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Applications of a Novel Whole Body Counter in Radiation Protection and Human Body Composition Studies

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Abstract

A prototype shadow-shield whole body counter was designed, constructed and tested as a radiation protection, medical and research tool, such as in *in vivo* human body composition and in occupational exposure studies. In the present study potential fields of application of a prototype whole body counter were investigated carrying out measurements in groups of adult volunteers. Among others, the naturally occurring ^{40}K and ^{214}Bi whole body radioactivity was assessed. The activity of the former was correlated with the amount of the total body potassium, a quantity related to both cell mass and lean mass in the human body. Increased ^{214}Bi levels found in two subjects was attributed to radium intake by ingestion. Patients were found contaminated with long lived radionuclides after administration of radiopharmaceutical of short half-life, administered for either diagnosis or treatment. Among the radiation workers monitored for internal occupational exposure, two were found contaminated with small amounts of $^{99\text{m}}\text{Tc}$.

Key words: Whole body counter, radiation protection, ^{40}K , internal contamination, occupational exposure

1. Introduction

Whole body counting refers in Health Physics and Medicine as the main method for the *in vivo* measurement of radioactivity within the entire body at the time of measurement (the term whole body counting is often also loosely applied to any measurement of accumulated radioactivity in specific organs or regions, such as the lungs, thyroid, skull and hands). The first generation of whole body counters (WBC) was built to assess internal contamination in occupationally exposed groups (the first measurements were performed around 1925 on radium dial painters). Nowadays, the technique allows rapid and accurate detection and quantification of internally deposited radionuclides and elemental analysis of human body.

Whole body counting is applicable to radionuclides emitting β^+ , X and γ -radiation, although in certain circumstances β^- emitters can be also measured. Whole body counters (WBC) consist of detectors, shielding and data processing and analysis units. The accuracy of the activity measurements depends on several parameters, such as the interaction characteristics of the human body with the radiation and the variations in the geometry of the source relative to one or more detectors. Therefore, optimum design and use of WBCs require the evaluation of many different and often competing performance parameters, such as detection sensitivity (related to counting efficiency and background signal) and uniformity in spatial response.

A prototype shadow-shield whole body counter was designed, constructed and tested at the University of Ioannina Medical Physics Laboratory (UIMPL) as a direct monitor of internal contamination and as a tool in clinical research [1]. The counter is

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an upgraded version of a counter in use since 1986, that was equipped with two NaI(Tl) detectors [2]. The set-up of the upgraded counter consists of sixteen cylindrical NaI(Tl) detectors located at the central region of a shielded tunnel with 210 cm x 60 cm x 49 dimensions, made of lead bricks and 2.0 cm- thick pre-world-war II iron plates. Fourteen detectors with nominal active diameter and height of 15 and 5 cm, respectively, are arranged in two arrays of seven detectors each, above or below the subject to be scanned with a constant bed velocity and two detectors, 29 cm x 10 cm, placed laterally at the central region of the 2.1 m-long shielding tunnel. The signal for each detector is acquired and analyzed using a 16 multichannel buffer and the MAESTRO 32 MCA emulation software. The counting room is ventilated for the reduction of airborne radioactivity levels by forced insertion of outdoor air in the room [3]. Bottles, made of high density polyethylene and filled with aqueous solution of known specific radioactivity, were used to assess the background signal and validate the predictions Monte Carlo simulations carried out using the MCNP5 simulation code [4].

The scope of the this study was to present some of the applications of the upgraded WBC during the first year of its use, i.e., *in vivo* quantification of potassium, detection of internal contamination in patients and general public, as well as monitoring of workers that handle unsealed radioactive sources.

2. Potassium and ^{214}Bi measurements

Potassium-40, a long-lived nuclide that emits 1.46 MeV γ -rays, is the most abundant naturally occurring γ -emitter present in the human body. The measurement of its activity allows the assessment of the amount of potassium in the entire body (TBK), based on the detection of the γ -rays emitted with a mean rate of 3.31 s^{-1} per g of K. Potassium is an essential element for vital processes, such as propagation of nerve pulses and muscular contraction. Potassium is mainly found inside living cells and practically absent in adipose tissue and thus TBK is correlated with total body cell [5] and lean mass [6]. Moreover, TBK concentration is reduced in some diseases, such as obesity, end-stage renal failure, myopathy and some degenerative diseases, such as cancer and AIDS. Bismuth-214, a ^{222}Rn product, is present in human body mainly due the retention of radon and its decay products, taken-up mainly *via* inhalation of air and ingestion of tap water.

During the study period TBK was measured in 20 male and 24 female volunteers, aged 20 to 74 years (mean age 34.0 years) with body mass index ranging between 18 and 37 kg m^{-2} (mean value 25.8 kg m^{-2}). TBK decreased in the studied group of 20 healthy females with increasing age (a finding related among others with the gradual reduction in estrogen production, leading to increase in adiposity). In addition, TBK concentration was about 20% lower in healthy women aged 20 to 27 y than in men in the same age group, a finding consistent with the well known high adipose tissue concentration in females, i.e. a tissue with large fat content and low potassium concentration.

Successive measurements carried out mainly during winter time [7] showed ^{214}Bi body burden higher in male than in female subjects, 140 Bq and 90 Bq on the average, respectively and reduced by about 30% in both groups after a ~1 h-long stay in the counting room (radon concentration in the counting room was about 50% of the median indoor concentration in the region of Ioannina).

Contamination with ^{214}Bi was detected in two volunteers, 370 and 170 Bq, respectively, and their data was excluded from the previous analysis. The elevated activity in their body, assessed by three measurements to each of them, two successive and a third one after 10 days, was attributed mainly to ingestion for therapeutic reasons of about 8.5 and 3.5 l, respectively of mineral water from a thermal spring in Yalova, Turkey, known for its high radium concentration, over a 10 d period starting almost 1 month before their first counting. These findings coupled with relevant metabolic data allowed the estimation of their radiation burden, 3.2 and 1.4 mSv respectively, due to ingestion of water with high total mineral content. The additional effective dose due to inhalation during bathing in the spa center was not assessed, due to the limited radon effective half-life; however it was considered to be negligible compared to effective dose that due ingestion.

3. Contamination in patients following radiopharmaceutical administration

Specific production processes of radionuclides used in radiopharmaceutical industry may result in radioactive impurities. Depending on their physical and chemical properties in the end-product, such impurities can be taken-up and retained in the patient's body, resulting in energy deposition in his body and irradiation of those in his vicinity. Data on such two radiopharmaceuticals in use at Ioannina University Hospital (IUH) are presented.

The loss of dopaminoergic terminals in brain can be detected and quantified *in vivo* using the radiiodinated cocaine analogue, ^{123}I ioflupane (DaTSCAN[®]). Whole body counting was carried in two patients injected with 148 and 185 MBq of ^{123}I ioflupane 25 d post administration, i.e., after ~ 45 ^{123}I half-lives. Their bodies were found contaminated with ~ 2.0 and 2.5 kBq of the γ -emitter ^{121}Te , respectively, at a time about 1.3 ^{121}Te half-lives post administration. Spectroscopic analysis of the administration residues indicated the existence of ^{121}Te and ^{125}I impurities, radionuclides that decay with 19 d and 60 d half-lives (^{125}I decay by electron capture results in emission of photons of energy up to 35.5 keV greatly attenuated in the human body). The contaminants were produced during the target irradiation with medium energy protons and were incorporated in the commercial product [8].

Two patients with multiple bone metastatic disease treated for pain relief with ^{153}Sm -EDTMP (Quadramet[®]) were counted few weeks after ^{153}Sm administration, i.e. a radionuclide that decays with a half-life of 1.93 d. The detected whole body total activity with ^{152}Eu and ^{154}Eu was 80 kBq and 75 kBq, 14 and 21 d post administration respectively. Both long-lived isotopes ($T_{1/2}$: 13.6 and 8.6 y, respectively) were also detected by γ -spectroscopy in the treatment residues. Their presence in the end-product was attributed to contamination during ^{153}Sm production by thermal / epithermal neutron activation of ^{152}Sm targets [9] and the physical and chemical similarities of Eu and Sm. Therefore, they are taken-up and retained over long time, mainly in skeleton and osteoblastic metastatic sites.

Radioactive contaminants at such levels result in long-term irradiation not only of the patient, but also of his relatives, caregiver and general public in their vicinity and may cause "innocent alarms" in radiation monitors used for homeland security, such as at check points at airports and borders. Moreover, due to their presence, treatment residues and patients' excretions may require special management.

4. Occupational exposure

Workers handling radioactive substances in their daily activities are vulnerable to contamination. Among the radiation workers monitored for internal occupational exposure during the study period, two were found contaminated with 0.8 to 2 kBq of the short-lived ^{99m}Tc . The detected contamination was attributed to routine ^{99m}Tc administration processes at the IUH Nuclear Medicine Laboratory which had carried out earlier the same day by the two young medical doctors. The contamination level was low and was not detected by the routine radiation protection procedures applied in their laboratory.

5. Conclusions

Following the completion of construction and commissioning testing of the upgraded UIMPL multidetector shadow-shield counter, whole body radioactivity measurements were carried out covering broad areas of potential uses. The examples given demonstrated that the UIMPLWBC is an instrument that can support efficiently applications related to radiological safety, clinical practice and research.

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