	25	2.50–3.21	4.75–5.36
	Female		2.10–2.60	4.57–5.12

*Non-users.
**Index volume of chest, abdomen and jointed part of upper legs.

2.85 ± 0.57 g K kg^{-1} for males and 2.62 ± 0.52 g K kg^{-1} for females while for nonuser subjects the value was found to be 2.69 ± 0.54 g K kg^{-1} for males and 2.38 ± 0.47 g K kg^{-1} for females. This is significantly higher than the value of 2.0 g K kg^{-1} given for reference man (ICRP, 1974). The solid line represents the average fitted potassium content in male and female subjects which can be predicted using the empirical formula

$$y = 1.75x + 67.4 \text{ g}.$$

In Fig. 6, the estimated values of total body potassium are plotted against $(W/H)^{1/2}$, where W is the weight (kg) of the subject and H is the height (m). The parameter (W/H) was chosen because it represents the average body thickness and thus has been accepted as a body-build index (Gupta *et al.*, 1976). The graph indicates that the potassium content increases with body-build index, but is slightly sex dependent. The solid lines of the fitted anomalous behavior of the potassium content can be deduced from the following regression formulas

$$y = 11.03x + 120 \text{ g for males},$$

and

$$y = 8.50x + 128.4 \text{ g for females}.$$

Mostly, data of Figs 5 and 6 showed a scattered and statistical distribution of the potassium content. This may be ascribed to the nonuniformity of the subjects' relative heights with respect to the fitted weight. However, the whole body counting system using the chair geometry is mainly confined to scanning the most condensed region of each human subject (80% of the total body weight). For this reason it is reasonable to predict the relation between the fitted volume of the subject (from neck to knees) and the total body potassium activity. The results shown in Fig. 7 reflect that relation. The data show a less statistically scattered distribution in the experimentally measured TBK with the change of body volume index. The average body burden potassium can be calculated from the fitted results using the formulas:

$$y = 11.7(10^{-4})x + 131.7 \text{ g/cc for males}$$

and

$$y = 7.8(10^{-4})x + 141.7 \text{ g/cc for females}.$$

The experimentally deduced activity of TBK according to Figs 5, 6 and 7 is relatively higher than the value recommended by ICRP, i.e. in our experimental observations it is found to be an average of 2.65 ± 0.53 g K kg^{-1} while the ICRP recommended value is about 2.0 g K kg^{-1}. This may be attributed to the nature of the food eaten by Egyptians, which may contain different orders of potassium activity. Prediction of the potassium in human beings due to different diets are within the scope of our study and will be published later.

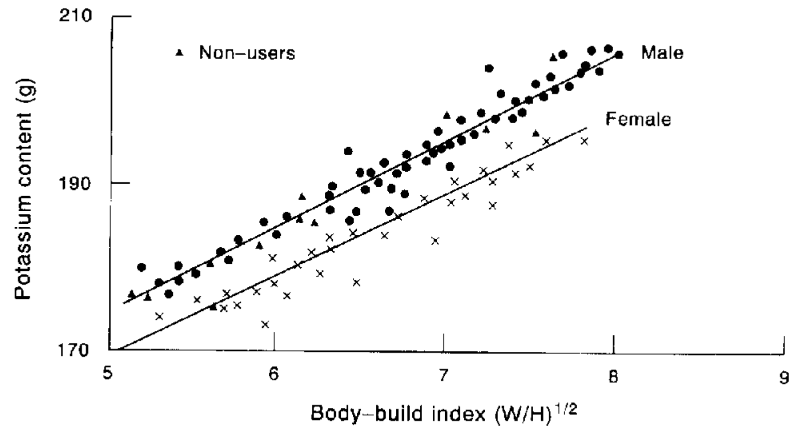

Fig. 6. Variation of TBK with body-build index $(W/H)^{1/2}$.

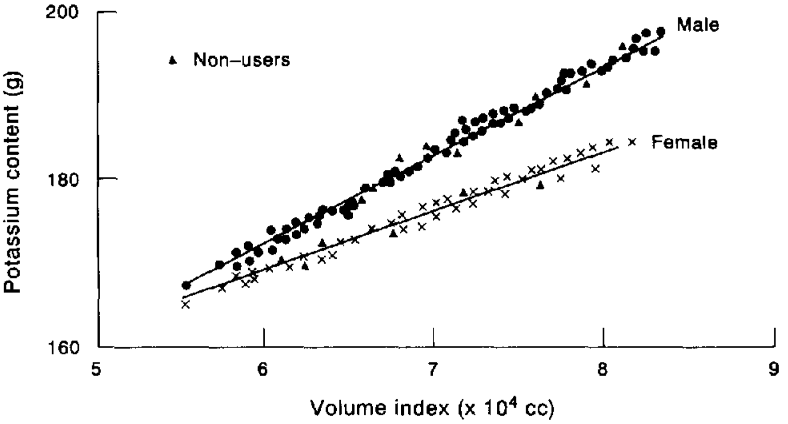

Fig. 7. Variation of TBK with volume index of neck up to knees.

4. Conclusion

The present calibration technique allows determination of TBK from observed subject counts taking into consideration correction parameters due to body size. We believe that our simple calibration procedure and use of the whole body counter system might be useful in the future to other investigators confronted with similar situations. The authors re-emphasized the importance of the periodic measurement of the activity level of TBK in humans even though the radiation dose is expected to be within the recommended level.

Acknowledgement—The authors are greatly indebted to Professor M. A. Gomaa, Head of the Radiation Protection Department (N.R.C.) of the Egyptian Atomic Energy Establishment, for his valuable discussions.

References

Boddy K., King P. C., Tothill P. and Strong J. A. (1971) Measurement of total body potassium with a shadow shield whole-body counter: Calibration and errors. *Phys. Med. Biol.* **16,** 275.

Chao-Yeh Lan (1989) Body K and ^{40}K in Chinese subjects measured with a whole-body counter. *Health Phys.* **57,** 743.

Gupta M. M., Bhola G. C. and Gupta N. K. (1976) Body potassium measurement by ^{40}K gamma ray spectrometry. *Med. J. Armed Forces India* **32,** 557.

Hawkins T. and Goode A. W. (1976) The determination of total-body potassium using a whole-body monitor. *Phys. Med. Biol.* **21,** 293.

Hughes D. and Williams R. E. (1967), The calibration of a whole-body radioactivity counter for the measurement of body potassium content in clinical studies. *Clin. Sci.* **32,** 495.

International Commission on Radiological Protection (ICRP) (1974) *Reference Man*. ICRP Publication 23. Pergamon Press, Oxford.

Miller C. E. and Remenchik A. P. (1963) Problems involved in accurately measuring the K content of the human body. *Ann. NY Acad. Sci.* **110,** 175.

Mitra S., Sutcliffe J. F. and Hill G. L. (1989) A simple calibration of a shadow shield counter for the measurement of total body potassium in critically ill patients. *Phys. Med. Biol.* **34,** 61.

Moore F. D. and Boyden C. M. (1963), Body cell mass and limits of hydration of the fat-free body: their relation to estimated skeletal weight. *Ann. NY Acad. Sci.* **110,** 62.