COUNTING ^{241}AM IN THE BFS HUMAN SKULL PHANTOM ON CONTACT—EVALUATION IN THE HUMAN MONITORING LABORATORY

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Abstract—**Skull counting can be used to assess the activity of radionuclides internally deposited in the bone. The Human Monitoring Laboratory (HML) at Health Canada conducted the measurement of ^{241}Am in the BfS (Bundesamt für Strahlenschuts) skull phantom on contact with the skull for various positions. By placing the detector in contact, the HML can improve the counting efficiency by over 20% compared to placing the detector 1 cm above the surface of the skull. Among all the positions tested, the forehead position is the preferred counting geometry due to the design of HML's counting facility and the comfort it would provide to the individual being counted, although this counting position did not offer the highest counting efficiency for the gamma rays (either the 59.5 keV or the 26.3 keV) emitted by ^{241}Am.**
Health Phys. 108(3):380–382; 2015

Key words: ^{241}Am; bioassay; bones, human; phantom

INTRODUCTION

AMERICIUM-241 IS highly radiotoxic. Following an intake, a fraction can deposit in the skeleton (ATSDR 2004). Bone counting can be used to estimate the intake and its associated health risk (Kramer et al. 2011). Assuming a homogenous distribution of ^{241}Am in the skeleton and with a known percentage of the bone mass in the skull over that in the skeleton (ICRP 1995), results from a skull count can be used to infer the total activity of ^{241}Am in the skeleton.

The BfS (Bundesamt für Strahlenschutz) skull phantom was manufactured around 1983 by Laurer[§] based on real human bone from a small head. Americium-241was artificially labeled on both the inner and outer surfaces of the phantom (Vrba 2011) with an overall activity of 5,239 Bq on 1 January 2012.

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(*Manuscript accepted* 16 *July* 2014)
0017-9078/15/0

DOI: 10.1097/HP.0000000000000180

The Human Monitoring Laboratory (HML) of Health Canada, which operates the Canadian National Calibration Reference Centre for Bioassay and in vivo Monitoring (Kramer and Limson Zamora 1994; Daka and Kramer 2009), conducted detailed measurements for the BfS phantom at various positions with the detector in contact or 1 cm above the surface. This paper reports the results of the measured counting efficiencies on contact for both the 26.3 keV and the 59.5 keV gamma rays of ^{241}Am using HML's lung counting facility (Kramer and Hauck 2005). This facility has been used previously in the measurement of ^{241}Am in two leg phantoms (Kramer et al. 2011).

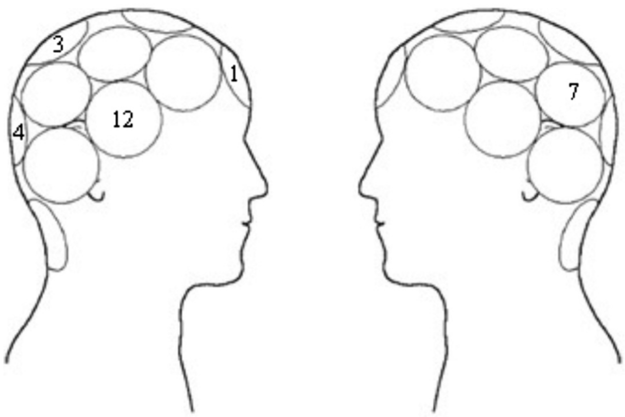
MATERIALS AND METHODS

Fig. 1 depicts the specified counting positions for the BfS skull phantom. In total, five positions were selected as they either offered convenient counting geometries or provided large bone mass for a good counting efficiency. For counting on contact, the detector was placed about 1 mm above the surface of the skull to obtain a higher counting efficiency. Fig. 2 shows the placement of the detector when the counting was conducted at one of the counting positions, the forehead position ("Position 1").

The measurements were performed in the HML's lung counting facility, which has four high purity germanium detectors mounted individually on a track that allows each detector to be moved independently. These detectors are used typically for in vivo monitoring of radionuclides such as ^{238}U and ^{241}Am in the energy range of 10–500 keV. For the measurements of ^{241}Am in the BfS skull phantom, only one of the four detectors was used.

The detector was a GEM Series coaxial detector manufactured by Ortec®. It is a p-type germanium crystal with the nominal dimensions of 85 mm diameter and 30 mm length. The crystal is mounted within an aluminium end cap with a 0.76-mm-thick carbon fiber window. The counting chamber is made of low background steel walls, with the inner surface

§Laurer G. Letter to W. Burkhart from 8th April 1993. New York University Medical Center, Laboratory for Radiation Studies; 1993.



Counting Position	Inclination (degrees)
1	43°
3	57°
4	0°
7	0°
12	0°

Fig. 1. The BfS Phantom with specified counting positions.

covered by 6.3 mm of lead as well as a graded Z liner consisting of tin (0.8 mm thick) and copper (1.8 mm thick). The inside dimensions of the counting chamber are 1.52 m × 2.13 m × 2.13 m (W × D × H). The access to the chamber is made through a set of double doors made of the same material as the chamber. The doors are operated by electric motors outside the chamber. The thickness of the chamber wall, doors, floor, and ceiling is 0.2 m. The chamber has a large water-filled window of dimensions 0.3 m × 0.46 m × 0.6 m.

Measurements were made either for a 60,000-s count (long counting) or a 3,600-s count (short counting), and both the 59.5 keV (branching ratio, 35.9%) and the 26.3 keV (branching ratio, 2.4%) gamma rays were counted. The acquisition and analysis of spectral data were performed using the Ortec® Renaissance Version 4.01 software.

Fig. 2. Counting the BfS phantom at the forehead contact position ("Position 1") using the HML lung counter.

Table 1. Counting efficiencies (cps Bq^{-1}) for ^{241}Am in BfS skull phantom at HML contact geometry with uncertainty (counting time: 60,000 s; from counting statistics only).

	26.3 keV		59.5 keV	
Position	Efficiency	Uncertainty	Efficiency	Uncertainty
1	8.21×10^{-3}	0.03×10^{-3}	2.190×10^{-2}	0.01×10^{-3}
3	1.047×10^{-2}	0.04×10^{-3}	2.729×10^{-2}	0.02×10^{-3}
4	9.28×10^{-3}	0.04×10^{-3}	2.463×10^{-2}	0.01×10^{-3}
7	8.57×10^{-3}	0.03×10^{-3}	2.365×10^{-2}	0.01×10^{-3}
12	7.49×10^{-3}	0.03×10^{-3}	2.066×10^{-2}	0.01×10^{-3}

At the HML, the forehead counting position (position "1", Fig. 1) is the preferred position, as the detector placement is constrained by the design of the counting facility. This position also provides the best comfort to an individual being measured.

RESULTS AND DISCUSSION

Table 1 shows the counting efficiencies (cps Bq^{-1}) for ^{241}Am in the BfS skull phantom for the on-contact geometry obtained for various positions as shown in Fig. 1. Each of the five counting positions was counted for 60,000 s. Both the 59.5 keV and the 26.3 keV gamma rays were measured and evaluated. The uncertainty associated with each of the reported efficiencies (Table 1) was calculated from counting statistics only. The counting efficiency was derived from dividing the count rate (total counts/counting time in seconds) by the activity (Bq) of ^{241}Am in the phantom at the time of counting and the respective branching ratio of the gamma ray, 35.9% for the 59.5 keV gamma and 2.4% for the 26.3 keV gamma, respectively.

For the 59.5 keV gamma ray, position "3" (Fig. 1) offered the highest counting efficiency, possibly due to the higher bone mass being counted, while position "12" (Fig. 1) offered the lowest counting efficiency. It was lower by over 24% compared to that of position "1." The HML's preferred position, the forehead position ("1", Fig. 1), offered an efficiency lower by about 20% compared to that of position "3."

Table 2. Counting efficiencies (cps Bq^{-1}) for ^{241}Am (59.5 keV) in BfS skull phantom at HML contact geometry: short counting (3,600 s) versus long (60,000 s) counting, with uncertainty (from counting statistics only).

	Short counting		Long counting	
Position	Efficiency	Uncertainty	Efficiency	Uncertainty
1	2.193×10^{-2}	0.06×10^{-3}	2.190×10^{-2}	0.01×10^{-3}
3	2.697×10^{-2}	0.06×10^{-3}	2.729×10^{-2}	0.02×10^{-3}
4	2.486×10^{-2}	0.06×10^{-3}	2.463×10^{-2}	0.01×10^{-3}
7	2.335×10^{-2}	0.06×10^{-3}	2.365×10^{-2}	0.01×10^{-3}
12	2.073×10^{-2}	0.06×10^{-3}	2.066×10^{-2}	0.01×10^{-3}

Table 3. Comparison of counting efficiencies (cps Bq^{-1}) for ^{241}Am in BfS skull phantom "position 1" at the contact geometry and at 1 cm above the surface using the HML lung counter (60,000 s counting; uncertainty from counting statistics only).

Position	26.3 keV		59.5 keV	
	Efficiency	Uncertainty	Efficiency	Uncertainty
Contact	8.21×10^{-3}	0.03×10^{-3}	2.190×10^{-2}	0.01×10^{-3}
1 cm	6.80×10^{-3}	0.03×10^{-3}	1.747×10^{-2}	0.01×10^{-3}
Gain (%)	20.7		25.4	

For the 26.3 keV gamma ray, the advantage of position "3" in counting efficiency was even more significant over other counting positions, probably due to lower attenuation at this position for this lower energy gamma. As expected, the 59.5 keV gamma had a higher counting efficiency than the 26.3 keV gamma by a factor of over 2.6 throughout the five counting positions. As a result, the 59.5 keV gamma would be the preferred energy for the measurement of ^{241}Am in the skull, as expected.

For real-life skull counting, it is more practical to count the individual for a shorter time than 60,000 seconds. A 3,600-s counting was performed for each counting position. Table 2 presents the obtained counting efficiencies and associated uncertainties for the shorter counting time and compares with those obtained from the longer counting time. Again, the uncertainties were from counting statistics only. As discussed above, the 59.5 keV gamma provides a higher counting efficiency. Therefore, Table 2 reports data for this gamma emission only. For each counting position, the counting efficiency for the 59.5 keV gamma rays obtained from the short counting does not differ significantly from that obtained from the long counting, as expected. However, the associated uncertainty becomes larger, by a factor of 5, increasing from 0.05% to 0.25% on average, for all of the counting positions. Nevertheless, the uncertainty is still small compared to the potential overall uncertainty in internal radiation assessment where skull counting is involved. Therefore, the 3,600-s short counting provides confirmation of the counting efficiency results obtained from the longer count time.

As discussed above, the HML's preferred counting geometry is the forehead position (position "1"), although the counting efficiency for the 59.5 keV gamma of ^{241}Am in the BfS skull phantom is lower by 20% compared to the highest efficiency obtained. Table 3 compares the counting efficiencies obtained at on-contact geometry and at the 1 cm geometry for both the 26.3 keV and the 59.5 keV gamma rays. For the 1-cm geometry, the detector was placed 1 cm above the surface of the skull phantom. Table 3 shows that compared to counting at the 1 cm geometry, counting on contact improved the counting efficiency by more than 20% and 25% for the 26.3 keV and the 59.5 keV gamma rays, respectively. This gain in counting efficiency was obtained by simply placing the detector closer to the surface of the skull phantom. In an actual skull measurement, this would help improve the quality of the measurement results when the counting time is fixed.

In summary, the HML has decided that the preferred counting position is a subject's forehead due to positioning constraints in the design of its counting facility. This counting position also provides the best comfort to the individual being counted in a real-life count, although this counting position doesn't provide the highest counting efficiency for the gamma rays emitted by ^{241}Am. By placing the detector just above the surface (on contact), the HML can improve the counting efficiency by over 20% compared to placing the detector 1 cm above the surface of the skull. Other laboratories that have no positioning constraints in the design of their counting facility would be advised to consider the more efficient counting positions for detector placement when performing skull counts.

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