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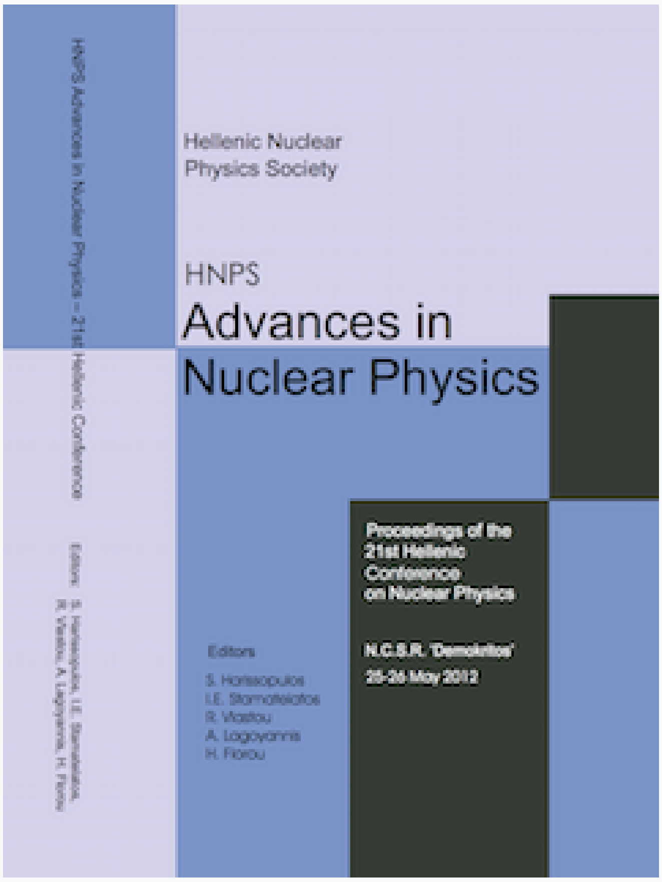

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Effect of Radon Concentration in Air on the Quality of Radioactivity Measurements in the Human Body

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Abstract

A prototype shadow-shield whole body counter is used at the University of Ioannina Medical Physics Laboratory as a tool in radiation protection and in biomedical research. In this study the effect of natural airborne radioactivity on the measurement quality features was investigated and performance improvements were developed. Radon air concentration in the counting room was assessed using electret and track detectors over short and long time periods, respectively under various ventilation conditions. A method based on the assessment of the ^{214}Bi 1.76 MeV spectral region was developed to correct for the interference of the radon products to the lower energies of the spectrum. Moreover airborne radioactivity in the counting room was controlled by forced ventilation. Double measurements were carried out in anthropomorphic phantoms and in adult volunteers to assess the impact of the room ventilation module in the measurement precision. Radon control coupled with corrections for the interference of its decay products improved substantially the counter performance characteristics.

Keyword: Whole body counter, precision, radon

1. Introduction

Whole Body Counters (WBC) are widely used for the detection and quantification of γ-emitting radionuclides retained in the body. A prototype shadow-shield WBC was designed and constructed at the University of Ioannina Medical Physics Laboratory (UIMPL) as a tool in radiation protection and biomedical research [1]. Fourteen cylindrical NaI(Tl) detectors with nominal active diameter and height 15 cm and 5 cm, respectively, were arranged above or below the subject to be scanned and two NaI(Tl) detectors, 29 cm by 10 cm, were placed laterally. The detectors were located at the central region of a 210 cm long shielding tunnel made of 10 cm thick lead bricks. The signal for each detector was acquired and analysed using a multichannel buffer and MCA emulation software. The counter is located in an air-conditioned room at the ground floor room (there is no basement) of the UIMPL building. The room is separated with a 70 cm thick concrete wall from two rooms, one for irradiations and one for source preparation and storage. The counting room is connected with two underground decay (holding) tanks with walls made of concrete (the tanks are used for the control of liquid discharges into the public sewage system).

Quality control tests carried out during WBC commissioning showed degraded measurement quality features in terms of inadequate precision values of radioactivity measurements carried out in either volunteers or in anthropomorphic phantoms made of polyethylene bottles filled with aqueous solutions. Parameters that could affect the quality of measurements were investigated, such as the function of WBC nuclear electronics [2] and the contribution of environmental radioactivity in

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the acquired spectrum [3]. In this study, the effect of temporal variations in radon (Rn) concentration in the air of the counting room on the quality of measurements was investigated and two correction methods are presented.

2. Experimental

Radon concentration assessment

The concentration of Rn decay products in the air of the counting room was assessed over short and long time periods using passive integrating detectors under natural and forced (pressurization) conditions [4]. More specifically, short-term ^{222}Rn concentration was assessed using E-PERM® electrets (ELECTRET, Rad Elec. Inc. Frederick, MD, USA). These detectors consist of a 1.5 mm - thick electrically charged and stabilized PTFE Teflon electret mounted inside a 210 cm^3 ion chamber in a plastic canister [5]. The voltage drop on the electret due to the production of ions in the chamber was assessed using a voltage reader.

The E-PERM® detectors were exposed at UIMPL over time periods ranging from 71 to 150 h during the period November 2011 to January 2012. Long term radon concentration was measured by CR-39 nuclear track detectors (polyallyl-diglycol carbonate) supplied by Track Analysis Ltd (Bristol, UK) in plastic holders developed by the Swedish Radiation Institute (SSI). Those measurements were carried out during a 3.5 month long period (November 2011- February 2012).

Correction methods

Two methods which aimed to reduce the effect of radon temporal variation on the measurements were developed and tested. First, two fans were installed in the counting room to facilitate the dilution of the counting room air and with outdoor air. Alternatively, the peak at the 1.76 MeV spectral regions (related to the ^{222}Rn product ^{214}Bi) was used to correct for the interference of the Rn products to the spectral shape at lower energies. These corrections were based on Monte Carlo simulations using the MCNP5 code and verified by experimental data obtained in phantoms [6].

Counter measurements

The precision of 2100 s - long ^{40}K measurements with constant scanning bed velocity was assessed by multiple measurements of anthropomorphic phantoms loaded with KCl and healthy volunteers under various air ventilation conditions of the room. Each measurement was coupled with a background measurement of identical duration. More specifically, multiple measurements were carried out over a 1 month-time period under natural air ventilation conditions in two humanoid phantoms loaded with either 90 or 140 g of K (the naturally occurring ^{40}K emits 1461 keV γ-rays).

Double total body potassium (TBK) measurements with repositioning in the scanning bed were conducted in groups of at least ten adults per group (body mass and height in the range 54 to 113 kg and 150 to 176 cm) under natural air ventilation conditions. Double TBK measurements were also carried out in a secondgroup of 50 adults of various body habitus (body mass and height in the range 50 to 120 kg and 150 to 190 cm, respectively) under forced ventilation conditions (1840 m^3/h fresh air intake, or 3300 m^3/h extract velocity) using two window exhaust/supply fans and sealed sink to eliminate radon entry from the delay tanks through the sink.

3. Results and discussion

The mean short-term radon concentration in the air of the counting room under forced ventilation (pressurization) and sealing of visible radon entry routes was 37 Bq/m^3 (the range of the measured concentrations at seven locations in the room was 34 to 41 Bq/m^3). On the other hand, the short-term radon concentration in the counting room under natural ventilation conditions and air recycle of the interior air by the air conditioner was much about nine times higher, 340 Bq/m^3. Measurements carried out in a similar naturally ventilated room at the first floor of the UIMPL building also connected with the underground decay tanks, just above the WBC room, indicated a 130 Bq/m^3 radon concentration during the same time period.

Long-term radon measurement under forced ventilation of the counting room with outdoor air indicated a mean 56 Bq/m^3 concentration in the air of the room (range 45 to 73 Bq/m^3 at five locations at 0.9 m height from the floor) and 77 Bq/m^3 inside the shielding tunnel between the two 29 cm x 10 cm NaI(Tl) detectors and the WBC tunnel internal walls (forced ventilation was turned-off over small time periods for safety reasons). Measurements in the two poorly ventilated adjacent rooms indicated a 77 Bq/m^3 radon concentration. Moreover, radon measurements during the same period carried out in the similar room at the first floor showed a 112 Bq/m^3 concentration under natural ventilation, while measurements in two other UIMPL rooms used as offices showed 62 Bq/m^3.

Twelve earlier measurements carried out under natural room ventilation over a 1-month period under stable meteorological conditions in a 71 kg/174 cm phantom loaded with 139 g of K showed improved long-term precision with no spectrum correction, of 3.7 g, [1]. However, twenty TBK measurements also carried out over another 1-month period also natural ventilation conditions, but under unstable meteorological conditions, in two humanoid phantoms loaded with either 92 g or 140 g of K respectively, indicated a long-term precision error (68.3%) of 7 g, which was reduced to 2.7 g applying corrections based on spectral shape. From the other hand, measurements carried out in a phantom loaded with 140 g of K under forced fresh air intake and unstable meteorological conditions indicated a precision error of 2.5 g of K, resulting in a 1.8% coefficient of variation of the potassium measurements.

Double measurements carried out in groups of at least ten adult volunteers per group under natural room ventilation conditions indicated a relative short-term precision error of the *in vivo* TBK measurements ranging from 3.0% to 6.5% (mean value 4.5%) depending on the meteorological conditions. Double TBK measurements in twelve adults with forced exhaust of air (reversed function of the fans) resulted in a 4.1% short-term precision error [7]. However, double TBK measurements carried out in 38 adults (20 male and18 female; mean age 34 y, range 20 to 74 y; mean TBK of 116 g, range 71 to 188 g) with forced entrance of fresh air in the room and sealing of visible radon entry routes in the room, resulted in a short-term 3.6 g precision error, or a 3.1% relative precision error.

4. Conclusions

Forced ventilation by insertion of fresh outdoor air in the counting room resulted in reduced indoor radon levels associated by reduction in the coefficient of variation of repeated measurements. Application of correction factors based on the spectral shape also decreased drastically the precision error. In conclusion, radon control and corrections for the interference of radon decay products improved substantially the performance characteristics of the counter.

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