Comparison of sliced lungs with whole lung sets for a Torso Phantom measured with Ge detectors using MCNP and autoradiography.

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INTRODUCTION: Lung counting systems that measure low energy photons emitted from the lung must be calibrated with a realistic phantom to better simulate the counting geometry, photon scattering and attenuation effects. The Human Monitoring Laboratory (HML), which operates the Canadian National Calibration Reference Centre for *In Vivo* Monitoring, uses both the Lawrence Livermore National Laboratory (LLNL) realistic torso phantom and the Japanese Atomic Energy Research Institute (JAERI) realistic torso phantom to conduct the Canadian National Lung Counting Intercomparison Program .

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.

Lung counters are usually calibrated with lung sets that are manufactured from a lung tissue substitute material that contains homogeneously distributed activity. This can be an expensive proposition if a facility requires many radionuclide standards and several activity levels. Homogeneous lung sets also have the disadvantage that it is difficult to verify the activity in the phantom without destructive testing. It is also difficult to verify that the activity distribution is homogeneous. Previous work has shown that lung sets can have activities that are as much as 25% different from the expected value.

An alternative method to using homogeneous lungs to calibrate a lung counter is to use a sliced lung with planar inserts. This is also an inexpensive alternative and has been shown to be satisfactory arrangement for two germanium detector based lung counting systems (70 mm diameter or 50 mm diameter) with the two torso phantoms described above. The mean agreement between sliced lungs and whole lungs was a factor of 1.04 " 0.01 and 0.99 " 0.03 for the large diameter and small diameter detectors, respectively.

This work has extended the study by the use of Monte Carlo simulation to both validate the experimental findings that sliced and whole lungs are equivalent, and also to determine where the equivalence between the types of lung sources breaks down. The latter point deserves amplification: a lung that has the activity homogeneously distributed throughout the tissue equivalent material is nothing more than an infinite stack of thin planar sources. If alternate slices are replaced with inactive

thin slices there will be no change in the counting characteristics of the lung phantom. The Monte Carlo simulations presented in this paper have determined the maximum separation of the planar sources beyond which sliced lungs and whole lungs are no longer equivalent. Autioradiography has also been used to look at the radionuclide distribution on the planar sources and a homogeneous lung set that was sliced apart.

METHODS AND MATERIALS: The modelling of the virtual phantom and Ge detectors has been adequately described elsewhere. Slices, 0.03 cm thick (to be consistent with experimental work), were inserted in the lungs at a spacing of 0.5 cm. The slices used in the experimental work were made from filter paper (density, 0.5157 $g.cm^{-3}$). To model the slices, the composition of the virtual slices was made equivalent to rice powder (assuming that to be similar to paper) with a density set to that of the measured density. The photon source was defined to be a homogeneous distribution in each slice and weighted according to the volume of the slice.

The simulations were repeated with the spacing between the slices increased by 0.5 cm so that the spacings were simulated from 1.0, to 9.0 cm. Simulations at each photon energy were also made with a homogeneously distributed photon source. The following energies were simulated: 17 keV, 20 keV, 40 keV, 60 keV, 120 keV, 240 keV, 660 keV, and 1000 keV.

The Monte Carlo code used for the simulations was MCNP4A. The number of photons used in the simulations was varied from 10^6 to 10^9 so that the relative error varied from 0.004 to 0.099.

Autoradiography was performed with a Fuji Film Bio-Image Analyser BAS2000: The concept of the technology involves radiation-induced trapping in a re-useable semi-flexible sensor plate coated with a thin layer of a special phosphor material and release of the trapped energy as light when the sensor is stimulated under the scanning of a 50 micron laser beam in a reader unit. A photomultiplier tube detects the light and coordinates the light intensity measured in photostimulable luminescence (PSL) with the scanned positions, creating a digital image of the radiation field. One PSL is roughly equivalent to the light generated by four 5 MeV alpha particles.

RESULTS AND DISCUSSION: Fig. 1 shows the counting efficiency of the virtual phantom as a function of photon energy and spacing between the virtual slices using a four Ge detector array at 17 keV. The diminished effect of increasing the spacing is shown in Fig. 2 for 60 keV photons.

The counting efficiency of the four detector array at a spacing of 0.5 cm agrees well with the counting efficiency of the homogeneous lung set at all energies and it lies between -1.3% and 1%. The effect of increasing the spacing worsens the agreement, especially at low energy. At 17 keV the agreement lies between -37% and 12% for all spacings. As the energy rises, the bias values decrease so that at 1MeV the agreement lies between -5% to 1% for all spacings.

A spacing of 1.7 cm is predicted to give a counting efficiency that could be either slightly greater or slightly less than the counting efficiency of the homogeneous lung set. The agreement of the counting efficiency of sliced lungs with the counting efficiency of the homogeneous lung set is predicted to be within "4% at 17 keV. At 60 keV the difference between a sliced lung set and a homogeneous lung set is " 1% at all spacings of 3.0 cm or less.

Finally, it should be pointed out that homogeneous lung sets do not always agree well

with each other. An intercomparison of thirteen lung sets manufactured by three facilities for the JAERI phantom showed that at 17 keV the agreement of the measured counting efficiency of some lung sets with the mean value of that set of measurements was as poor as 30%. The situation improved as the photon energy rose to 60 keV where the agreement was 12% or better. An intercomparison of fourteen lung sets manufactured by four facilities for the LLNL phantom has shown that at 17 keV the agreement of the measured counting efficiency with the mean values of the set of measurements was within 13%. The situation improved as the photon energy rose to 60 keV where the agreement of the measured counting efficiency with the mean values of the set of measurements was within 9%.

At the time of writing this extended abstract the autoradiography results had not been fully analysed; however, preliminary analysis shows that there is little difference in the activity distributions between the two source types. They will be detailed during the presentation.

CONCLUSIONS:

Homogeneous lung sets for either the LLNL or JAERI phantom suffer from manufacturing problems and the amount of radioactivity in the lungs set cannot be altered after fabrication is completed. Lung sets with short lived radionuclides can only be used until the nuclides decay and then must be discarded. Replacement of these lungs sets can be expensive. Sliced lung sets on the other hand suffer none of these problems.

This presentation has shown that homogeneous lungs can be replaced by sliced lung providing that the slice thickness remains below 2.0 cm. This finding applies primarily to the LLNL torso phantom as the virtual phantom was modelled on that phantom; however, based on the experimental data referred to above, the findings are most likely valid for the JAERI phantom. The presentation will also show that the activity distribution on the planar sources and within the homogeneous lungs are sufficiently similar so that they can be interchanged with no adverse affect on performance.

Fig. 1: Counting efficiency of a four Ge detector array as a function of the spacing between the

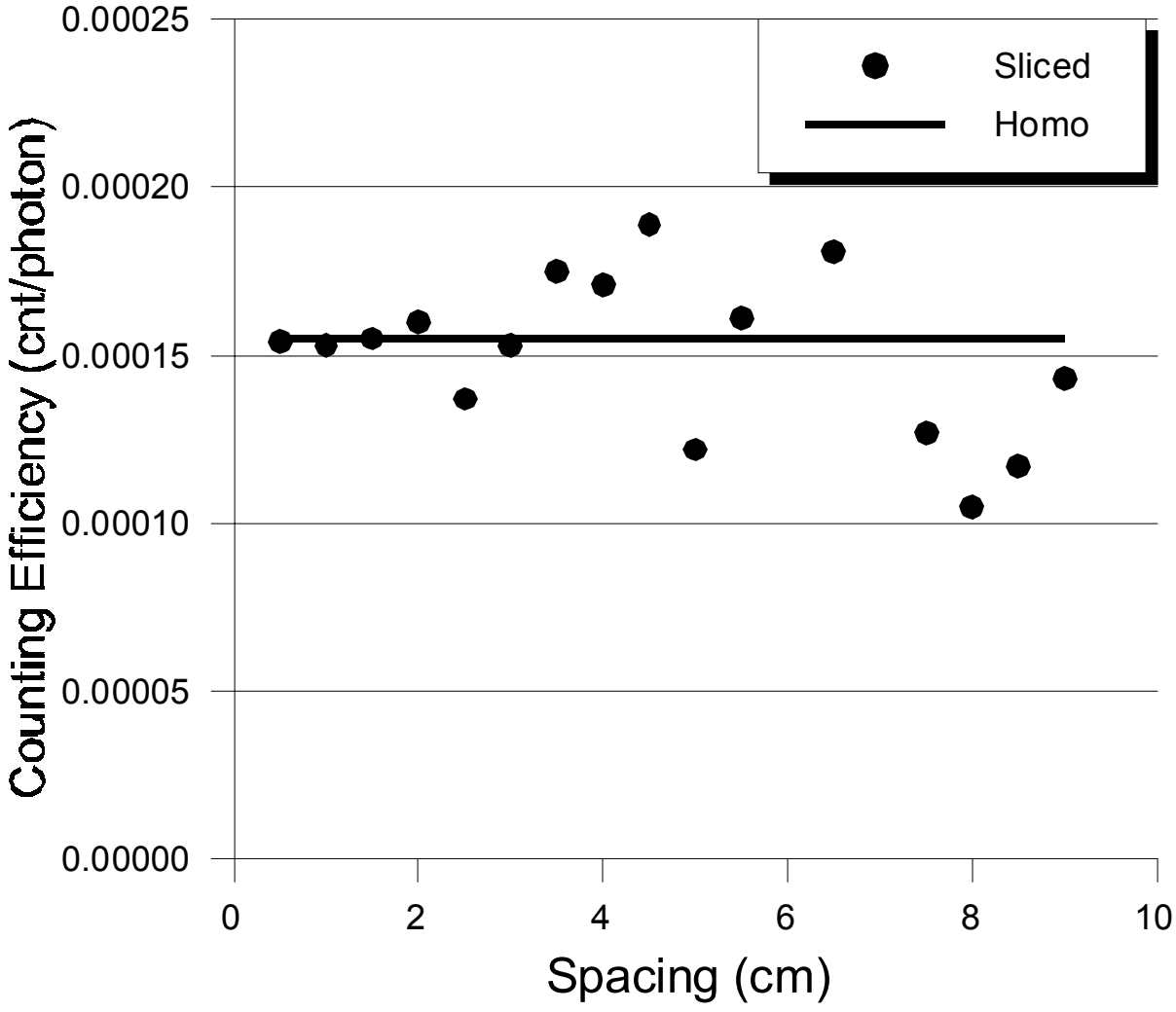

Fig. 2: Counting efficiency of a four Ge detector array as a function of the spacing between the