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■Papers■

CHEST WALL THICKNESS MEASUREMENTS AND THE DOSIMETRIC IMPLICATIONS FOR MALE RADIATION WORKERS AT THE KAERI

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Abstract - Using ultrasound techniques, the Korea Atomic Energy Research Institute has measured chest wall thicknesses of a group of male workers at the Korea Atomic Energy Research Institute. A site-specific biometric equation has been developed for these workers. Chest wall thickness is an important modifier on lung counting efficiency. These data have been put into the perspective of the ICRP recommended dose limits for occupationally exposed workers: 100 mSv in a 5-year period with a maximum of 50 mSv in any one year. For measured chest wall thicknesses of 1.9 cm to 4.1 cm and a 30 min counting time, the achievable MDAs for natural uranium in the KAERI lung counter vary from 5.75 mg to 11.28 mg. These values are close to, or even exceed, the predicted amounts of natural uranium that will remain in the lung (absorption type M and S) after an intake equal to the Annual Limit on Intake corresponding to a committed dose of 20 mSv. This paper shows that the KAERI lung counter probably cannot detect an intake of Type S natural uranium in a worker with a chest wall thickness equal to the average value (2.7 cm) under routine counting conditions.

INTRODUCTION

Counting of low energy photons emitted by radionuclides deposited in the lungs requires the application of well known photon attenuation factors to account for photon absorption by the chest wall to assess correctly the amount of activity present. Chest wall thickness(CWT) is often estimated by biometric equations; however, as Vickers[1] has shown, these equations are site specific. This means that large errors can be introduced into the CWT estimate, and hence the activity estimate, if a literature equation is simply applied to a worker population without verification. Korea Atomic Energy Research Institute(KAERI) has measured chest wall thickness of a representative number of male w orkers at the KAERI to derive the appropriate biometric equation.

The CWT data has been used to estimate the sensitivity of the lung counting for natural uranium for KAERI's Ge detectors based on lung counting system. The dosimetric implications have put into the perspective of the latest recommendations from the International Commission on Radiological Protection(ICRP)[2]. The recommended dose limit is a 100 mSv in a five-year period with a maximum of 50 mSv in any one year. An average of 20 mSv per year has been assumed in this paper.

METHODS AND MATERIALS

Ultrasonic chest wall measurements were made with a portable ultrasound unit(Aloka SSD-500 echo camera). A 5 MHz linear array was used to make the measurements. Each subject was asked to strip to the waist. A clear template and a black marker were used to mark 14 measurement positions on the subject's chest above each lung(Fig. 1). These positions represented areas of the chest that would be measured by KAERI's germanium detectors. A stand-off pad was found to be unnecessary as the broad ultrasound probe did not distort the subject's skin surface. The ultrasound probe was covered with Aquasonic 100 gel prior to application to the subject's chest. The gel was reapplied to the probe whenever signal loss prevented a clear image being obtained on the ultrasound unit. One hundred and twenty one male subjects were measured in a supine geometry simulating the counting position of a lung counter. The subject's name, height, weight, and age were recorded. The height, weight, and age data were used to determine an empirical equation that could be used to calculate chest wall thickness for routine counting. Ultrasonic chest wall measurements should be used in the event of an actual contamination to reduce the error in estimating the chest wall thickness.

Fig. 1. Template and black marker for ultrasound measurements.

The lung counting system at KAERI, supplied by Canberra, consists of two ACT-II units. Each unit contains two Ge detectors(50 mm diameter, 20 mm thick, 0.5 mm Be window) 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. Spectra acquired with the Ge detectors are stored and analysed using AB · COSGPC software. The lung counter have been calibrated using the LLNL phantom[3] with and without 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 KAERI lung counting efficiency has been fitted to adipose mass fraction, CWT, and photon energy as described elsewhere[4]. The background counts used for the MDA estimate of the lung counter were obtained from the spectra of ten uncontaminated persons who were measured for 1800 seconds in the KAERI's lung counter. The counts in the appropriate spectral region of interest were used with the appropriate calibration factor for that energy. Units of MDA will depend on the units of the calibration factor and the counting time. For natural and enriched uranium, KAERI uses both Bq and milligrams. The following formula is based on the work of Currie[5], with Brodsky's[6] modification:

$$\mathbf{MDA} = \frac{\mathbf{4.65\sqrt{N}}}{\mathbf{E \cdot T}} + \frac{\mathbf{3}}{\mathbf{E \cdot T}} \qquad (1)$$

where N is background counts in the region of interest, E is counting efficiency(cps Bq-1 or cps mg-1), and T is counting time(sec).

RESULTS AND DISCUSSION

The 14 measurement points on both left and right lungs were averaged to give an average chest wall thickness above each lung. The 28 points were also combined and averaged to give an average chest wall thickness for a lung counting detector array. Table 1 shows the site specific data for the average, standard deviation of a single measurement, standard deviation of the mean, the median, the maximum, and the minimum of Age, Height, Weight, and CWT of the 121 KAERI male workers. The grand average of a male supine subjects was 2.70 cm. Table 1 summarises the weight, height and age data that were used to derive an empirical equation to predict CWT. Linear regression was performed on the data using the function published elsewhere[7]:

$$\mathbf{CWT = a + b\left(\frac{Wt}{Ht^2}\right) + c(age)} \qquad (2)$$

where CWT is predicted chest wall thickness(cm), Wt is subject's weight(kg), Ht is subject's height(m), and a, b, c are the coefficients of regression. The results of the regression are shown in Table 2. The standard error in Table 2 indicates that 68% of the predicted CWT values will be within 0.28 cm, 95% within 0.56 cm, and 99% within 0.84 cm. Fig. 2 shows measured CWT values of 121 subjects plotted against CWT values predicted by eq. (2).

Table 1. Site specific data showing the average, standard deviation of a single measurement, standard deviation of the mean, the median, the maximum, and the minimum of Age, Height, Weight, and CWT of the 121 KAERI male workers

	Age(y)	Height(m)	Weight(kg)	CWT(cm)
Average	40.7	1.71	69.3	2.70
σ	6.6	0.0501	8.14	0.444
σ_{mean}	0.6	0.00455	0.74	0.0404
Median	41.0	1.71	69.0	3.6
Maximum value	59.0	1.82	98.0	4.14
Minimum value	24.0	1.59	54.0	1.88

Table 2. Parameters for the fitted regression line for CWT as a function of weight, height and age

Parameter	Value	Standard Deviation
a(cm)	-0.366	0.295
b(cm m^2 kg^{-1})	0.145	0.0108
c(cm y^{-1})	-9.15×10^{-3}	3.87×10^{-3}
Corr coeff	0.61	
Stand. Error(cm)	0.279	

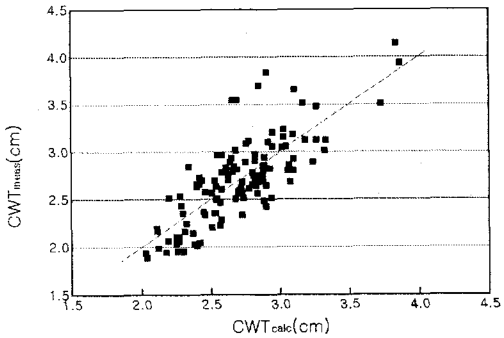

Fig. 2. Plot of calculated CWT values vs measured CWT values showing the linear regression line.

Table 3 shows calculated MDA values for the KAERI four-detector germanium array. Given that the range of CWT values is 1.9 cm to about 4.1 cm, the achievable range of MDA is about 5.75 mg to 11.28 mg of natural uranium using photons emitted from ^{235}U. The grand average CWT is 2.7 cm so the corresponding MDA will be about 7.35 mg. Doubling the counting time to 60 minutes will reduce the MDA to about 5 mg of natural uranium. Table 4 shows the predicted values of measured quantity in the lungs following an single intake of either 439 mg or 130 mg(the Annual Limit on Intake for Type M and S, i.e., that amount of activity that will give a committed effective dose of 20 mSv). The values were calculated from data published elsewhere[8]. Type F was not considered as it will not be retained in the lung and should be part of a urinalysis bioassay program.

Table 3. MDA values for the KAERI four-detector Ge lung counting array using a 30 and 60 minute counting time

CWT(cm)	Minimum Detectable Activity(mg) of natural uranium	
	Counting time= 30 min	Counting time =60 min
1.9	5.75	3.91
2.7	7.35	5.00
4.1	11.28	7.67

Eight intake scenarios were investigated: 7, 14, 30, 60, 90, 120, 180 and 360 days before a lung count. It is assumed that a hypothetical individual who has a CWT equal to the average value(2.7 cm, AMF 20%) has an intake at each time before a lung count. The hypothetical individual is measured using the KAERI lung counting Ge detector array and the activity estimate is based on ^{235}U.

Type M intake: it will be readily detected on days 7, 14, 30, 60, 90 and 120; however, as the MDA for a 30 minute count time is 7.35 mg, days 180 and 360 will be missed. If the counting time increased to 60 minutes the MDA would be expected to drop to 5 mg which is still too high to detect the in take on day 360.

Type S intake: it will be detected on days 7 if the counting time is 30 minutes. Days 7, 14, 30 and 60 will be detected if the counting time is 60 minutes, but days 90, 120, 180 and 360 will be missed as they are below the MDA.

For countries using earlier ICRP recommendations and a dose limit of 50 mSv per year the situation is somewhat different. The values in Table 4 would be multiplied by 2.5 and then compared against the MDA values in Table 3. Under these circumstances the hypothetical individual would have a Type M or S intake detected for days 7, 14, 30, 60, 90, 120 and 180 if the counting time was 30 minutes.

Table 4. Special monitoring : predicted values(mg per one ALI intake) of measured quantity in the lungs following single intake by inhalation(5μ m AMAD)

Time after intake, days	Type M	Type S
7	22.7	7.7
14	20.6	7.3
30	16.9	6.4
60	12.3	5.4
90	9.6	4.9
120	7.7	4.6
180	5.2	4.2
360	1.8	3.5

CONCLUSIONS

The average chest wall thickness of 121 male workers at the KAERI was 2.7 cm. Achievable MDAs(30 minute counting time) with the KAERI lung counting Ge detector array lie in the range of about 5.75 mg to 11.28 mg of natural uranium based on the ^{235}U emissions over a range of CWT of 1.9 cm to 4.1 cm. The average achievable MDA is about 7.35 mg which can be reduced to about 5 mg by doubling the counting time. Unfortunately, these MDA values are close to, or above, the predicted amounts of natural uranium that will remain in the lung after an intake equivalent to the Annual Limit on Intake that corresponds to 20 mSv has occurred.

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