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A Monte Carlo study of lung counting efficiency for female workers of different breast sizes using deformable phantoms

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Abstract

There are currently no physical phantoms available for calibrating *in vivo* counting devices that represent women with different breast sizes because such phantoms are difficult, time consuming and expensive to fabricate. In this work, a feasible alternative involving computational phantoms was explored. A series of new female voxel phantoms with different breast sizes were developed and ported into a Monte Carlo radiation transport code for performing virtual lung counting efficiency calibrations. The phantoms are based on the RPI adult female phantom, a boundary representation (BREP) model. They were created with novel deformation techniques and then voxelized for the Monte Carlo simulations. Eight models have been selected with cup sizes ranging from AA to G according to brassiere industry standards. Monte Carlo simulations of a lung counting system were performed with these phantoms to study the effect of breast size on lung counting efficiencies, which are needed to determine the activity of a radionuclide deposited in the lung and hence to estimate the resulting dose to the worker. Contamination scenarios involving three different radionuclides, namely Am-241, Cs-137 and Co-60, were considered. The results show that detector efficiencies considerably decrease with increasing breast size, especially for low energy photon emitting radionuclides. When the counting efficiencies of models with cup size AA were compared to those with cup size G, a difference of up to 50% was observed. The detector efficiencies for each radionuclide can be approximated by curve fitting in the total breast mass (polynomial of second order) or the cup size (power).

1. Introduction

Lung counting refers to the measurement of internally deposited radionuclides within the human lung. Such measurements are performed periodically on workers who regularly come in contact with airborne radioactive material or in the event of a suspected inhalation incident. Scintillation or semiconductor detectors are commonly used to measure penetrating photons so that the activity and the resulting absorbed dose from the radionuclide in the lungs can be estimated. The detectors are placed on or near the surface of the chest to maximize the counting efficiency, the quotient of measured counts and emitted photons from the radionuclide. Besides the energy calibration that is needed for these measurements, lung counting also requires an efficiency calibration which depends on the worker's anatomy and the detector-to-body geometry. Once the efficiency calibration has been performed, the response of the detectors can be directly correlated with the retained activity within the lungs.

Typically, a counting efficiency calibration is performed with physical phantoms that are spiked with known radionuclides and radioactivities in the organ of interest. Ideally, the phantom is identical or at least similar in anatomy to the measured person. The uncertainty in such an efficiency calibration is known to be quite high in part because that only a limited number of physical phantoms are available (Kramer and Capello 2005, Kramer and Burns 1995, Palmer *et al* 1989). This is particularly true when the lung counting is performed for female workers whose chest wall thickness (CWT), a major factor in determining lung counting efficiency (Kramer and Burns 1999), can vary considerably. Unlike for male workers, the CWT of female workers is difficult to standardize due to the large variety of possible breast sizes and shapes. For lung counting, male physical phantoms with adjustable plates to represent different CWT, e.g. Lawrence Livermore National Laboratory Torso-Phantom, have been developed (Griffith *et al* 1978). However, currently there are no physical female phantoms available with adjustable breasts because such models are difficult to fabricate.

Female breasts can vary greatly in size and shape. Like most anthropometric data, breast dimensions depend on factors such as race, culture, age, gender, diet and social status. Berger and Lane (1985) introduced an empirical formula to determine female CWT involving simple measurements of the chest circumferences in the vertical and supine positions. Their investigation was based on 77 women. The parameters in Berger and Lane's formula may need to be updated because increases in body weight over the last few decades have caused considerable changes in breast sizes of women (Odgen *et al* 2006, Lee *et al* 2007).

A recent study by Lee *et al* (2004) commented that it is difficult to select reliable anthropometrical points for quantifying and describing breast size and shape because of its complex shape. Consequently, Lee's investigation used a 3D body scanner to acquire precise information about breast shape. However, there may be still hidden areas of nude breasts which cannot be scanned. In order to improve lung counting measurements on women, a novel measurement approach will be needed.

This paper presents a study of the dependence of lung counting efficiency on various female breast sizes. Instead of using physical phantoms, this study used a novel method to create deformable female chest phantoms virtually on a computer using the so-called boundary-representation (BREP) geometry (Xu *et al* 2007) and then to calculate the counting efficiencies of these models using a well-validated Monte Carlo radiation transport code.

2. Materials and methods

2.1. Bra sizing

Anthropometric data for the female breast in terms of dimensions, total weight, tissue composition and tissue densities have been recommended by the ICRP and discussed by several authors (ICRP 1975, Kramer and Drexler 1981, Cristy 1982). New values for total weight and the fraction of glandular tissue of total breast tissue were suggested, but no other dimensions were given (ICRP 2003). Kramer and Drexler (1981) used information from the brasserie industry to estimate data for representative breast mass. Such statistical data are based on thousands of sold bras, and can give useful information about female breast size. Although few women wear bras of the wrong size or do not wear one at all, sales statistics from the brasserie industry provide a reasonable estimate of the female breast size distribution of a population. Dimensions typically used in brasserie sizing were used in this study to quantify the breast size of women.

According to Morris *et al* (2002), since the late 1920s the fashion industry has commonly used two dimensions to measure women's breast size, namely the bust girth (BG), which is the maximum horizontal girth, and the underbust girth (UBG), which is the horizontal girth just

below the breast. These two dimensions are defined in the norm of size designation of clothes published by the European Committee for Standardization (CEN 2001). According to EN 13402-2 and -3 (CEN 2002, CEN 2004) a secondary dimension called cup size (CS) characterizes the difference between BG and UBG, which is

$$CS = BG - UBG.$$

Bras are labeled compactly using a letter code (table 1) appended to the UBG.

For routine lung counting measurements, the easiest way of obtaining breast size information is for a female worker to submit the cup size together with other anthropometric data such as height and weight as part of the survey record. In this study, the worker is assumed to be in a standing position and wearing a bra, which may not be representative of lung counting procedures used in every *in vivo* laboratory.

2.2. The RPI adult female phantom

This investigation uses the mesh-based RPI adult female phantom (Na *et al* 2008, Xu *et al* 2008, Zhang *et al* 2008a, Zhang *et al* 2008b), which was developed using BREP geometry modeling techniques that were first applied to the RPI pregnant female phantoms (Xu *et al* 2007). The anatomical information was based on the *Anatomium*TM 3D models P1 Dataset (CFLietzau 2007). Using methods developed by Xu *et al* (2007), organ geometries were morphed to agree within 0.5% with reference female organ volume and mass data recommended by the ICRP (1975, 2002) and the ICRU (1992).

2.3. Phantom deformation

The RPI adult female's breast shape was deformed in order to generate a series of models with cup sizes ranging from AA to G. The deformation of the models was achieved using software developed in-house that translates the vertices of the breast mesh in their normal vector direction. The model is designed to represent a standing, bra-wearing woman. In spite of wearing a bra the effect of gravity on the breast tissue must still be considered for the deformed models. Consequently, adjustments were made to the breast shape in order to ensure a realistic result. To this end, the breast tissues were morphed with a 60° downward angle to simulate a gravity-caused tissue deformation. Additionally, to provide a smooth transition between relocated and non-relocated vertices, the skin mesh was softened with a Laplacian smoothing algorithm (Vollmer *et al* 1999). The mass of the glandular breast tissue was kept constant for simplicity, but the tissue was aligned to the new nipple position. The space between the glandular tissue and skin was filled with adipose tissue during the voxelization process to be described later in section 2.6. The mass and center-of-mass of the adipose breast tissue and skin tissue changed because they are affected by the breast deformation. All other organ masses and their center-of-masses were kept constant.

2.4. Cup size determination

A series of deformed female models were developed with different breast sizes. Both bust girth and underbust girth were measured according to the definition (CEN 2001) at the outermost breast skin contour using the rolling ball method (Armato *et al* 1999). This method skips deep cavities such as the cleavage between the breasts, allowing a good comparison with real bust girth measurements. For this study, a total of eight models were selected to represent eight different cup sizes of AA, A, B, C, D, E, F and G. In the following, each of these letters is used to denote a specifically sized model.

2.5. Glandularity

Mammary glands, which are responsible for producing milk for infants, are composed of glandular tissue. The term glandularity stands for the mass fraction of glandular tissue of the total breast mass and is an important parameter for mammography dose calculations. Glandular tissue has a different elemental composition and a different density from the surrounding adipose breast tissue (ICRP 2002). To study the effect of glandularity for lung counting, the original E model, which has 7% glandularity, was modified to generate a second E model with 40% glandularity. This model is denoted in the following as the E40 model. A value of 40% glandular tissue is recommended by the ICRP (2002) for the reference female adult. Jamal *et al* (2004) review investigations on glandularity and compared them to their own measured data. The range of observed glandularities was from 0.2 to 99.9% with a median of 46.6%. Younger women tend to have a higher glandularity and obese women tend to have a lower glandularity.

2.6. Voxelization

The series of mesh models were then voxelized so that they could be adopted into a Monte Carlo radiation transport code. The voxelization method developed in this study is based on the parity count method together with the method of ray stabbing on a polygon surface (Nooruddin and Turk 2003). The voxel dimension was chosen to be cubical with a side length of 3 mm in order to achieve a total number of voxels (approx. 22 million) that was suitable for implementation in the Monte Carlo code.

The density and elemental composition of all the voxelized RPI adult female phantom's tissues and organs were defined according to ICRP (2002), except for the skin. The density of the skin was reduced from its nominal value of 1.09 g cm^{-3} in order to comply with the mass of the skin recommended by ICRP (2002) for the AA model. Without this change, the skin mass would be artificially high because the small dimensions of the skin tissue cannot be described accurately with cubic voxels of side 3 mm. The clothing worn by the female worker (i.e. bra or shirt) was not taken into account in this investigation because they have little effect on radiation attenuation and because clothes are difficult to model.

2.7. Monte Carlo simulations

Monte Carlo simulations were performed using Monte Carlo N-Particle eXtended (MCNPX) 2.5.0 (Pelowitz 2005). The simulations were run in photon and electron modes using cross section libraries *mcplib04* for and *el03*, respectively. The MCNPX input file was created with the aid of the in-house developed software Voxel2MCNP (Hegenbart and Heide 2006). Voxel2MCNP facilitates the management of voxel phantom and detector geometry, materials and organ parameters, and source definitions according to recommendations by Taranenko *et al* (2005). The software has a 3D viewer that conveniently allows for interactive detector positioning. In this study, the radioactive contamination of the phantoms' lung lobes was assumed to be evenly distributed throughout the entire organ. Three radionuclides (Am-241, Cs-137 and Co-60 listed in table 2) were chosen for the simulations to investigate the energy dependence of the counting efficiency. A total of 5 million particle histories were run for each simulation to achieve results with relative errors (one standard deviation) less than 0.38%.

2.8. Detectors and geometry

The Phoswich scintillation detectors installed at the Karlsruhe Institute of Technology (KIT) *in vivo* laboratory were modeled for the Monte Carlo simulations described in this paper using dimensions supplied by the manufacturer (Doerfel *et al* 2006). The thickness of the NaI(Tl)-crystal, used for detecting low energy photons, is 1.0 mm and the diameter is 203.2 mm. The higher energy photons are measured with a 50.8 mm thick, 203.2 mm diameter CsI(Tl)-crystal that is coupled to the NaI(Tl)-crystal. A third light-conducting, non-doped NaI-crystal is

located beyond the detector crystals. All crystals are embedded in Al_2O_3 powder and sealed airtight in steel housing with a front Beryllium window. For simplicity, other detector parts (e.g. photomultiplier, mounting rack, etc) are not modeled in the simulations. MCNPX's Gaussian energy broadening (GEB) was used to obtain realistic spectra that are similar to those obtained experimentally. The necessary GEB parameters were determined experimentally by measuring the FWHM (full width at half peak maximum) at different energies. The energy range of interest (ROI) for Am-241 was 20-80 keV, which is the typical range used at the KIT *in vivo* laboratory for Am-241. Am-241 is measured by the NaI(Tl)-part of the detectors. For Cs-137 and Co-60, which are measured by the CsI(Tl)-part of the detector, the ROIs were set to ± 1.25 FWHM around the peak maxima (661.6 keV for Cs-137 and 1.173 23 MeV and 1.332 49 MeV for Co-60). The respective bins of MCNPX's pulse height tally are summed up to yield the counting efficiency in units of *counts per particle history*.

Figure 1 illustrates the counting geometry which was chosen for simplicity and reproducibility. The two Phoswich detector axes were positioned in the AP (antero-posterior) direction over the center of mass of the lungs. Both detector axes are parallel to the DV (dorso-ventral) direction. The distance of the two axes in the DS (dextro-sinister) direction is 210 mm. The middle of the distance of these axes is centered in the AP and DS direction over the centre of mass of the lungs. The DV position of both detectors' fronts is equal. Positioning was done interactively with Voxel2MCNP's 3D viewer. The detectors were positioned 1 mm (in the DV direction) above the breast skin of each model. The described detector positioning does not reflect the lung counting procedures currently used at the Human Monitoring Laboratory (HML) (Kramer 2008) or KIT (Doerfel *et al* 2006). The authors would like to stress that the detector position methodology used in this study was chosen for reasons of simplicity and reproducibility, and not realism. For perfect realism, the detector should be placed relative to anatomic landmarks (e.g. sternum, clavicle, etc) in an inclined position, tangential to the chest surface.

3. Results and discussion

Figure 2 shows rendered views of the deformed skin in the chest region of the selected models with different cup sizes. Table 3 summarizes the measured anthropometric data, i.e. bust girth, under bust girth, cup size, and also provides the glandularity and total mass of the breasts of the phantoms used in this study.

Figure 3 shows AP cross-sectional images of the different voxelized models. All of the images correspond to the same position within the chest.

Tables 4-6 document the results of the Monte Carlo simulations for the radionuclides Am-241, Cs-137 and Co-60 respectively. For easy comparison, the efficiencies of both detectors were summed and normalized to the efficiency of the AA model in each table. The left detector generally has a lower counting efficiency due to the smaller left lung lobe and due to the attenuation of the radiation by the heart. The efficiency drops with increasing cup size because the increase in breast tissue results in greater attenuation of the photons emerging from the lungs. The low-energy photon emitter, Am-241, shows the greatest differences in counting efficiencies when breast size increases. The Am-241 counting efficiency for the G model was roughly 50% less than the value for the smaller breasted AA model. For the radionulides Cs-137 (mid-energy photon emitter) and Co-60 (high-energy photon emitter), these values were about 55% and 58%, respectively.

Figure 4 shows the relationship of efficiency and breast mass in grams. In the order from left to right, the values of the models AA, A, B, C, D, E, E40, F and, rightmost, G are plotted. These curves depend on mass attenuation and body-to-detector geometry. The relationships

for each nuclide can be approximated well with a second-order polynomial fit performed by *Microsoft Excel 2008™* for *MacOSX™* with R^2 -values of at least 99.92%. For Cs-137 and Co-60 the efficiency of the E40 model fits well on each fitted curve.

For the low-energy range, glandularity seems to play a more important role, as can be seen at E40 for Am-241. The difference of the E- and the E40 model is roughly 1.7% for Am-241, while it is just 0.5% for Cs-137 and just 0.4% for Co-60. Higher glandularities will result in lower efficiencies. This makes sense, because the mass and thus attenuation of the radiation increases. For smaller cup sizes than E the effect of glandularity is expected to be lower because the total breast mass is smaller and the fraction of glandular tissue (see table 2) is closer to Jamal's (2004) median glandularity of 46.6% or ICRP's (2004) value of 40%. Therefore, deviations caused by variations in glandularity can be neglected because the woman's glandularity is usually unknown and not easy to determine and because in routine lung counting statistical counting errors are at least as high as 1.7%.

Figure 5 shows the efficiencies plotted over the cup size in centimeters. The efficiencies displayed in the plot from left to right correspond to the models AA, A, B, C, D, E and E40 (E40 just below E), F and G. The relationships for each nuclide can be approximated with a power fit with R^2 -values of at least 99.8%. A 1.7% gap between the counting efficiencies of the E and E40 model for the Am-241 ROI is clearly visible.

4. Conclusions

In lung counting, the chest thickness of a female worker is a major cause of counting uncertainty. Using a novel deformable mesh-based phantom, this study produced a series of female voxel phantoms with different cup sizes and then calculated the lung counting efficiencies for various radioisotopes of interest. The models' breasts were quantified according to the cup size, a brasserie industry standard dimension, by measuring the bust and underbust girth of the model.

Monte Carlo simulations with these individualized models were performed to determine the lung counting efficiencies in three different energy ranges. Especially for the low-photon emitter Am-241, detector efficiencies decrease considerably with breast size. If this decrease in counting efficiency is not considered, the calculation of the activity, and hence the estimate of the dose received by the female worker, will be underestimated. It was found that second-order polynomial equations can describe the relationship of detector efficiency and cup size. Power equations can describe the relationship of detector efficiency and total breast mass. For an Am-241 incorporation in the lung of a woman, measured in a standing position, wearing a bra with large cup sizes such as G, one has to consider a decreased detector efficiency of about 50% compared to a woman with AA cup size. Furthermore, it was brought forward that for practical lung counting purposes, differences in breast glandularity can be ignored because the systematic error introduced into the activity measurement by such differences negligibly small compared to other sources of error (e.g. geometry differences between the patient and phantom, detector positioning and homogeneity of the radionuclides in the lungs).

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Figure 1.

The position of the detectors for the voxelized phantom with cup size C viewed from three different perspectives: (a) front left, (b) right side and (c) top. A thin axis goes from the middle of the two detectors through the center of mass of the lung. The images are screenshots from Voxel2MCNP's 3D viewer.

Figure 2.
The chest of the different models (standing, naked) viewed from the front and the left side.

Figure 3.

Comparison of the transversal slice #415 of the voxelized phantoms, which is the position of the nipple in the AA model. Due to the gravity effect, the nipple position moves to posterior positions.

Figure 4.

Counting efficiencies (counts per particle history) of the three radionuclides normalized relatively to the values of the AA model versus total breast mass in grams and polynomial (second-order) fitting curves, plotted by *Microsoft Excel 2008™*: Am-241 (squares, dotted line) fitting curve: $y = 3.485 \times 10^{-8} \cdot x^2 - 3.008 \times 10^{-4} \cdot x + 1.142 \times 10^0$, $R^2 = 9.994 \times 10^{-1}$. Cs-137 (diamonds, solid line) fitting curve: $y = 2.962 \times 10^{-8} \cdot x^2 - 2.610 \times 10^{-4} \cdot x + 1.122 \times 10^0$, $R^2 = 9.993 \times 10^{-1}$. Co-60 (triangles, dashed line) fitting curve: $y = 2.537 \times 10^{-8} \cdot x^2 - 2.345 \times 10^{-4} \cdot x + 1.111 \times 10^0$, $R^2 = 9.992 \times 10^{-1}$.

Figure 5.

Counting efficiencies (counts per particle history) of the three radionuclides normalized relatively to the values of the AA model versus cup size in centimeters, plotted by *Microsoft Excel 2008™*. The calculated power fitting curves have R^2 -values of more than 99.8%: Am-241 (squares, dotted line) fitting curve: $y = 6.536 \times 10^0 \cdot x^{-8.020 \times 10^{-1}}$, $R^2 = 9.986 \times 10^{-1}$. Cs-137 (diamonds, solid line) fitting curve: $y = 4.844 \times 10^0 \cdot x^{-6.75 \times 10^{-1}}$, $R^2 = 9.992 \times 10^{-1}$. Co-60 (triangles, dashed line) fitting curve: $y = 4.244 \times 10^0 \cdot x^{-6.176 \times 10^{-1}}$, $R^2 = 9.993 \times 10^{-1}$.

Table 1

Cup size ranges letter coded according to (CEN 2004)

Code	AA	A	B	C	D	E	F	G
CS range (cm)	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26

Table 2

Radionuclides and their energy used according to Schötzg and Schrader (2000). Only those energies with emission probabilities larger than 0.01 are considered

Nuclide	Photon energy (MeV)	Emission probability
Am-241	0.013 76	0.010 80
	0.013 90	0.119 30
	0.017 54	0.186 10
	0.021 01	0.048 20
	0.026 34	0.024 00
	0.059 54	0.359 00
Cs-137	0.031 82	0.019 50
	0.032 19	0.035 90
	0.036 40	0.010 55
	0.661 60	0.850 00
Co-60	1.173 23	0.998 50
	1.332 49	0.999 83

Table 3
Relevant anthropometric data of the models sorted by cup size letter code

CS letter code/model	BG (cm)	UBG (cm)	CS (cm)	Glandularity (%)	Mass of breasts (g)
AA	99.6	89.2	10.4	40	500
A	102.6	89.2	13.4	15	1317
B	104.6	89.2	15.4	12	1700
C	105.8	89.2	16.6	11	1897
D	107.6	89.2	18.4	9	2331
E	110.0	89.2	20.8	7	2791
E40	110.0	89.2	20.8	40	2854
F	112.0	89.2	22.8	6	3304
G	114.0	89.2	24.8	5	3855

Efficiencies (left, right detector and their sum) for the Am-241 ROI of 20-80 keV. The rows are sorted by model with increasing cup size. Relative counting errors are given for the total counts in per cent. For comparison purposes, the total efficiencies have been normalized to that of the model AA

Table 4

Cup size letter code/ model	Am-241, efficiency (counts per photon) in ROI 20-80 keV				
	Phoswich 1 (left)	Phoswich 2 (right)	Total (Sum)	Relative counting error	Sum relative to AA
AA	1.28×10^{-2}	1.50×10^{-2}	2.78×10^{-2}	2.68×10^{-3}	1.00×10^0
A	1.04×10^{-2}	1.22×10^{-2}	2.26×10^{-2}	2.98×10^{-3}	8.12×10^{-1}
B	9.39×10^{-3}	1.09×10^{-2}	2.03×10^{-2}	3.14×10^{-3}	7.29×10^{-1}
C	8.93×10^{-3}	1.03×10^{-2}	1.92×10^{-2}	3.22×10^{-3}	6.92×10^{-1}
D	8.19×10^{-3}	9.40×10^{-3}	1.76×10^{-2}	3.37×10^{-3}	6.33×10^{-1}
E	7.49×10^{-3}	8.62×10^{-3}	1.61×10^{-2}	3.52×10^{-3}	5.80×10^{-1}
E40	7.29×10^{-3}	8.36×10^{-3}	1.57×10^{-2}	3.57×10^{-3}	5.63×10^{-1}
F	6.92×10^{-3}	7.84×10^{-3}	1.48×10^{-2}	3.68×10^{-3}	5.31×10^{-1}
G	6.53×10^{-3}	7.36×10^{-3}	1.39×10^{-2}	3.79×10^{-3}	5.00×10^{-1}

Table 5
Efficiencies (left, right detector and their sum) for the Cs-137 ROI of 574-749 keV. The rows are sorted by a model with increasing cup size. Relative counting errors are given for the total counts in per cent. The total efficiencies are normalized to the result of model AA for easy comparison

Cup size letter code / model	Cs-137, efficiency (counts per photon) in ROI 574-749 keV				
	Phoswich 1 (left)	Phoswich 2 (right)	Total (Sum)	Relative counting error	Sum relative to AA
AA	1.26×10^{-2}	1.40×10^{-2}	2.66×10^{-2}	2.74×10^{-3}	1.00×10^0
A	1.06×10^{-2}	1.16×10^{-2}	2.22×10^{-2}	3.00×10^{-3}	8.34×10^{-1}
B	9.63×10^{-3}	1.06×10^{-2}	2.02×10^{-2}	3.15×10^{-3}	7.58×10^{-1}
C	9.32×10^{-3}	1.01×10^{-2}	1.94×10^{-2}	3.21×10^{-3}	7.30×10^{-1}
D	8.62×10^{-3}	9.35×10^{-3}	1.80×10^{-2}	3.34×10^{-3}	6.74×10^{-1}
E	8.06×10^{-3}	8.67×10^{-3}	1.67×10^{-2}	3.46×10^{-3}	6.28×10^{-1}
E40	7.99×10^{-3}	8.60×10^{-3}	1.66×10^{-2}	3.47×10^{-3}	6.23×10^{-1}
F	7.45×10^{-3}	8.10×10^{-3}	1.55×10^{-2}	3.59×10^{-3}	5.84×10^{-1}
G	7.10×10^{-3}	7.64×10^{-3}	1.47×10^{-2}	3.68×10^{-3}	5.53×10^{-1}

Efficiencies (left, right detector and their sum) for the Co-60 ROI of 1056-1458 keV. The rows are sorted by model with increasing cup size. Relative counting errors are given for the total counts in per cent. The total efficiencies are normalized to the result of model AA

Table 6

Cup size letter code / model	Co-60, efficiency (counts per photon) in ROI 1056-1458 keV				
	Phoswich 1 (left)	Phoswich 2 (right)	Total (Sum)	Relative counting error	Sum relative to AA
AA	1.05×10^{-2}	1.15×10^{-2}	2.20×10^{-2}	3.02×10^{-3}	1.00×10^0
A	8.98×10^{-3}	9.76×10^{-3}	1.87×10^{-2}	3.27×10^{-3}	8.52×10^{-1}
B	8.23×10^{-3}	8.94×10^{-3}	1.72×10^{-2}	3.41×10^{-3}	7.80×10^{-1}
C	7.99×10^{-3}	8.58×10^{-3}	1.66×10^{-2}	3.47×10^{-3}	7.53×10^{-1}
D	7.44×10^{-3}	7.99×10^{-3}	1.54×10^{-2}	3.60×10^{-3}	7.01×10^{-1}
E	7.00×10^{-3}	7.45×10^{-3}	1.45×10^{-2}	3.72×10^{-3}	6.57×10^{-1}
E40	6.95×10^{-3}	7.40×10^{-3}	1.44×10^{-2}	3.73×10^{-3}	6.52×10^{-1}
F	6.51×10^{-3}	6.98×10^{-3}	1.35×10^{-2}	3.85×10^{-3}	6.13×10^{-1}
G	6.22×10^{-3}	6.59×10^{-3}	1.28×10^{-2}	3.95×10^{-3}	5.82×10^{-1}