THE EFFECTS OF PLUTONIUM REDISTRIBUTION ON LUNG COUNTING

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INTRODUCTION

Lung counting procedures are influenced by both interorgan and intraorgan distributions. The influence of interorgan distribution (translocation to liver, lymph nodes, etc.) is widely recognized and calibrations have been made for such distributions. Although nonuniform distribution within the lung is recognized, calibrations generally assume a uniform distribution since the magnitude of nonuniformities is unknown. At a meeting on the measurement of heavy elements in vivo (Swinth 1976), it was pointed out by several authors that "reasonable" nonuniform distributions could lead to changes of 200-300% in the calibration factor as compared to a uniform distribution. The purpose of this paper is to show that a nonuniform distribution is a reasonable expectation and to indicate the influence of a nonuniform distribution on assessment of plutonium depositions in the lungs by external counting techniques.

BACKGROUND

The spatial distribution of plutonium within the lungs is not uniform. The initial distribution depends on health, the breathing pattern at time of deposition and the particle size. Deposited materials do not remain at or near the site of deposition for the duration of their residence in the lung. McInroy (McInroy et al. 1975) measured concentration ratios ranging from 10 to 37 times as great in the subpleural region as the parenchyma (internal or central area) of the lung. Nelson (Nelson et al. 1972) reported a concentration ratio of 59:1. These results are for workers with 25 and 26 years of potential exposure, respectively. Results from an autopsy one month post exposure (McInroy et al. 1975) did not show a difference in the subpleural and parenchymal region concentrations.

Data from animal studies (Rhoads, Mchaffey and Sanders 1982) was analyzed to determine the change in concentration with time for the subpleural and internal regions of the lungs of rats. It was found that the relative particle concentration in the subpleural areas increased to 122% of the original after 180 days while the concentration in the rest of the lung decreased to 92% of the original. Calculating the subpleural to internal ratios for individual animals, one obtains a best-fit line of $y = 1.35 + 0.0029t$ where t is in days.

MATHEMATICAL MODEL

To further study the influence of non-uniform distributions on lung counting, a mathematical model of the thorax and phoswich counting system was developed paralleling the work of Dudley and ben Haim (Dudley and ben Haim 1968). The model assumes an elliptical thorax and was refined to study nonuniform distributions and different tissue types. Two 5-inch diameter scintillation counters (Phoswich detectors) are positioned over the upper chest to simulate the commonly used counting geometry.

The model assumes linear attenuation with the attenuation for a given tissue type being the combination of photoelectric and Compton effects

($\mu_{pi} + \mu_{ci} - \mu_i$, for tissue type i). Detector response for a given configuration of lung, chest wall, and detector is calculated by the sum of the transmission fraction for each path from the lung inversely weighted by the square of the total path length. This assumption is performed for a matrix of points throughout the chest model.

$$\text{Detector response} = \sum_{\text{Detector}} \sum_{\text{Lung}} \frac{p(x,y,z)e^{-\Sigma_i \mu_i d_i}}{(\Sigma_i d_i)^2}$$

where $\sum_{\text{Lung}} = \sum_x \sum_y \sum_z$

$$\sum_{\text{Detector}} = \sum_{i=1}^{\text{Number of detector points}}$$

$\Sigma_i \mu_i d_i$ = summation of path-length absorption product over tissue type i

d_i = distance of vector through tissue type i

$p(x,y,z)$ = intensity at point (x,y,z)

The tissue types included for study are bone, adipose tissue, muscle, lung, and soft tissue. Assumptions concerning tissue parameters are the following: bone covers 45% of frontal area with a uniform thickness; the chest wall is made up of 20% adipose tissue, 80% muscle tissue; and the density of lung tissue is 0.3 that of soft tissue. The attenuation coefficients used are identical to those in Newton et al (Newton, Taylor and Anderson 1978).

The model was verified by reproducing a configuration used in an empirical ^{103}Pd study (Newton, Taylor and Anderson 1978) and comparing the values for the response ratio, R (R is the ratio of ^{103}Pd x-ray intensity to the ^{238}Pu x-ray intensity). The maximum error in the three cases used for verification was 2% which was felt to be adequate verification.

In order to disperse unit activity in the model for different cases in a manner simulating the expected concentration ratios, calculation of the volume and number of mathematical sample points in a tissue for a given condition was required. The activity is assigned to each point as a function of: a) concentration ratio, b) volume of the respective tissue, and c) the number of sample points in each tissue. For the lung-lymph conditions the same method was used to assure the correct concentration ratios. The basic assumptions were a lymph tissue mass of 15 g, a lung of 900 g and densities for the respective tissues of 1.0 and 0.3 g/cc.

RESULTS

Figure 1 shows the change in detector response to the L x-rays compared to the uniform case response for various subpleural to lung concentration ratios. There is a rapid increase until a concentration ratio of 20:1 is reached at which point the increase tends to level out. At 20:1, approximately 64% of the activity is subpleural for the 3-mm case and 75% for the 5-mm case in our model. At 60:1, the respective percentages increase to

84% and 90%. Two subpleural thicknesses are shown to indicate the effect of increasing thickness on the count rate ratios. In actual tissue samples the subpleural activity will be concentrated near the surface and thicker samples will decrease the observed concentration ratio.

Curves for the ^{241}Am gamma ray (60 keV) are similar, but the curves do not increase as rapidly since the contribution from the deep lung (less attenuation) is greater.

Figure 2 shows the effect of movement to the tracheobronchial lymph nodes on detector calibration. Movement to the subpleural tissues leads to an increased detector response while movement to the lymph nodes leads to a decreased response compared to the same activity uniformly distributed in the lung volume. The change at 60 keV will not be as large as indicated on the figure due to the detection of scattered photons which were not considered in these calculations.

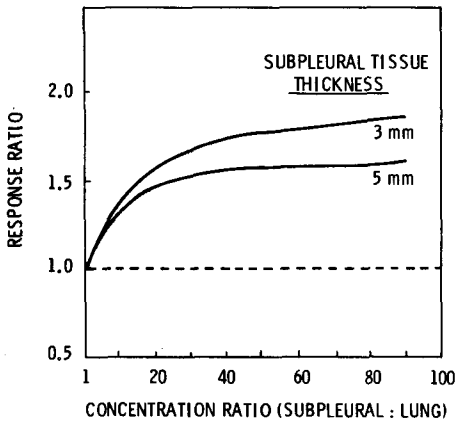

FIGURE 1: Change in Detector Response at X-Ray Energies with Increasing Concentration in the Subpleural Region of the Lung

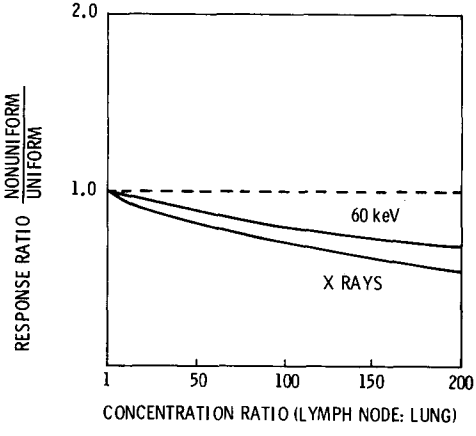

FIGURE 2: The Effect of Movement to the Trachebronchial Lymph Nodes on Lung Counter Response

Table 1 combines the features to show a modeled detector response at x-ray energies for time postexposure based on a linear extrapolation of data from Nelson (Nelson et al. 1972). This indicates that at increasing times postexposure the translocation of material will cause an increase in observed count rate compared to the uniform calibration phantom. This will result in overestimation of retained lung burdens by as much as 50%.

Although the uniform deposition model is adequate at short times postexposure, it is clear that translocation of material will be important in the continued analysis of lung depositions.

The uncertainties in a lung burden estimate caused by subject background estimation, counting statistics, and errors in chest wall attenuation corrections have been estimated to cause a collective uncertainty of approximately 80% in lung burden estimation (Swinth 1976). This is based on an individual containing 16 nCi with a 2.5 cm thick chest wall. Counting time is assumed to be 2000 seconds and errors were estimated at the 2σ level. Based on the current research, the effect of nonuniform distribution is to add an additional biased error of +50%. This would change the uncertainty to +95% and -80%. For a first order correction the regression equation

TABLE 1. Change in Count Rate for L X-Rays Compared to a Uniform Tissue Distribution at Various Times Postexposure

Years Postexposure	Assumed Concentration Ratios Subpleural to Lung	Lymph Nodes to Lung	Normalized Count Rate Ratios
0	1:1	1:1	1.0
5	10:1	30:1	1.26
10	20:1	60:1	1.35
15	35:1	90:1	1.43
25	60:1	140:1	1.48

$y = 1.35 + 0.0029t$ could be used if the time since exposure is known and a correction is necessary. When the other sources of error are considered, the overall impact of nonuniform distribution is not a dominant factor based on the present model. This ignores the effect of illness, breathing pattern, and aerosol characteristics on the initial deposition pattern and translocation rates.

ACKNOWLEDGEMENTS

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