A Joint HML-KAERI Project: Comparison of sliced and whole lung sets for the LLNL and JAERI Torso Phantoms using Ge Detectors

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INTRODUCTION

Lung counting systems that measure low energy photons emitted from the lung must be calibrated with a realistic phantom.. The LLNL phantom has, by consensus opinion, been acclaimed as the de facto standard phantom for the calibration of lung counting systems. However, the design of the LLNL torso phantom is based on a cadaver which was representative of a population of radiation workers at the Lawrence Livermore National Laboratories and at Los Alamos National Laboratories. The phantom represents a 1.77 m tall male weighing 76 kg. The body size of the JAERI phantom was based on a person who was close to the average size of an adult Japanese Male, and represents a 1.68 m tall male weighing 63.5 kg. The phantoms have been compared elsewhere - Health Physics 74(5). Lung counters are usually calibrated with lung sets that are manufactured from lung tissue substitute material that contains homogeneously distributed activity. It can be an expensive proposition if a facility requires many radionuclide standards and several activity levels. An alternative is to use point sources placed in a lung set that has been drilled to accept them. This joint work between the Human Monitoring Laboratory (HML) and the Korea Atomic Energy Institute (KAERI) has explored an alternate arrangement: sliced planar sources.

METHODOLOGY AND RESULTS

The Phantoms: The LLNL phantom was measured in the lung counter with and without the B-series overlay plates. These plates simulate 50% adipose and 50% muscle so that when they are added to the chest plate, which is 0% adipose, the following adipose contents can be simulated: 0%, 15%, 21%, 26% and 30%. The adipose content of the JAERI phantom is either 10%, 20% or 30%. The JAERI phantom has two lung sets: the original sliced lung (11 slices approximately 2.5 cm thick) set from Japan and a homogeneous set manufactured for the HML by Pacific Northwest National Laboratories (PNNL). The LLNL phantom=s homogeneous lung set was manufactured by the University of Cincinnati and contains ^{241}Am/^{152}Eu homogeneously distributed throughout the lung tissue substitute material. The LLNL=s sliced lung set, manufactured by Canberra, consisted of a tissue substitute lung sliced into 11 sections approximately 1.7 cm thick. The planar sources consisted of laminated paper which had the activity evenly spread over its surface.

Preparation of Planar Inserts for the JAERI phantom: Tracings were taken of each JAERI lung slice and a cardboard template was created. The templates were used for the production of the filter paper inserts that were spiked with activity. The filter paper inserts (Whatman No. 54 was used because of its wet strength and chemical resistivity) were labeled with a location identifier and nuclide identification. The inserts were then glued inside one half of a laminating pouch using a glue stick. Each of the pouches, which is 21.6 cm x 28.0 cm, could hold three to five of the inserts depending upon their size and leaving adequate space between the filter papers so that the laminated inserts could be cut apart. A standard solution (^{241}Am or ^{152}Eu) was prepared from a commercially purchased radionuclide solution of known concentration. The activity was deposited on the filter paper by wetting the filter paper with a series of small overlapping dots. The wetting commenced on the outer edge of the insert and worked in towards the middle until the paper was entirely wetted. The weight of the solution added to the insert was determined by weighing the baby bottle before and after the addition. Once the entire filter paper was wetted and the desired activity deposited, the filter paper was allowed to air-dry in a fumehood.

Counting Systems: The lung counting system at KAERI, supplied by Canberrra, consists of two ACTII units. Each unit contains two 50 mm Ge detectors cooled by one Dewar. Each two-detector unit is fitted with a graded shield consisting of 1.0 cm lead and 0.32 cm of copper to reduce background. The units are mounted in a Model 2275 dual purpose lung and whole body counter chamber, constructed of 10 cm thick low background steel, lined with stainless steel. The lung counting system at the HML supplied by EG&G Ortec, consists of four 70 mm diameter Ge detector. Each is detector cooled by a 17 liter Dewar. The units are mounted in a counting chamber, constructed of 20 cm thick low background steel, lined. with 0.6cm lead.

Counting Protocol: The JAERI and LLNL phantom=s sliced lungs, containing the mixed ^{241}Am/^{152}Eu planar sources, and homogeneous lung sets were measured with the 70 mm detector systems. Additionally the LLNL=s lung sets were measured with the 50 mm detectors. The phantoms were measured with each overlay plate and with no overlay plate. Detectors were placed in the usual position for lung counting. The 70 mm detectors were directly above 6 slices of the JAERI sliced lung set and 8 slices of the LLNL lung set. The 50 mm detectors were directly above 4 slices of the JAERI sliced lung set and 6 slices of the LLNL lung set. Counting times were up to 10 hours (36,000 sec) to obtain good counting statistics at low energies. For example, the counting error at 17.7 keV is no more than 2.5% (at 2σ) for either phantom. The energies of interest were 17.7 keV, 59.5 keV, 121.8 keV, 344 keV.

DISCUSSION

Planar lung sets offer the advantage of being inexpensive to produce and allow the user a great deal of flexibility in simulating activity distributions. However, they must also be able to provide a primary calibration if they are to replace homogeneous lung sets. Comparison of the sliced lung sets to the homogeneous lung sets has been made by assuming that the latter set is correct. Activity estimates made from the calibration factors obtained from the sliced lung sets can then be compared to the Acorrect≅ values and discrepancies can be expressed as either an activity underestimate (i.e., a value for activity content that is lower than the Acorrect≅ value) or as an activity overestimate (i.e., a value for activity content that is higher than the Acorrect≅ value). The counting efficiency can be expressed as a ratio of counting efficiency for the sliced lung set to the homogeneous lung set. These ratios are shown in Tables 1 and 2.

Table 1. Ratio of the JAERI counting efficiencies obtained for the sliced lung set divided by the counting efficiency obtained for the homogeneous lung set for the 50 mm and 70 mm detector systems. CWT is chest wall thickness**.**

adipose (%)	10	10	20	30	10	20	30		
CWT (mm)	19.64	28.1	28.1	27.8	34.9	34.7	34.7		
	50 mm detector system								
Energy (keV)								Average	1σ
17.7	0.89	0.90	0.94	0.86	0.82	0.85	0.93	0.88	0.04
59.5	1.05	1.03	1.02	1.05	1.05	1.06	1.05	1.04	0.01
121.8	1.02	1.02	1.01	1.02	1.02	1.02	1.02	1.02	0.00
244.7	1.01	1.01	1.00	1.02	1.02	1.03	1.02	1.02	0.01
344.3	1.01	1.00	1.00	1.01	1.00	1.02	1.01	1.01	0.01
	70 mm detector system								
17.7	0.95	1.03	0.98	0.93	1.01	0.95	0.96	0.97	0.04
59.5	0.98	1.01	1.01	0.98	0.97	0.99	1.00	0.99	0.01
121.8	1.03	1.05	1.04	1.04	1.02	1.02	1.03	1.03	0.01
244.7	1.02	1.04	1.03	1.03	1.01	1.02	1.03	1.03	0.01
344.3	1.01	1.04	1.03	1.03	1.02	1.02	1.02	1.02	0.01

Table 1 shows that for photon energies above 59.5 keV there appears to be little difference between the two types of lung sets measured in the JAERI phantom; however, as the photon energy decreases the difference between the lung sets increases. At 17.7 keV, the sliced lungs set emitted less photons than the homogeneous lung set and this maybe due to attenuation by the lamination, self absorption by the source material, or due to differing depth profile of the radioactivity on the filter paper. The chest wall thickness should not affect the ratios if the activity loadings of the planar inserts and the whole lung set are equivalent. As the chest wall thickness increases, low energy photons will be attenuated more severely than the higher energy photons. One would expect that only photons near the surface of the lung insert will be transmitted at higher values of chest wall thickness whereas at lower values of chest wall thickness some photons from deeper in the lung insert will also be transmitted. Table 1 shows no trend of ratio with chest wall thickness; therefore, it must be concluded that the activity depth profiles of the planar inserts manufactured in the HML are equivalent to the homogeneous lungs.

Table 2 shows a different trend to Table 1 as the ratios are all greater than unity, i.e., the planar inserts are give a higher counting efficiency at all photon energies. There is no apparent reason for this as the lamination thickness is the same as the sets manufactured in the HML and as there is no noticeable trend with increasing chest wall thickness the depth profiles appear to be essentially equivalent to the homogeneous lungs.

Table 2. Ratio of the LLNL counting efficiencies obtained for the sliced lung set divided by the counting efficiency obtained for the homogeneous lung set as a function for the 70 mm detector system. CWT is chest wall thickness**.**

Adipose (%)	0	15	21	26	30		
CWT (mm)	15.4	22.3	27.3	32.8	38.3		
Energy (keV)						Average	1σ
17.7	1.08	1.01	1.07	1.13	1.11	1.08	0.05
59.5	1.09	1.09	1.08	1.12	1.06	1.09	0.02
121.8	1.08	1.09	1.07	1.11	1.05	1.08	0.02
244.7	1.04	1.06	1.04	1.09	1.03	1.05	0.02
344.3	1.03	1.06	1.04	1.08	1.02	1.05	0.02

The data in Tables 1 and 2 have been tested statistically to determine if the ratios are significantly different from unity. A t-test at the 95% confidence level shows that the hypotheses that the average values are not statistically different from unity is untrue (i.e., they are statistically different) for both data sets except for the 17.7 and 59.5 keV photons measured with the 70 mm detectors in Table 1. Although sliced lung sets are not exactly equivalent to homogeneous lung sets they do give very similar results. A calibration performed with planar sources could underestimate the activity by a factor of about 1.1 at photon energies of 59.5 keV and higher. At 17 keV the situation is more complex as some data shows an underestimate of 1.1 or an overestimate of 1.14, depending on the construction of the lung set. Other work has shown (Rad Prot Dosim 74(3): 173-182; 1997) that 17 keV photons are highly dependent on the deposition pattern. Lung counting should not be used for an accurate assessment of the amount of activity in the lung if the only photon emitted is much lower than 59.5 keV.

CONCLUSIONS

This work has shown that sliced lung sets are different from homogeneous lung sets probably due to geometry effects; however, this difference is small (14% or less) compared to other uncertainties commonly encountered in lung counting i.e., activity deposition pattern in the lung, detector placement, size difference between individuals, etc. Sliced lung sets could be used instead of homogeneous lung sets to test or provide an interim calibration for a lung counting system. The activity estimate from sliced lung sets differs from the estimate from homogeneous lung sets by a factor of 0.88 to 1.09 depending on the photon energy. The use of a single sliced lung set with a set of planar sources can result in a considerable cost saving to a facility. Furthermore, several sets of planar inserts, which could contain a variety of radionuclides, can be used with a single sliced lung set instead of having to purchase many different types of lung sets. Additionally, the user has the capability to easily simulate heterogeneous distributions, something that cannot be done with homogeneous lung sets.