MONITORING OF LOW-ENERGY X-RAY RADIONUCLIDE CONTENT IN HUMAN BODY

E.I.Dolguirev, G.N.Kajdanovsky, N.V.Porozov, V.M.Shamov

Institute of Radiation Hygiene

Leningrad

USSR

Abstract

A 15 cm -dia 0.1 cm thick NaI detector and an Ar-CH_4 proportional counter with a 300 cm^2 window are used for in vivo measurements of ^{210}Pb, ^{239}Pu and ^{241}Am content in human body. The subject's background was determined from the correlation of the counting rates in two channels, e.g. for ^{210}Pb: 30-55 and 100-150 keV, respectively. The detectors were calibrated on an anthropomorphous phantom with a thickness of the tissue absorption layer varying from zero to 4 cm.

Calculation methods for nuclide content in critical organs and cases illustrating different types of radionuclide distribution in human body are given.

Introduction

The amount of internally deposited radionuclides in personnel is accepted by present-day international and national standards as one of the basic criteria used in the sphere of radiation protection. However, the evaluation of human body burdens of incorporated ^{210}Pb,^{239}Pu and ^{241}Am is materially complicated by the difficulties involved in obtaining data on the distribution of these radionuclides in individual critical organs. The difficulties involved in detection are due to a number of factors and particularly, to the low-energy radiation of radionuclides assessed. The possibility of obtaining such information is determined to a large extent, by proper choice of techniques of in vivo and calibration measurements which depend on the pattern of radionuclide distribution among and in the subject's organs.

There are three main types of distribution of the above radionulcides in human organism: lung, osteohepatic and a combined one. The specific pattern of distribution is determined by the rhythm and route of the nuclide administration, the chemical form of the deposited compound and some other factors. The combined type of radionuclide distribution is the most general and complicated one, as far as direct measurements are concerned.

Many important aspects of in vivo assessment of low-energy radionuclide content in human body have been discussed in the papers[1-6]. This work deals with the methods and illustrations of measurement procedures for ^{210}Pb, ^{239}Pu and ^{241}Am for different patterns of their distribution in the body.

Equipment

The unit comprises a detection system and a measurement panel with channels for registering energies in the ranges of 10-25, 30-55, 35-70 and 100-150 keV. The detection system consists of two proportional 7.5 cm Ar-CH_4 gas filled counters with a 300 cm^2 window each and two scintillation counters with 15 cm-dia 0.1 cm thick crystals of NaI(Tl). The counter window panes are made of 0.03 cm-thick beryllium plates. The counters are mounted in an iron chamber 2x1.5x1.5 m with a wall thickness of 15 cm. The scintillation counter background is 20 cpm (10-25 keV) and 65 cpm (35-70 keV). The proportional counter background is 3 cpm (10-25 keV). The counter sensitivity is characterized by the magnitude of calibration coefficients (see Fig.1).

Prediction of the Subject's Background

The sensitivity and accuracy of in vivo measurements of low-energy internally-deposited nuclides are determined, to a great extent,by the individual subject's background level and precision of its measurement. It is impossible to measure directly the specific background in a given contaminated subject because the continuous distribution of pulses of the diffused radiation of high-energy radionuclides ^{40}K, ^{137}Cs, etc. and the photopeak of the low-energy radionuclide measured, e.g. ^{210}Pb, ^{239}Pu, ^{241}Am are registered in the same energy interval. We suggested a method of prediction of the subject's background which is based on the probable correlation between the background counting rate in the main channel where the photopeak of the nuclide measured is registered, and the background counting rate in the reference channel, where this peak does not occur. The correlation between the background counting rates in these two channels was derived from our measurements carried out in a group of people of the different build and with different body contents of high-energy radionuclides. The experimental data processed by the method of least squares were approximated by the following equation:

$$N^M = \alpha + \beta N ,$$

where N^M - expected background counting rate, cpm, in the main channel in the energy interval of E_1-E_2; N - registered counting rate in the reference channel in the energy interval of $E_3 - E_4$ = 100 - 150 keV; α and β - parameters whose numerical values for different energy intervals are given in the Table:

Radionuclide	E_1-E_2keV	Position of Detector	α	β
^{210}Pb	30 - 55	Over chest	42.5	1.37
		Over skull	14.80	0.50
^{239}Pu	10 - 25	Over chest	9.7	0.19
		Over skull	0.19	0.33
^{241}Am	35 - 70	Over chest	18.6	1.33
		Over skull	11.5	0.88

Methods

Since the radionuclides of lead, plutonium and americium are generally deposited in the lungs, liver and skeleton. The detectors were placed over the lungs and the liver in front of the subject's chest and over the frontal bone of the skull, a location most convenient for skeletal measurements.

The body contents of ^{210}Pb and ^{241}Am were measured by scintillation counters, while that of ^{239}Pu - by both scintillation and proportional counters.

The set of equations for the values of the activity of the radionuclide deposited in each of the critical organs is:

$$J_i = \sum_{j=1}^{4} q_j \varepsilon_{ij} , \qquad (i=1,2,3,4) \qquad \text{(Eq.1)}$$

where J_i - the counting rate of the detector over the i-organ, which is determined by the measured nuclide radiation; q_j - the desired activity of the radionuclide deposited in the j - organ; ε_{ij} - calibration coefficient which is numerically equal to the counting rate measured by the detector over the i-organ for unit activity of the radionuclide in the j-organ of the phantom. The indices used of the equation set (Eq.1) are : 1 - the right lung 2 - the lung; 3 - the liver and 4 - the skeleton.

The value J_4 includes the counting rate measured over the skull, while ε_{44}-the same for unit activity of the radionuclide content in the entire skeleton.

Radionuclide quantum radiation was measured in the intervals: 10 - 25 keV for ^{239}Pu; 10-25 keV and 35-70 keV for ^{241}Am and 30-55 keV for ^{210}Pb. The calibration coefficients ε_{ij} (Fig.1) were obtained by means of an anthropomorphous phantom which comprised the skull, trunk and arms and legs.

Since the actual distribution of deposited radionuclides involves the values of ε_{41}, ε_{42} and ε_{43} close to zero, these values were disregarded in the calculations, too.

Solutions to the equation set (Eq.1) were found from $q_j = \Delta_j/\Delta$ where Δ is the determinant of the system and Δ_j is the determinant of the undetermined value q_j.

The fourth equation was excluded from the set of equations (Eq.1) and the terms containing ε_{14}, ε_{24} and ε_{34} - from the three first equations, when ^{239}Pu content was calculated, on the assumption that the X-ray radiation of ^{239}Pu is nearly completely absorbed by skeletal bones.

In assessing ^{210}Pb or ^{241}Am, the counting rate J_4 determined by the measured radionuclide radiation was found to be equal to that registered by the detector less the background value. In the measurements of ^{239}Pu content this equation may be upset due to the presence of the impurities of ^{241}Am, the energies of the X-ray lines of which lie within the range of ^{239}Pu radiation. In such case, the values of J_i were obtained from the expression:

$$J_i = I_i - \sum_{j=1}^{3} q_j^{Am} \varepsilon_{ij\,(10-25)}^{Am} \qquad \text{(Eq.2)}$$

where I_i - the counting rate detected over the i-organ less the background value; q_j^{Am} - the amount of the activity of ^{241}Am deposited in the j-organ; $\varepsilon_{ij}^{Am}(10-25)$ - calibration coefficients in the interval of 10-25 keV obtained experimentally as a result of insertion of ^{241}Am-emitters into the phantom organs. Values for q_j^{Am} were computed from the data of measurements of the gamma-radiation of ^{241}Am in the energy interval of 35-70 keV.

In Vivo Measurements Examples

Case of Lung Distribution of ^{241}Am

Four people were exposed to the radiation from an americium source as a result of a failure of containment during experiments. The nuclide was inhaled in the form of insolible americium dioxide. 0.4 to 2.2 nCi ^{241}Am was found in the lungs. Fig.2 shows the spectrumof ^{241}Am radiation recorded over the lungs of one of the subjects three months after the exposure. Distinct gamma-spectra recorded over the subject's head were detected at the beginning of measurements only (Fig.3). As they were not detected after repeated decontamination measures had been taken, it was an indication of the surface contamination of the skin and hair. Therefore, it provides evidence that it was a case of lung distribution of ^{241}Am.

Case of Osteohepatic Distribution of ^{210}Pb

The measurements were carried out in a group of volunteers who took a hydrochloric acid solution of ^{210}Pb, at pH = 3. The gamma-spectra recorded over the subjects' head and liver are given in Fig.4 and 5. The activity Q deposited in the whole skeleton was assessed with due regard to the equation: $Q = q \cdot k(t)$, where q is the activity deposited in the skull; k(t) is the coefficient of conversion of the skull activity to that of the skeleton which allows for both the ratio of the masses of the skull and the whole skeleton and the nuclide distribution in the compact and trabeculate tissue portions of skeletal bones. The value k(t) varies with time from 16.5 on the first day of radionuclide administration to 12.3 on the 100th day, owing to the continuous re-distribution of bone-seeking elements.

The measurement results showed the skeleton/liver ratio to be 3 to 4 in the average of four subjects on the 100-th day of ^{210}Pb administration, which points to the skeletal distribution of lead chloride in human body.

Case of Combined Lung-Osteo-Hepatic Distribution of ^{239}Pu and ^{241}Am

Measurements in man usually fail to produce statistically significant spectra of plutonium and americium radiation. Such spectra, however, may be obtained by long-term measurements, if the thickness of the muscular, fat and skin tissues of the subject is not great. Fig.6 shows the spectra recorded by a scintillation counter placed over the lungs, liver and skull of the subject. The peaks of the pulse amplitude distribution corresponds to the energies of 17 keV and 60 keV, which indicates at the incorporated plutonium and americium. Fig.7 shows the spectra obtained by means of a proportional counter placed over the skull and the right lung of the same subject. It also shows three characteristic peaks which make it possible to identify the X-ray radiation of plutonium with energies of 13.6 keV, 17.4 keV and 20.4 keV respectively. The said spectra provided evidence that this is a typical case of the lung-osteo-hepatic type of radio-nuclide distribution.

References

1. R.Ehret, H.Kiefer, R.Maushart and G.Möhrle, Assessment of Radioactivity in Man, Vol.1, I.A.E.A., Vienna, 1964.
2. D.Ramsden and R.Speight, AEEV-R494, 1967.
3. B.Taylor, Health Physics, v.17, No.1, 1969.
4. T.Tomitani and E.Tanaka, Health Physics, v.18, No.3, 1970.
5. J.Rundo, K.Rudran and B.Taylor, Health Physics, v.17, 1969.
6. M.Eisenbud et al., Health Physics, v.16, 1969.

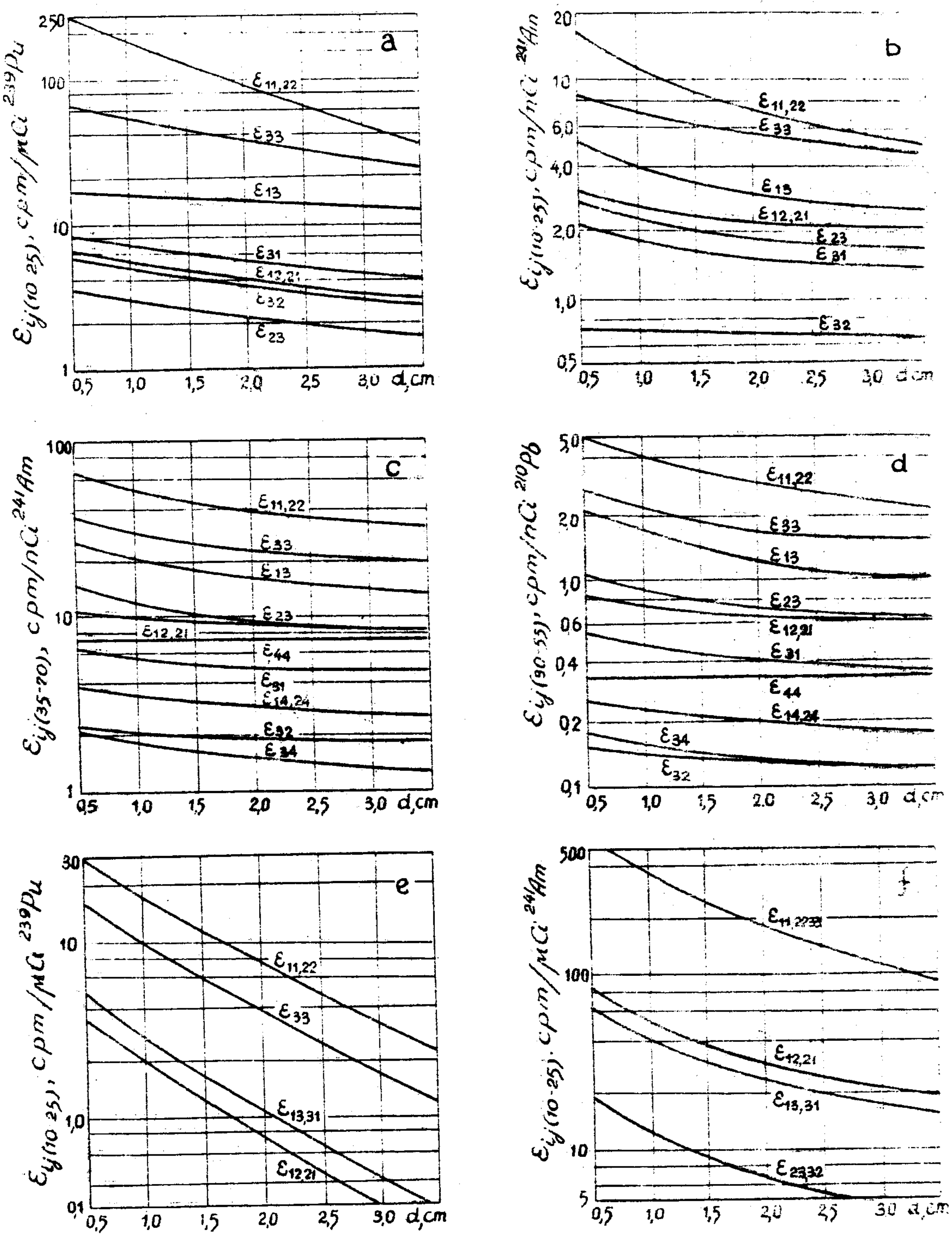

Fig.I.Calibration coefficients ε_{ij} vs soft tissue thickness for scintillation counter in the energe range: a)IO-25keV ^{239}Pu, b)IO-25keV ^{241}Am, c)35-70keV ^{241} Am, d)30-55keV ^{241} Pb and for proportional counter in the energe range IO-25keV: e) ^{239}Pu, f) ^{241} Am.

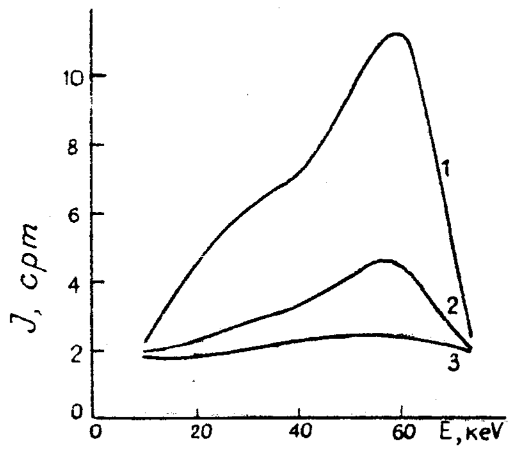

Fig.2.Spectra ^{241}Am:I-fantom (I0nCi),2-contaminated sub- ect(2nCi),3-control subject.

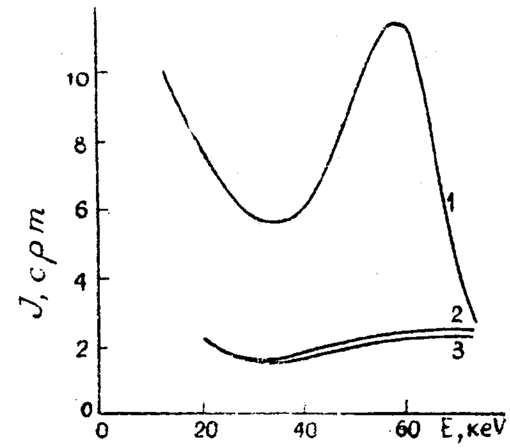

Fig.3.Spectra ^{241}Am:I-conta- minated 3.I0.72; 2-6.22.72. 3-control subject.

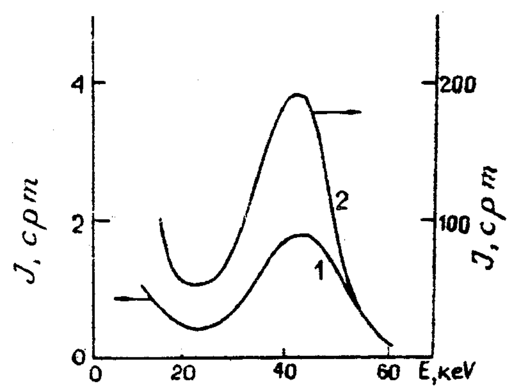

Fig.4.Net spectra ^{210}Pb: I-over head contaminated subject;2-over skull of fantom.

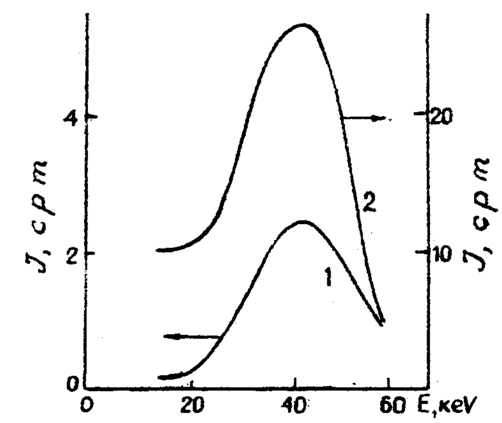

Fig.5.Net spectra ^{210}Pb over liver: I-contaminated sub- ject, 2-fantom.

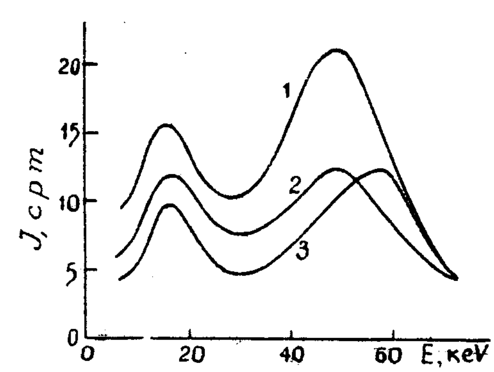

Fig.o.Spectra Pu+Am over: I-right lung, 2-liver, 3-Head of contaminated subject.

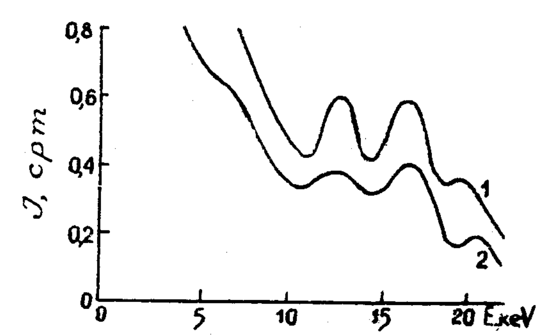

Fig.7.Spectra Pu+Am over: 1-right lung, 2-head con- taminated subject.