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EURADOS ^{241}Am skull measurement intercomparison

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HIGHLIGHTS

- The results revealed some of the difficulties associated with the phantoms use.
- The results obtained show that it is necessary the fabrication of a new phantom.
- The participants validated their measurements and calibrations.
- This work contributed for the harmonization of skull measurements and calibration.

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ABSTRACT

In 2011 a measurement intercomparison was launched by EURADOS WG7, with the objective of providing the participants with the tools to calibrate their detection systems for detection of ^{241}Am in the skull bone, and evaluate the variability due to the used of the different calibration phantoms. Three skull phantoms were used in this intercomparison: the USTUR Case 0102 skull phantom, the BfS skull phantom and the CSR skull phantom. Very good agreement was found between the results of the twelve participating laboratories, with relative deviations of less than 15% for the BfS phantom and less than 17% for the USTUR phantom when measurement efficiency in defined positions was compared. However, the phantoms' measured absolute ^{241}Am activities showed discrepancies of up to a factor of 3.4. This is mainly due to the physical differences between the standard calibration phantoms used by the participants and those used in this intercomparison exercise.

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1. Introduction

“Bone-seeking” radionuclides are of special concern since on the long term they are incorporated into the bone matrix. More specifically, according to their biokinetics, these radionuclides could be divided in two categories, i.e., the “bone-volume seekers” and “bone-surface seekers”. ^{241}Am belongs to the latter one and, as other “bone-surface seeking” radionuclides which deposits on bone surfaces and thus irradiate osteocytes and also red bone marrow and because of its long physical (432.6 years) and biological half – life (46.6 years in the skeleton according model from ICRP-78 (1997), it has a high radiotoxicity It could be found in the environment following nuclear reprocessing, nuclear weapons test in atmosphere and major nuclear accidents. Moreover, it can be found in daily life objects such as smoke detectors.

^{241}Am can be detected and assessed by *in vivo* gamma monitoring of the lungs and/or the skeleton, usually through the 59.54 keV photons emitted with a high yield of 35.92% (Ferreux, 2008). Due to the low energy of these photons, detectors are usually arranged around and close to the surface of a certain body region, to increase the counting efficiency of the detection system. This procedure is called Partial Body Counting (PBC). Typical sites of the human body used are the lungs, the skull and the knees. The two latter counting regions are convenient due to the overlying thin soft tissue that absorbs a smaller fraction of the emitted low-energy photons compared to the thicker soft tissue covering the lung region, thus allowing for a higher detection efficiency.

PBC detection systems require efficiency calibration with anthropomorphic phantoms, which reproduce the shape and attenuation characteristics of the measured region of the human body and contain a known activity of the radionuclide of interest. For knee measurements, there are a number of commercial knee phantoms available, such as the Spitz knee phantom (Spitz and Lodwick, 2000). Such commercial phantoms for skull geometries do not exist. Currently, there are only a limited number of dedicated non-commercial skull phantoms available worldwide. Due to the uniqueness of each of these phantoms and due to the lack of a standardized manufacturing process, the calibration process of PBC detection systems and the activity estimation performed in different laboratories include large uncertainties. As it was observed by Rühm et al. (1998) the use of different skull phantoms for calibration resulted in differences of up to 60% between assessments in different laboratories.

The European Radiation Dosimetry Group (EURADOS) Working Group 7 (WG7) is acting as a network in the field of Internal Dosimetry for scientists, services, regulators, and laboratories whose main aims are harmonization, coordination of research, training, and dissemination of scientific knowledge in the field of the assessments of internal exposures due to intakes of radionuclides (Lopez et al., 2011; Lopez and Nogueira, 2012).

In 2011, a skull measurement intercomparison was launched by EURADOS WG7, with the objective of providing the participants with the tools to calibrate their detection system for skull counting geometries. The protocol of the exercise was designed to allow for the assessment of the measurement reproducibility of different laboratories. This required assessment of the ^{241}Am activity of different phantoms, to determine the capabilities of the PBC systems available in the frame of the EURADOS network. Parallel to this action a Monte Carlo exercise was launched, to evaluate and to promote the use of Monte Carlo methods for calibration of PBC systems.

There were 12 participants in this intercomparison: 10 from Europe – Helmholtz Centre Munich (HMGU, Germany), Federal Office for Radiation Protection (BfS, Germany), Karlsruhe Institute of Technology (KIT, Germany), National Radiation Protection Institute (NRPI, Czech Republic), Slovak Medical University (SZU, Slovakia), Belgian Nuclear Research Centre (SCK·CEN, Belgium), Institute for Radiological Protection and Nuclear Safety (IRSN, France), Centre for Energy, Environment and Technology Investigations (CIEMAT, Spain), Public Health England (PHE, UK), Finnish Radiation and Nuclear Safety Authority (STUK, Finland), National Centre for Nuclear Research (NCBJ, Poland); two from North America – the Mission Support Alliance (MSA, USA), and Health Canada (HC, Canada).

Three skull phantoms, were used in this intercomparison: the USTUR Case 0102 skull phantom, the BfS phantom and the CSR hemispherical phantom. From the initial fourteen participants, finally a total of twelve laboratories from Europe and North America delivered results. These results are presented and discussed in detail in this paper.

2. Methods

The intercomparison exercise was divided in two tasks. Task one included measurement at predefined positions on the surface of the skull phantoms, at 1 cm distance. The second task required estimation of the absolute ^{241}Am activities of the three phantoms used. This task was for participants who had already calibrated their PBC system previously with another physical skull phantom or who are using Monte Carlo methods to calibrate their systems. Several of the participants also participated in the EURADOS Monte Carlo skull phantom intercomparison (Vrba et al., 2015, 2014b). To be consistent, the same participant ID was used here, for those who participated in both intercomparisons.

In order to estimate the accuracy of the results, the Gaussian propagation of the counting statistic, emission probability, and the phantoms activities was performed using the values presented in Table 1 for a confidence level of approximately 68% (k = 1).

3. Detection systems

Despite the fact that most of the detectors used by the participants were commercial germanium crystals built by only two companies, all PBC systems were quite different in terms of the number of detectors, crystal dimension, end-cap window, flexibility in geometry, and dedicated shielding (see Fig. 1 and Table 2).

In Table 3 one can find details on the intercomparison measurements times, PBC detectors energy calibration, energy range typically used by the participant in routine measurements and software used for the spectrum analysis. Concerning the laboratories natural radioactive background, most participants have subtracted this contribution to the count rate, by determining the counts on the left and on the right of the ^{241}Am 59.54 keV peak to calculate the number of counts under this peak (the background counts). The number of background counts was then subtracted from the total number of counts in the 59.54 keV peak area. Only a few participants have previous to this step, monitored the natural background and subtracted the measured radionuclides peak areas

Table 1
Uncertainty values for a confidence level of 95% (k = 2) used for the efficiency uncertainty and normalization results uncertainty.* Note that the counting statistic value and uncertainty depends on each of participant measurement.

Source of uncertainty	Value	Uncertainty (k = 2)
Counting statistic	–	>2%*
Emission probability	0.3592	0.0034
USTUR phantom activity	287.2	7.4
BfS phantom activity	5239.3	226.8
CSR phantom activity	981.4	19.6