Efficiency maps of the LLNL and JAERI realistic torso phantoms using a 70 mm Diameter Germanium and implications on the minimum detectable activity.

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INTRODUCTION

Detector technology has advanced since the LLNL phantom was designed and built; many phoswich-based lung counting systems have been replaced by germanium detectors arrays. The LLNL phantom is in routine use for calibrating germanium based lung counting systems in many countries. Germanium detectors are smaller than phoswich detectors and are placed on different parts of the torso. Work at the Human Monitoring Laboratory (HML) published elsewhere (Health Physics 73(5): 831-837;1997) has shown that the chest wall thickness of the phantom must be re-measured if lung counting is performed with a germanium detector array instead of a phoswich detector system.

The LLNL phantom=s chest plate is marked with circles that denote the optimum positions for lung counting using phoswich detectors; however, there is no indication where an array of germanium detectors should be placed. The JAERI phantom=s chest plate is not marked, unlike the LLNL phantom=s chest plate, with circles that denote the optimum detector positions for lung counting. This study was carried out to determine the optimum positions for placement of germanium detectors and to assess the implications on the minimum detectable activity (MDA) of a detector array as a function of the number of detectors in that array.

METHODS AND MATERIALS

Counting Positions: The LLNL Torso phantom=s chest plate was covered with saran wrap. Counting positions were marked on the transparent cover using a black marker pen. The reference point was taken to be mid-point of the chest plate, 10 cm from the top edge. The counting positions were marked and measured relative to that point. The sagittal counting positions were 4.5, 0, -4.5, -9. The negative values denote positions lower than the mid point of the chest plate. The transverse counting positions were -12, -8, -4, 0, 4, 8, 12. , the negative values are positions right side of the chest plate (i.e. above the right lung).

The JAERI Torso phantom=s overlay plate was covered with saran wrap and placed on the phantom for counting. Counting positions were marked on the transparent cover using a black marker pen. The reference point was taken to be mid-point of the chest plate, 15 cm from the top edge of the overlay plate. The counting positions were marked and measured relative to that point. The sagittal counting positions were 12, 8, 4, 0, -4, -8. The negative values denote positions lower than the mid point of the chest plate. The transverse counting positions were -12, -8, -4, 0, 4, 8, 12. , the negative values are positions right side of the chest plate (i.e. above the left lung). Each counting position had a 7 cm circle inscribed around it to aid in the positioning of the detector. Counting positions for the MDA estimations were: Detector 1 - lower left (above the heart); Detector 2 - upper left; Detector 3 - lower right; Detector 4 - upper right.

Counting Protocol and Data Analysis: The counting chair was placed in the flat position and the phantom placed on a solid support on the chair=s cushion. . One germanium detector was used to measure the counts at each energy (17.7 keV, 59.5 keV, 121.8 keV, 244.7 keV, and 344 keV). The detector was placed tangential to the surface of the phantom=s chest plate for each measurement. This procedure was repeated for each counting positions. At each energy, the net counts in the photopeak of interest were normalised by dividing by the highest number of counts measured. Therefore, the most efficient position is denoted by unity.

The LLNL phantom was measured containing a lung set made of tissue substitute material containing a mixture of ^{241}Am/^{152}Eu which was manufactured by the University of Cincinnati. The activity of the sources was 38.9 kBq ^{241}Am and 16.4 kBq of ^{152}Eu on 1-Jan-96. The JAERI phantom was measured containing a lung set made of tissue substitute material containing a mixture of ^{241}Am/^{152}Eu which was manufactured by the Pacific Northwest National Laboratories. The activity of the sources was 18.2 kBq ^{241}Am and 18.2 kBq of ^{152}Eu on 12-Mar-96 .

Counts times were up to 60,000 seconds to ensure that good counting statistics were obtained. In some cases, however, it was impossible to obtain many counts for the lowest energy photon. For example, in one position (detector placed directly above the heart) no counts above background were observed. Excepting for a few positions such as this, the counting error was always less than 1%.

MDA Determination: The background used for the MDA determinations was obtained by counting an uncontaminated subject in the HML=s lung counter. The counting time was 1800 seconds. Chest wall thickness was converted to muscle-equivalent-chest-wall-thickness (MEQ-CWT) to eliminate the confounding factor of adipose content of the chest wall. MDA=s have been calculated for photons of a given energy. The appropriate branching ratio must be factored in to convert these values to activity.

RESULTS AND DISCUSSION

LLNL phantom: The position of maximum efficiency, above the mid point of the right lung, at any energy does not change. The most efficient region of this phantom=s chest plate is on the right side. It also poses a dilemma for actual counting as it shows the most efficient point to be almost directly midway between the current positioning of the two detectors now used in the HML. If the upper detector were lowered to take advantage of the increased efficiency the lower right detector would have to be placed in a region where the counting efficiency was half of the what it was in the original position. The HML has chosen to keep the detectors in the positions shown in the figures. The relative counting efficiency of the left side of the LLNL phantom=s chest plate is much less than that of the right. This is especially true above the heart. The fourth detector adds very little information when performing lung counting for plutonium. As the photon energy rises to 59.5 keV the differences in the relative counting efficiencies are reduced due to the lower attenuation of these higher energy photons. The relative counting efficiencies in the region directly above the heart are still greatly reduced compared to other positions on the LLNL phantom=s chest plate. The difference between the upper left detector and the right detectors is also diminished. Higher energies show the same trend. Even at the highest energy (344 keV), the relative counting efficiencies in the region above the heart are approximately half of the other regions.

JAERI Phantom: The design of the phantom makes it difficult to get an accurate estimate of the relative efficiency across the upper part of the chest. The chest plate joins the core in the mid part of the upper half of the lungs; consequently, there is about 9 cm of lung above the join. This design is different from the LLNL phantom where the chest plate cover join is almost at the top of the lungs. The relative efficiencies above the join show misleadingly high values due to photon leakage and, therefore, must be disregarded.

The most efficient region of the JAERI phantom=s chest plate is on the right side. Ignoring the high value above the chest plate cover join one can see that the highest counting efficiency is directly underneath one of the HML=s detectors. The relative counting efficiency of the left side of the JAERI phantom=s chest plate is much less than that of the right when the values above the chest plate cover join are rejected. This is especially true above the heart. As for the LLNL phantom, the fourth detector adds very little information when performing lung counting for plutonium.

The most efficient counting position for 59.5 keV photons is above the middle of the right lung, which is where the HML=s upper right detector is placed. The relative efficiency values above the chest plate cover join are still high, but the higher photon energy has somewhat diminished this effect. The relative counting efficiencies in the region directly above the heart are still greatly reduced compared to other positions on the JAERI phantom=s chest plate. The difference between the upper left detector and the right detectors is also diminished. Higher energies show the same trend.

Phantom Comparison: The shapes of the high efficiency regions (0.8 to 1.0) are quite different between the two phantoms; indicative perhaps of how real people will either differ from each other or differ from a calibration phantom. As the photon energy increases the shapes of the high efficiency areas remain distinct. This might suggest that activity estimates made on one phantom (or a person) using calibration factors derived from the other phantom would result in large differences (or inaccuracy). Fortunately, this is not so as we have shown elsewhere (Health Phys. 74:613-618; 1998 and Health Phys. 74:594-601; 1998).

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Implications for MDA: The MDA at each of four detector positions and for a two-, three- and four-detector array using both phantoms has been evaluated. As might be expected the arrays perform better than single detector measurements. MDA=s have been calculated for both phantoms as a function of MEQ-CWT at the energies of interest. Table 1 shows the data for a four detector array.

Table 1: MDA (Photons) values for a four-detector array (upper left + upper right + lower right + lower left) at 17.7, 59.5, 121.8, and 344 keV

MEQ-CWT (mm)		Energy		
LLNL Phantom	17.7 keV	59.5 keV	121.8 keV	344 keV
15.4	37.3	1.1	0.9	1.0
21.0	72.4	1.5	1.2	1.4
25.0	132.5	1.8	1.4	1.5
29.4	248.2	2.2	1.6	1.8
33.7	382.5	2.5	1.9	2.0
JAERI Phantom	17.7 keV	59.5 keV	121.8 keV	344 keV
18.9	41.4	1.0	0.9	1.1
24.5	95.9	1.4	1.2	1.4
27.6	112.9	1.5	1.2	1.5
27.0	118.6	1.4	1.2	1.4
30.6	210.5	1.9	1.5	1.7
30.3	177.0	1.7	1.4	1.5
33.4	209.7	1.8	1.5	1.7

Single detectors give the following MDA (in terms of photons detected) for 17 keV photons for a MEQ-CWT of approximately 29 mm using the LLNL phantom: lower left - 1740; upper left - 400; lower right - 430; upper right - 400. A two detector array (upper left + upper right) gives an MDA of 280. A three-detector array (upper left + upper right + lower right) gives an MDA of 230. A four-detector array (upper left + upper right + lower right + lower left) give an MDA of 240. These MDA values must be adjusted by the appropriate branching ratio to determine a radionuclide specific MDA.

At the highest energy, 344 keV, the corresponding MDA values are as follows: lower left - 6; upper left - 3; lower right - 4; upper right - 3. A two detector array (upper left + upper right) gives an MDA of 2. A three-detector array (upper left + upper right + lower right) gives an MDA of 2. A four-detector array (upper left + upper right + lower right + lower left) give an MDA of 2.

CONCLUSIONS

The efficiency mapping of the LLNL and JAERI phantom=s chest plate has verified that the HML=s detectors are optimally placed. This work with the two torso phantoms has also shown that a three-large-area-germanium-detector array would be a satisfactory lung counting system over the energy range studied.