Defence Science Journal, Vol 44, No 1, January 1994, pp 15-19


# Whole Body Counters in Biomedical Research*

S.C. Jain

*Institute of Nuclear Medicine & Allied Sciences, Delhi-110 054*

**ABSTRACT**

Whole body counter plays an important role in medical diagnosis and clinical research. It has been used for monitoring of radiation workers for the assessment of internal contamination or assessment of activity in persons exposed to radiation fallout. In a nuclear emergency like Chernobyl, neutron exposure to the radiation victims was assessed by measuring the induced activity of $^{24}Na$. Apart from its use in determining certain element composition in the body, it has got a number of clinical applications like absorption tests, and metabolic and kinetic studies. The work done at INMAS whole body counter facility is also discussed.

## 1. INTRODUCTION

The whole body counter is a device intended to measure minute quantities of radioactivity in human subjects. The first generation of whole body counters were built in the 1930s to assess internal contamination in occupationally exposed groups. The sensitivity, precision and accuracy of present day systems permit the measurement of radioactive contamination at levels far below the limits set by International Commission on Radiological Protection (ICRP). Although whole body counting was basically developed for radiological protection, its potentialities in the field of clinical and biomedical research were soon realised, in particular, for turnover studies in health and disease using minute quantities of radiotracers. In fact, around 75 per cent of the existing whole body counters of the world are being used wholly or partially for clinical research.

The first whole body counter was installed in 1949 by RM Sievert[1] in Sweden. He could measure the body burden of naturally-occurring radionuclides, using four large volume high pressure ionisation chambers surrounding the subject. Such a system was placed in a cave under 55 m rock to reduce background with water providing additional shield. With advancement of instrumentation, newer techniques were developed, which include surrounding the subject with liquid scintillator or plastic scintillator fitted with photomultiplier tubes. The most prevalent system uses an array of sodium iodide detectors with the subject lying horizontal. Other improved designs are shadow-shield whole body counter and scanning bed whole body counter.

## 2 COMPONENTS OF WHOLE BODY COUNTER

The main components of the whole body counting system are the detector, the shielding, the associated electronics and subject-detector geometry. Ideally a whole body counter should be able to detect, identify and measure minute quantity of radioactivity and its response should depend only on the quantity and not on the distribution of the radioactivity within the subject.

### 2.1 Detectors

The detectors at present in use include both inorganic and organic scintillators. Organic scintillators (plastic as well as liquid) offer the advantage of high sensitivity, low cost and nearly $4\pi$ geometry. But they

Received 3 August 1993

* Invited paper for the DSJ Special Issue on Biomedical Engineering (July 1993)

have poor energy resolution which makes them comparatively unsuitable in multiple tracer studies and identification of unknown radioisotopes. Inorganic scintillators, *NaI(Tl)* in particular, are largely used for whole body counting due to their excellent energy resolution. The efficiency of these scintillators increases with the size of the crystal. For single detector systems, 20.4 cm dia and 10.2 cm thick size is best suited. In a multiple detectors system, 12.5 cm dia and 10.2 cm thick crystals seem to be preferable with practical considerations of size and related cost. There are other types of detectors in use for special purposes. Thin window proportional counter and Phoswich detector system (*NaI(Tl)* crystal sandwiched to a *CsI(Tl)* crystal in anticoincidence to reduce the background) find applications for low energy gamma and x-radiation[2].

### 2.2 Shielding

Since the levels of radioactivity to be measured are very low, the high sensitivity detectors must be shielded from the cosmic and terrestrial radiation or from residual radioactivity in the immediate environment. It is interesting to note that the total natural gamma activity of an adult man (chiefly *K*-40) is about $10^{-3}$ Bq/g while the natural radioactivity of ordinary soil and rock is one to two orders of magnitude higher. Steel is most commonly used as shielding material, but lead, water, concrete and chalk have also been used. The background in a steel room with walls of optimal thickness (15 to 20 cm of steel) reduces to less than 5 per cent of that in unshielded enclosure. Thin lead, cadmium or copper linings can be used to further reduce the low energy component of the background. A shadow shield system, in which only the detectors are shielded locally with lead, can be a good alternative if one wants to cut down the costs. Such shielding is carefully designed so that no background radiation reaches the detectors without passing through the shielding and is adequate enough for most of the clinical studies and medical research. It is essential that all materials to be used in whole body counter room have to be vigorously checked for their intrinsic activity.

### 2.3 Detector-Subject Geometry

A detector-to-body geometry should be such that the response of the detector is not significantly affected by the distribution of the radioisotope within the body. At the same time, the efficiency of the counting should be optimized to be the maximum. The main geometries using *NaI(Tl)* detector for whole body counting are: (i) arc geometry, (ii) chair geometry, and (iii) bed geometry with an array of fixed detectors[3]. The bed geometry with multi-*NaI(Tl)* detector system are largely employed in various centres. In this geometry, the subject lies in a horizontal bed with several detectors above and below him (Fig. 1). The detectors are

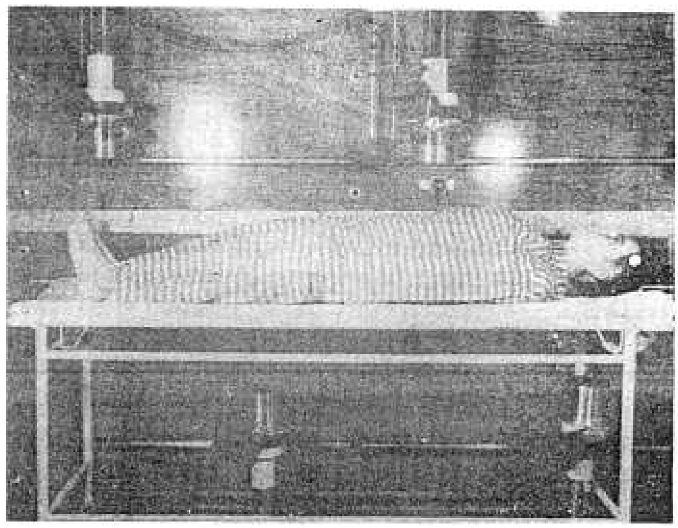

**Figure 1. Counting geometry of INMAS whole body counter.**

arranged such that the response is nearly independent of radioactivity distribution[4]. The calibration of multidetector system is slightly complex and problems of matching the response of different crystals to give identical spectral positions have to be tackled. With the advent of more sophisticated multichannel analyser systems, the problem of matching the response of the different crystals has become a bit easier. Another popular counting geometry is scanning bed geometry, in which one detector (or two detectors, one above and one beneath the subject) scans the length of the body giving a uniform response. In such a fixed detector system, also known as shadow shield geometry, shielded room is not necessary and the detector is collimated with a shield such that any direct pathway for external radiation to the crystal is cut out. About a dozen such systems are operational with the Department of Atomic Energy in India and these are mainly used for internal monitoring of radiation workers[5].

## 3. APPLICATIONS IN BIOMEDICAL RESEARCH

The popularity of the whole body counters as a tool in clinical diagnosis and medical research stems largely from the relative ease of measurement, the speed of determination and the accuracy of the results. Since the amount of radiotracer administered is very small, long term studies are possible even in radio-sensitive groups. The clinical applications can be divided into three groups: absorption tests, metabolic studies and kinetic studies. The intestinal absorption of various elements, compounds, proteins, vitamins and nutrients can be easily measured by incorporating suitable radioactive labels in the components of interest. After oral administration of labelled components, the person is counted in a whole body counter. Again after elapse of one week or so, the activity in the person is measured and compared with the initial value to give the percentage absorption. Iron absorption has been extensively studied from a large number of foods and in various clinical conditions. For example, 5 to 15 per cent of an oral labelled ferrous citrate is absorbed in normal humans and an increased absorption is found in patients with polycythemia and iron deficiency anaemia. Patients with pernicious anaemia have a higher absorption of radiolabelled Vitamin $B_{12}$.

The metabolic behaviour of various elements, compounds, proteins and hormones have been studied by whole body counting. $^{51}Cr$ labelled RBC's have been used for measurement of blood loss. The retention of $^{131}I$ in thyroid cancer patients with ablated thyroid has been a useful diagnostic tool for diagnosis of residual metastases[6]. The natural content of certain elements like *Na, Cl, Ca* in the human body can be estimated by subjecting the subject to a flux of neutrons. The induced radioactivity in the subjects is compared to an irradiated humanoid phantom containing a known amount of element to give the actual content of element in the body.

The total body potassium can be easily estimated by whole body counting. Potassium contains 0.0118 per cent $^{40}K$ which is a beta-gamma emitter, the gamma ray energy of 1.46 MeV is suitable for external *in-vivo* counting. By quantitating the $^{40}K$ activity in a subject and comparing with humanoid phantom studies, the body content of naturally occurring potassium can be obtained. Changes in body potassium levels are of relevance in muscular diseases, chronic illness or long term treatment with kaliuratic agents such as steroids or diuretics[7]. The measurement of total body potassium is used to estimate lean tissue degradation or its synthesis.

## 4. APPLICATIONS IN RADIOLOGICAL PROTECTION

In nuclear industry and research with radiotracers, the hazards of internal contamination of the workers is ever present and the whole body counter is accepted to be the most suitable monitoring device. Historically, R.D. Evans measured whole body radioactivity in persons with Geiger-Muller tubes and could detect upto 1 microgram of radium. It can also be used for monitoring the personnel who might be subjected to internal radioactive contamination in the event of fallout from a nuclear weapon burst. Figure 2 demonstrates the capability of the system to detect 1 nCi of $^{137}Cs$ along with $^{40}K$ from natural potassium. For monitoring of the radiation workers, it is important to identify the radioactive contaminant as well as its activity. This criteria is best met by having two *NaI(Tl)* detectors with a slit collimator and a moving stretcher-bed geometry with shadow shield configuration. Such a system can measure whole-body radioactivity as well as provide estimates of its spatial distribution[5,8]. The information on spatial distribution can be of help in estimating internal dose as well as in medical management of such contamination. It can also be used to know the extent of neutron exposure by monitoring the induced activity of certain elements like *Na* as was done in Chernobyl victims[9]. The hospital staff handling Chernobyl victims were evaluated periodically with whole body counter to rule out internal contamination in them.

## 5. WORK CARRIED OUT AT INMAS

At the Institute of Nuclear Medicine & Allied Sciences (INMAS), an advanced whole body counter[10] is functional since 1972. It consists of four *NaI(Tl)* 12.5 × 10.2 cm cylindrical crystal detectors, two above the subject's couch at a height of 47 cm and two below at a distance of 25 cm with horizontal separation of 100 cm. The system is located in a 20 cm old steel shielded enclosure (Fig. 1). This placement of the detectors ensures the variation in the combined response of the detectors which is less than 10 per cent, whether the activity is in the form of point source or uniformly *distributed in a child, adolescent or an adult.*

Efforts were made to have physiological norms for Indian population. Body potassium measurements were carried out in about 400 subjects[11]. Figure 2 depicts the gamma-ray spectrum from a subject showing a peak of

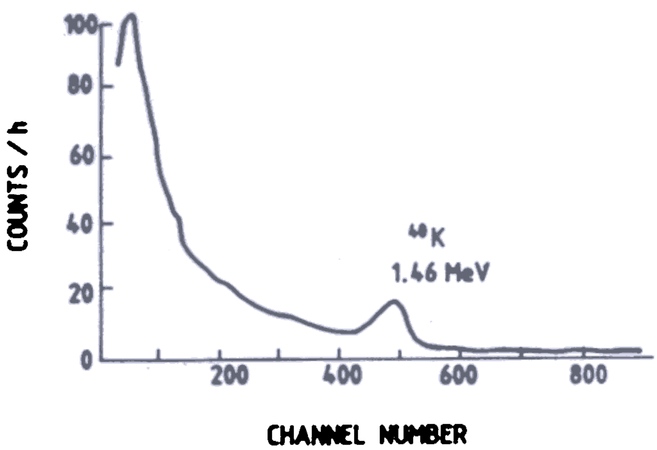


Figure 2. Gamma-ray spectrum showing body potassium from a healthy subject.

$^{40}K$. Total body potassium levels were calculated as a function of sex, age, weight, height and food habits. Total body potassium was measured in patients with thyrotoxicosis, iron deficiency, Vitamin $B_{12}$ deficiency, myopathy and nephrotic syndrome. Only in case of myopathy, moderate depression of total body potassium was absorbed.

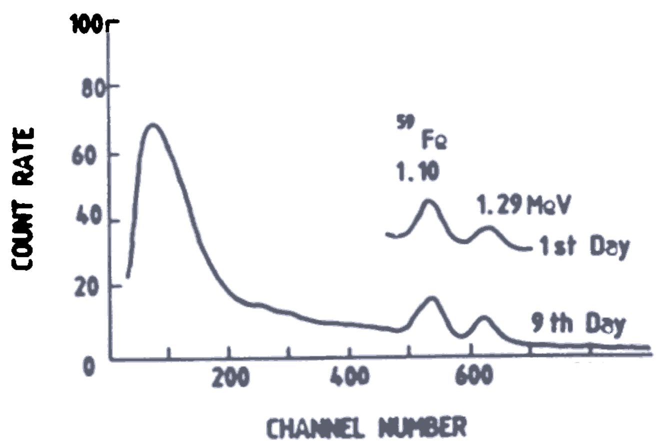


Figure 3. Gamma-ray spectrum of a subject showing the retention of $^{59}Fe$ in the body.

The system has also been used for studying absorption of Vitamin $B_{12}$ and iron[12]. Recently, iron absorption studies using *Fe*-59 were done on workers engaged in fabrication of *Ga-As* devices. The subject was studied thirty minutes after oral administration of 1 $\mu$Ci of $^{59}Fe$ and again on 9th day (Fig. 3). The system was also used to study the effects of irradiation on animals. No hemorrhagic loss[13] was observed in rabbits exposed to 4 Gy gamma irradiation as shown by sequential whole body counting of rabbits injected with $^{59}Fe$ earlier.

The whole body counter at INMAS will be of use in a nuclear emergency to identify and quantify the internal contamination. A mobile whole body counter having a single *NaI(Tl)* crystal of size 12.5 × 10.2 cm in a 5 cm steel shielding may be used to assess the extent of internal contamination under field conditions and also as support facility for clinical diagnosis in far off centres. Mobile whole body counters are being used in advanced countries to assess the potassium levels in their population apart from its easy accessibility in the event of nuclear emergency.

## ACKNOWLEDGEMENTS

The author is indebted to Prof VK Jain, Director, INMAS, for suggesting the topic and many useful suggestions and support. Thanks are also due to Shri GC Bhola and Shri RK Rawal for their help.

## REFERENCES


1. Spiers, W. Whole-body counting : An introductory review. *In* Proceedings of the Whole Body Counting. IAEA, Vienna, 1962.
2. Palmer, H.E.; Rieksts, G.A.; Jefferies, S.J. & Gunston, K.J. Improved counting efficiency for measuring $^{239}Pu$ in the lung in the sitting position. *Health Phys.*, 1989, **57**, 747-52.
3. Trott, N.G. & Cottrall, M.F. Multiple-crystal systems for whole body counting. *In* Proceedings of the Clinical Uses of Whole Body Counting. IAEA, Vienna, 1965. pp. 161-66.
4. Oliver, R. & Warner, G.T. Some factors affecting spatial uniformity of response in whole body counters. *Br. J. Radiol.*, 1966, **39**, 554-56.
5. Mehta, D.J.; Katoch, D.S.; Dhandayutham, R. & Sharma, R.C. Intercomparison of whole-body monitors in India. *Bull. Radiat. Prot.*, 1993, **15**, 35-39.
6. Oddie, T.H. Clinical applications of whole body radioiodine counting. *In* Proceedings of the Clinical Uses of Whole Body Counting. IAEA, 1965. pp. 228-40.
7. Blahd, W.H.; Cassen, B.; Lederer, M. & Drenick, E.J. Electrolyte metabolism by whole body counting techniques with particular reference to muscular disease and obesity. *In* Proceedings of the Clinical Uses of Whole Body Counting. IAEA, Vienna, 1965. pp. 169-86.

8 Novario, R. & Conte, L. A new method for calculating the distribution of radioactivity in man measured in a whole body counter. *Health Physics*, 1990, **58**, 597-607.

9 Bonte, F.J. Chernobyl restropestive. *Seminars in Nucl. Med.*, 1988, **18**, 16-24.

10. Kapoor, K.K.; Gupta, M.M.; Jain, S.C.; Bhola, G.C.; Ray, N.K.; Rao, G.S.V.B.; Gupta, N.K. & Nagaratnam, A. Design and performance of INMAS Whole Body Counter. *Def. Sci. J.*, 1974, **24**, 91-96.

11 Gupta, M.M.; Gupta, N.K.; Bhola, G.C. & Nagaratnam, A. Preliminary studies of body potassium in normal adults by whole body counter. *Ind. J. Med. Res.*, 1973, **61**, 1507-12.

12 Gupta, N.K.; Bhola, G.C.; Gupta, S.; Kalra, K. & Gupta, M.M. Absorption studies of iron and Vitamin $B_{12}$ by INMAS Whole Body Counter. *Ind. J. Med. Res.*, 1973, **61**, 105-08.

13. Jain, S.C. & Bhola, G.C. Plasma iron clearance on sublethal irradiation. Paper presented in the First Annual Conference of Indian Society for Radiation Biology, Delhi, 1991. (abstract).