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In Vivo Counting of ^{241}Am and Uranium in Human Lungs

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Abstract

Individual internal monitoring program by in-vivo measurement technique at the Korea Atomic Energy Research Institute includes the capability for the assessment of uranium and americium lung burdens. This capability is an important part of the health and safety program. This article addresses the lung burden assessment portion of our in vivo measurement capabilities.

1. Introduction

Inhalation of ^{241}Am and uranium compounds of widely varying chemical and physical properties can occur during the industrial processes used to produce nuclear fuels and may therefore constitute a health hazard. Therefore, monitoring programs for internal contamination should be designed to provide the information needed for estimating the exposure of workers in terms of primary or secondary limits.

Techniques employed to assess the intake of uranuim compounds comprise *in vivo* measurement, urinalysis and measurements of airborne contamination using static or personal air samplers. The choice of these techniques is mainly governed by inhalation class, isotopic composition and the sensitivity and availabilty of the appropriate measurement facilities. Therefore, in an attempt to further improve and upgrade internal dosimetry programs(1,2) at Korea Atomic Energy Research Institute, a lung counting system specially designed for *in vivo* measurement was installed.

This article describes the lung counting system, the backgrounds obtained, and the calibration method. Included is a brief discussion of origins of the uncertainty in the estimated lung burdens.

2. Radiological Characteristics

The isotope ^{241}Am decays by alpha particle emission with a half-life of 432 year. The decay is accompanied by gamma ray emission at 59.6 keV(abundance 36 %). L X and gamma rays of lower energy(range 14 - 26 keV) are also produced but are not favoured as a means of detection. The reason are (i) that they are severely attenuated in the body and (ii) that their contributions cannot be resolved from those given by X rays due to the decay of any associated nuclides. Radioactive decay properties of uranium isotopes are summarized in Table 1. The ^{235}U component is detected by measurement of 185.7 keV photon, and the ^{238}U component is detected by 63.3 keV and 92.8 keV emitted by its daughter.

Table 1. Radioactive decay properties of uranium isotopes$^{(3)}$.

nuclide	half-life (years)	specific activity (Bq/mg)	photon emissions^{a}
^{238}U^{b}	4.5 x 10^{9}	12.1	63.3[3.8], 92.4[2.7], 92.8[2.7]
^{234}U	2.5 x 10^{5}	12.8	53.2[0.12]
^{235}U	7.0 x 10^{8}	0.6	25.6[14.8]^{c}, 84.2[6.5]^{c}, 93.3[4.3], 143.8[10.5], 163.3[4.7], 185.7[54], 205[4.7]

^{a}energy(keV), followed by % abundance.

^{b}photons emissions are from ^{234}Th daughter.

^{c}emission from ^{231}Th daughter.

3. Lung Counting System

The shield is 10 cm thick, and is constructed of low background steel plates(top, bottom and four sides). The shield has inside dimensions of 213 x 86 x 137 cm W x D x H. The interior of the shield is covered with a stainless steel liner.

The detection system consists of two arrays of ACT(Actinide)-II detector system which combines two ACT-I LEGe(Low Energy Germanium) detectors and end caps onto a single 7 liter multi-attitude cryostat, which have been designed specially for the detection of internally deposited actinides, particulary uranium, plutonium and americium.

Each LEGe detector equipped with a 0.5 mm Be window has active area of 20 cm^2 and thickness of 20 mm. The resolution of four LEGe detector averages 400 eV FWHM at 5.9 keV and 700 eV FWHM at 122 keV. 1 cm Pb and 0.5 mm Cu is attached around sides of ACT-II detectors to reduce ^{40}K and scattered background contribution from the subject and surrounding materials.

The electronics system consists of HV power supplies, preamplifiers, amplifiers and analog multiplexer. Multiplexer accepts analog signals from multiple amplifier and routes them into their respective segments of MCA memory. The MCA is configured to provide 8192 channels of memory, and the ADC parameter of MCA is configured to provide four 2K groups. So data from detector # 1 is stored in the first 2048 channel group, data from detector # 2 is stored in the second 2048 channel group, and so on. This results in four individual spectra, each representing spectrum obtained from individual detectors. The MCA type used is PC-based MCA acquisition board which is supported by DOS software.

4. Calibration Method

Evaluation of internally deposited, photon-emitting radionuclides by *in vivo* measurements requires calibration of the counter for converting the counts obtained into amount of activity deposited in the lungs. Calibration of the counter may be by realistic phantoms, human volunteer inhalation programmes and theoretical calculations(4). The approach that has been used in this study was based on measurements made of Lawrence Livermore National Laboratory(LLNL) torso phantom(5) with accurately known activities.

The LLNL torso phantom was based on a cadaver which was representative of a population of radiation workers at the LLNL and at Los Alamos National Laboratoris. The phantom contains a simulated rib cage and removeable lungs, liver, heart and major tracheo-bronchial lymp nodes. And chest plate overlays can be used with the phantom to simulate the chest wall over the lungs. ANSI N13.30(6) recommends the use of the LLNL torso phantom for calibration and test of *in vivo* systems for measurements of ^{239}Pu, ^{241}Am and other transuranic radionuclides deposited in organs of the upper torso. Calibration source with the LLNL torso phantom was a mixture source of ^{241}Am and ^{152}Eu providing a number of prominent photon emissions with energies between 17 keV and 344 keV. The mixed source was deposited on the planar sheets to simulate a uniform activity matrix throughout the volume of the LLNL torso phantom lung inserts.

The lung inserts were loaded in both lungs of the LLNL torso phantom, and the phantom was positioned on the counting bed. Detector positions were adjusted to place the detector faces at the reference lung marking on the phantom chest wall. Detector angles were adusted to position the face of each detector as close to tangent as possible at point of contact with the phantom. Count was performed on phantom with the torso plate cover only. And counts were also peformed as the CWT was increased from 17.4 mm to 40.5 mm using chest plate overlays(50:50 muscle:adipose ratio). Figure 1 shows the counting efficiency as a function of chest wall thickness for energies of interest.

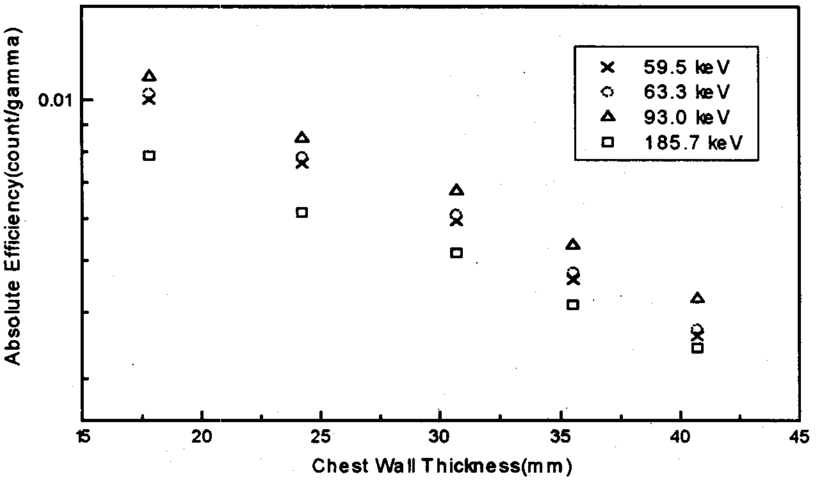

Figure 1. Absolute efficiency as a function of chest wall thickness for 59.5, 63.3, 93.0 and 185.7 keV.

5. Background Measurement

The background measurement have been taken of empty shield, water-filled BOMAB phantom ,LLNL torso phantom and 35 normal subjects. The background obtained in the energy regions of interest in the iron room are shown in Figure 2. The Minimum Detectable Activity(MDA) was determined using mean background of 35 normal subjects and applying the following expression to the results(6).

$$MDA(Bq) = 4.65 * \frac{\sqrt{BKG}}{F \cdot T \cdot Y} + \frac{3}{F \cdot T \cdot Y}$$

Where BKG is the number of counts in the ROI of background, F is the counting efficiency(count/gamma), and T is the counting time(sec). Y is the fractional yield of each energy lines. The MDAs for 59.5 keV, 63.3 keV, 93 keV and 185.7 keV at 95 % confidence level as function of chest wall thickness are shown in Figure 3.

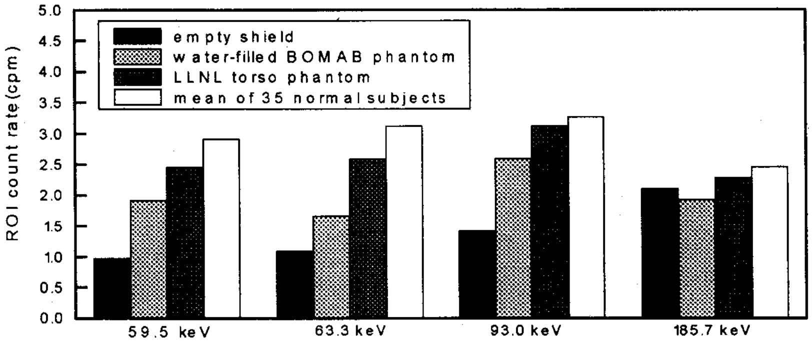

Figure 2. ROI background count rate comparisons in the iron room under various conditions.

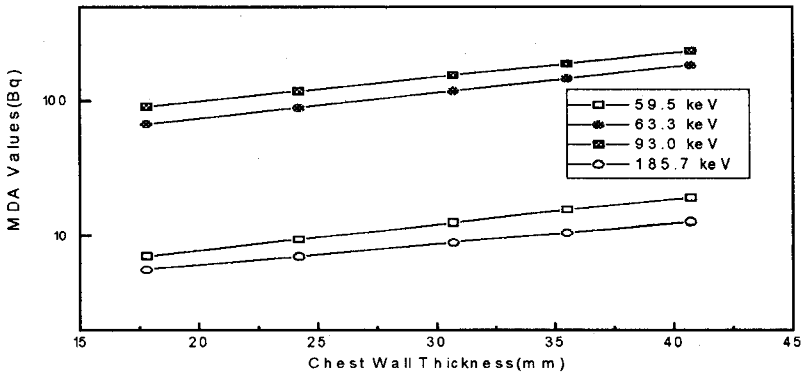

Figure 3. MDA values as a function of chest wall thickness for 1800 second counts.

6. Uncertainty in Lung Burdens

Errors associated with the calculated lung burdens of individuals, B, are determined by assuming that radionuclides are homogenously distributed in the lungs and that the uncertainty in all of the terms are random in nature. Since the burden calculations are of the form B=N・F , the fractional uncertainty in the lung burden is represented by

$$\frac{\sigma_B}{B}=\sqrt{\left(\frac{\sigma_N}{N}\right)^2+\left(\frac{\sigma_F}{F}\right)^2}$$

Where F is the calibration factor for uniformly distributed isotopes in the lungs, and N is the net count rates for energy regions of interest. The values of σ_F/F are determined to be 0.1 for 59.5 keV, 63.3 keV, 93 keV and 185.7 keV. Over the range of chest wall thickness from 15 mm to 30 mm, the values of σ_F/F are also nearly constant.

References

1. International Commission on Radiological Protection. *Individual Monitoring for Intakes of Radionuclides by Workers : Design and Interpretation.* Publication 54 (Oxford : Pergamon Press)(1987).
2. International Commission on Radiological Protection. *Limits for Intakes of Radionuclides by Workers.* Publication 30 part 1(Oxford : Pergamon Press)(1979).
3. International Commission on Radiological Protection. *Radionuclide Transformations, Energy and Intensity of Emissions.* Publication 38(Oxford : Pergamon Press)(1983).
4. International Atomic Energy Agency. *Direct Methods for Measuring Radionuclides in Man.* IAEA Safety Practices(Final Draft), IAEA, Vienna(1993).
5. Gary H. Kramer. *The LLNL Torso Phantom : A Description of Usage.* HMLTD-90 -3(1993).
6. American National Standards Institute. Draft American National Standard *for Performance Criteria for Radiobioassay.* ANSI N13.30(New York : ANSI)(1989).