CONSIDERATIONS IN ASSIGNING DOSE BASED ON UNCERTAINTIES FROM *IN VIVO* COUNTING.

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INTRODUCTION

The dose estimate obtained from activity measurements from an *in vivo* count can only be as accurate as the results obtained from that measurement and depending on the nature of the uncertainty the bias can be in either direction. Thus, if the *in vivo* measurement grossly underestimates the amount of activity present, then the dose will be underestimated by a corresponding factor and the resulting health risk will be predicted too low. If, on the other hand, the *in vivo* result is overestimated, the dose estimate will also be overestimated by a corresponding amount, and the health risk will be inflated. This could cause severe anxiety in the subject and, consequently, lead to other health problems.

The Human Monitoring Laboratory (HML), which acts as the Canadian National Calibration Reference Centre for In Vivo Monitoring (1), has been investigating the effect of counting geometry and activity distribution on the results obtained from an *in vivo* (lung) count. These uncertainties have been expressed in terms of bias. Bias, expressed as a percentage, is:

$$Bias = 100 \left| \frac{obs - true}{true} \right|$$

Where *obs* = observed value and *true* = true value.

LUNG COUNTING

A lung counter is usually calibrated using a realistic torso phantom that contains lungs that have the radioactivity distributed homogeneously. However, in occupational or accidental exposures the radioactive contaminant is often associated with aerosol particulates. These particulates do not deposit themselves homogeneously when inhaled. The deposition pattern is directly related to particle size, lung function and working conditions.

Monte Carlo (2) simulations have been used to estimate the errors that can be obtained if it is assumed that the deposition is homogeneous, when in fact it is not. A virtual chest phantom was created and four germanium detectors were modelled to correspond to the lung counting system in the HML (70 mm diameter by 30 mm thick). The lungs were loaded with activity corresponding to 65 deposition patterns and up to 100,000,000 photons were followed. The detector efficiencies for 17, 20, 40, 60, 120, 240, 660, and 1000 keV

were calculated for a homogeneous deposition and these efficiencies were used to estimate the bias when the deposition was heterogeneous (3). A summary of results is shown in Table 1 with some practical results obtained at Oak Ridge National Laboratory (ORNL) using a three-detector array. The detectors were the same size as those modelled. The HML provided the tissue substitute lung sets that contained radioactivity to ORNL. The radioactivity was distributed in the lung sets in the same geometry as those modelled in the Monte Carlo simulations.

WHOLE BODY COUNTING

The apparent activity determined by whole body counting will be affected by activity distribution and/or size of the subject. These effects can be measured using Bottle Manikin Absorber (BOMAB) phantoms (4). The accuracy of ^{137}Cs activity determined from whole body counting has been estimated from the Canadian Whole Body Intercomparison programme (5) and the results obtained from the joint US DOE - HML International Intercomparison Programme (6). Both projects have evaluated the performance of many different types of whole body counters: scanning bed, scanning detector, static detector over prone or standing subject, shadow shield, chair, tilt chair, and arc. A summary of results is shown in Table 2 for systems that have measured a small (P4) and a large (PM95) phantom.

THYROID COUNTING

The accuracy of the activity determined in thyroid counting is dependent on the following factors: neck detector distance, size of detector, collimation, thyroid size, amount of overlaying tissue, the precision of detector placement in the plane normal to the neck detector axis. These factors have been evaluated both practically an theoretically using Monte Carlo methods (7, 8, 9, 10). A summary of results is shown in Table 3.

DISCUSSION

The measure of inaccuracy used to evaluate lung counting, whole body counting and thyroid monitoring is bias. It is the ratio of the difference between the observed result and the true result, and the true result. It is often expressed as a percentage.

Table 1 shows that lung counting can be a very inexact procedure, especially at low energy. Single detectors often missed the activity entirely (-100% bias) or overestimated the activity by a factor of approximately 12 (bias 1057%) at 17 keV. An array of detectors performs little better and the bias varies from -100% to 283%, which means that the activity is either missed entirely or overestimated by a factor of 3.3. As the photon energy increases to 60 keV the underestimate is a factor of 2.9 and the overestimate is 2.2.

Practical data collected by ORNL, using a three-detector array (two on the right of the chest and one on the left side), showed similar results. At 17 keV the activity was missed completely in some activity distributions and overestimated by factor of 4.8 in others. The situation improves as the photon energy rises a little and at 20 keV the array does not miss any activity; however, the uncertainties are large: the bias varies from -96% to 231%, which means that the activity is underestimated by a factor of 25 and overestimated by a factor of 3.3. At 60 keV the activity is underestimated by a factor of 2.7 and overestimated by a factor of 3.4.

It is clear that lung counting should be performed with an array of detectors to

minimise the effect of the heterogeneous deposition. The actual deposition of the inhaled radioactivity will remain unknown so that the data gives uncertainty interval that must be assumed to accompany the derived activity. Plutonium measurements (17 keV) are the most imprecise and carry the largest inherent uncertainty. Otherwise, lung counting (60 keV or above) can estimate the deposited activity to within a factor of three.

Table 2 shows that the interpretation of whole body counting results needs to consider the size of the person being measured. If reference man calibration factors are used to estimate the activity in subjects of other sizes, an uncertainty will be introduced into the result. Table 2 shows that the activity can be underestimated by a factor of two or overestimated by a factor of 3.4, depending on the geometry of the whole body counter. Data in Table 2 is for the 661.6 keV photopeak of ^{137}Cs so similar results can be expected for higher energy emitters; however, as the photon energy decreases, these uncertainties could double.

Table 3 shows that thyroid counting can be the most exact of the three *in vivo* techniques providing the counting geometry is optimised and other geometry effects are minimised (e.g., size of thyroid). There is no reason that activities of radioiodine cannot be measured to within 20% if the conditions of the last column of Table 3 are satisfied. If the situation lies between the columns then the activity obtained from a thyroid count will be probably be within a factor of two.

Table 1. Range of bias (%) for 70 heterogeneous lung depositions when the activity is calculated using the calibration factor obtained from a homogeneous deposition at 17, 20, 40 and 60 keV. The bias ranges are expressed for a four-detector array and individually calibrated detectors (1 to 4) with their position on the chest shown in parentheses. ORNL data is based on an actual split-lung phantom that matches the MCNP simulated geometry.

Detector configuration	17 keV	20 keV	40 keV	60 keV
Array	-100 to 283	-96 to 231	-69 to 131	-66 to 119
1 (top left)	-100 to 1023	-100 to 895	-90 to 410	-86 to 330
2 (bottom left)	-100 to 1057	-100 to 741	-90 to 475	-86 to 419
3 (top right)	-100 to 751	-100 to 751	-93 to 378	-89 to 361
4 (bottom left)	-100 to 954	-100 to 682	-92 to 457	-89 to 397
ORNL data	17 keV	20 keV		60 keV
Array (det 1,3 and 4)	-100 to 382	-94 to 303		-64 to 240

Table 2. Size dependency as a function of counting system obtained from measuring the activity of ^{137}Cs in a phantom that simulates either a four-year-old (P4) or 95 percentile male (PM95) and using reference man calibration factors. A range is given when more than one counter type was assessed.

Whole Body Counter	P4 Bias (%)	PM95 Bias (%)
Scanning bed shadow shield	15 to 55	-16 to -54
Scanning detector supine subject	95	-27
Tilt chair	30	-26
Close chair	240	-43
Static detectors supine subject	72	-11

Table 3. Bias estimates for factors that influence the activity determination in thyroid counting. Maximum bias for each factor is given in parentheses. The *Total bias* is an expected value and not the propagated values of the maxima of all cases.

Geometry Factor	Worst case	Optimum
Neck-detector distance	contact	15 cm
Detector positioning on the neck-detector axis	off-centre (70%)	on-centre (5%)
Detector collimation	yes (50%)	no (5%)
Depth of thyroid gland	> 1 cm (260%)	1 cm (5%)
Thyroid gland size	non-standard (30%)	20 gm (5%)
Total bias	200 %	10 %

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