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Gross Distribution of ^{241}Am In A Man Seven Years After Inhalation

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By

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1. INTRODUCTION

In 1967, four individuals, who had been exposed in an industrial plant to airborne particles of americium over a period of several months in late 1966, were investigated at Argonne National Laboratory for possible internal contamination. Measurements of the 60-keV γ ray with a NaI(Tl) crystal showed that one man had a burden at least fifty times that of the others. A series of measurements was then made to determine the apparent distribution of the isotope within his body. The results indicated widespread deposition in the skeleton in addition to material remaining in the lungs. The relative uptakes of ^{241}Am in different parts of the skeleton were consistent with the assumption that americium was deposited on bone surfaces and, therefore, was concentrated more in trabecular bone than in cortical bone. [1] Since that time, this subject has undergone extensive chelation therapy with DTPA at a hospital. [2]

The subject visited the Center for Human Radiobiology in 1973 and new measurements were made in order to determine the gross distribution of radioactivity in his body seven years after exposure.

2. γ-RAY MEASUREMENTS

2.1 Seven-Position Scans

Measurements of the 60-keV γ ray were made along the body of the supine subject with a modified "seven-position-scan" technique, originally developed by Miller. [3] Two 29.2-cm diameter by 10.2-cm thick NaI(Tl) detectors were used, one at 30 cm above the bed and the other at 10 cm below the bed. The fourth position was at the midpoint of the subject's height, and the interval between successive positions was 15% of the subject's height.

The results of these measurements indicated the general longitudinal distribution of ^{241}Am in the body and are shown in Figure 1. The peak at position 2 arises from activity in the vertebrae, ribs, and thorax. The higher counting rates from the upper crystal at positions 5 and 6 indicate activity in the bones of the legs, and especially in the knees, since more soft tissue shields the lower crystal than the upper, even though the legs are much closer to the lower crystal than to the upper.

GROSS DISTRIBUTION OF ^{241}Am IN A MAN SEVEN YEARS AFTER INHALATION*

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ABSTRACT

The gross distribution of ^{241}Am remaining in a man seven years after exposure to airborne americium particles has been determined by several techniques.

Measurements were made of the radiation with NaI(Tl) crystals, one above and one below the supine subject at seven equally spaced points along the long axis. The patterns obtained indicated skeletal deposition in addition to material in the thorax. More detail was obtained from a longitudinal profile scan made at 10 cm intervals with a slit-collimated detector. A general labelling of the skeleton consistent with bone surface deposition was observed, together with a pronounced increased concentration in the thorax. A transverse profile scan was made at the point which had yielded the highest counting rate in the longitudinal scan. Unequivocal evidence for a lung burden was observed in the asymmetry of this scan.

The presence of the long-term lung burden was further confirmed by measurements made over the chest with a gas-filled proportional counter. The ratio of primary quanta in the 60-keV peak to those which had been forward scattered indicated that the radiation had passed through approximately 5 cm of soft-tissue equivalent absorber. Since estimates of the subject's chest wall thickness were only about 2.5 cm, the major part of the radiation was coming from deeper in the chest, below the level of

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the rib cage. Therefore, the material in the chest was primarily in the lungs and not in the bones of the thoracic cage.

The proportional counter also showed that there was little contamination in the liver and spleen. This was expected since the subject had undergone extensive chelation therapy with DTPA at another center. The whole-body content of ^{241}Am was estimated to be 1.00 ± 0.03 μCi, with about 25% of this amount in the lungs. Thus, a sizable fraction of the material retained is still in the lungs after seven years.

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These scans indicate that much of the activity in the thorax is actually in the lungs for the following reasons: 1) a higher counting rate is observed from the back than from the front; 2) the maximum counting rate appears to be nearer the vertex when measured from the front than from the back; and 3) a broader peak in the counting rates is observed from the back than from the front. All these characteristics can be predicted from a consideration of the size, shape, and positioning of the lungs in the thoracic cavity.

2.2 Profile Scans

In order to determine more exactly the distribution of radioactivity in the subject's body, a longitudinal profile scan was made. A lead collimator with a 2.54-cm-wide slit transverse to the long axis of the body was placed over the lower detector and measurements were taken at 10-cm intervals. The interval was decreased to 5 cm in regions where the response from ^{241}Am differed markedly from one position to the next. Figure 2 shows the profile obtained. Peak counting rates occur in the regions of the skull, chest, pelvis, knees, and feet, consistent with the 1967 results, which indicated labelling of the entire skeleton, but especially trabecular bone. The large peak from the chest is due to material both in bone and in the lungs, and the asymmetry of this peak at 50 cm from the vertex may be due to material in the liver and spleen, or in the rib cage and vertebrae. The aperture was then turned through 90° so as to be parallel to the long axis of the body, and a transverse profile scan was made of the chest at 40 cm from the vertex, the position which yielded the highest counting rate in the longitudinal scan. The transverse scan is shown in Figure 3. The asymmetry of this scan indicates that the response came primarily from material in the lungs rather than in the bone, since the right lung is larger than the left. Similar patterns of activity have been observed in several volunteers who inhaled a radioactive aerosol as part of an intercalibration experiment for the detection of plutonium *in vivo*. [4]

2.3 Whole Body Content

The subject's radioactivity was measured with a 29.2-cm diameter by 1.27-cm thick NaI(Tl) crystal while he lay on a curved bed of 1.5-m radius. Measurements were made both with the subject facing the detector and with his back to the detector, which was mounted 1.37 m above the bed. The efficiency of detection of the 60-keV γ ray in this configuration varied along the length of the bed. A correction was made for this by weighting the efficiency observed at each of several positions along the curved bed with the relative radioactivity of the subject at that position, obtained from the seven-position scan.

Transmission measurements through tissue-equivalent material established the mass attenuation coefficient for the 60-keV γ ray to be 0.130 cm^2/g. Because the NaI(Tl) crystals are unable to resolve scattered radiation from primary quanta in the 60-keV peak, a correction for forward scattering was necessary. This correction amounted to 28%. With the use of these values and of transmission data for the subject (measured at the upper back, lower back, and knee), the effective average thickness of the body was determined to be 12.4 cm.

With the assumption that the effective center of the radioactivity was at the midplane of the body, the whole body burden of ^{241}Am was calculated to be 1.0 ± 0.03 μCi. This value, when added to the total amount of ^{241}Am excreted under chelation therapy, [5] indicates an initial deposition of 2.2 μCi, some 20% higher than was estimated in 1967. [1]

3. MEASUREMENTS AT HIGHER RESOLUTION

In order to estimate directly the remaining lung burden of this subject, measurements were made with an 18-cm diameter xenon-filled proportional counter placed over midsternum of the supine subject. This counter has much higher resolution than the NaI(Tl) crystal and has the ability to resolve the ^{237}Np L x rays, as well as scattered γ rays.

3.1 Determination of Effective Source Depth

In order to determine the amount of ^{241}Am present in the lungs of this subject, the amount of absorber interposed between the source and detector had to be known. This quantity (the effective soft tissue thickness) was estimated from the equation suggested by Rundo et al. [6] (However, their empirical equation was derived for 20-keV photons, and may not be valid at 60 keV.) For this subject the effective soft tissue thickness, which allows for the lower density of lung tissue, was 5.17 ± 0.73 cm. Normally, a calibration factor is then obtained by layering tissue-equivalent absorber over a source of ^{241}Am to obtain a broad-beam attenuation curve, and a calibration factor (cpm/μCi ^{241}Am) is interpolated from this curve.

However, this procedure could not be applied directly to this subject because of the possibility of an unknown fraction of the total chest burden lying in the ribs, with the rest lying in the lungs. Consequently, an alternative empirical method of determining the amount of absorber through which the ^{241}Am radiations had passed was developed. [7]

Briefly, the method consists of measuring the ratio of scattered quanta to primary quanta from the 60-keV transition. The region from 35 to 45 keV consists entirely of scattered radiation, and the ratio of counts in this region to those in the 60-keV peak was found to be a linear function of the amount of tissue-equivalent absorber covering a ^{241}Am source.

The proportional counter spectrum obtained from the chest of this subject is shown in Figure 4. The peak at 26.3 keV is due to a γ ray from decay of ^{241}Am and the conversion x rays are at 13.9, 17.8, and 20.8 keV. The peak at 30 keV results from the escape of a 30-keV xenon x ray following complete ionization of an atom of the counting gas by a 60-keV γ ray.

In the spectrum of Figure 4, the ratio of scattered counts to peak counts indicates an absorber thickness of 4.86 ± 0.49 cm. This figure agrees quite well with the estimated effective soft tissue thickness of 5.17 ± 0.73 cm for radiation in the 20-keV region, confirming that the burden lies primarily in the lungs. A small fraction of the total amount present lying in the rib cage cannot be ruled out because of the rather large limits of precision of these numbers. For instance, a combination of 80% of the total amount of ^{241}Am present under 5.25 cm absorber and 20% of the total under 2.5 cm absorber gives a scattered-to-peak ratio lying within the lower limit of that obtained from the subject. However, the proportional counter, when placed over midsternum, directly views only a small fraction of the bone in the rib cage (except for the sternum itself). Consequently it is unlikely that ^{241}Am in the rib cage is contributing an appreciable fraction of the observed response.

The same technique was used to estimate the effective depth of ^{241}Am deposited in other regions of the body. The results are shown in Table I and all are consistent with what would be expected from anatomical considerations.

The counting rate observed when the detector was positioned over the liver was nearly equal to that observed over the left side. The absence of ^{241}Am from the liver was no doubt due to the chelation therapy.

3.2 Calibration Factor for ^{241}Am in the Lungs

Since the empirical method of determining the depth of ^{241}Am deposited in the thorax gave a value which agreed well with the estimated effective soft tissue thickness, a calibration factor was obtained as follows. A point source of ^{241}Am was placed at a distance from the counter equal to the half-thickness of the subject's thorax. Tissue-equivalent absorber was placed over the source to obtain a broad-beam attenuation curve, and a calibration factor was interpolated from this curve for 4.86 cm of absorber. Application of this factor to the counting rate measured over the subject's chest gave a value of 0.23 ± 0.03 μCi ^{241}Am for the lung content. The same value was obtained from counting either the x rays or the 60-keV γ rays. In the case of the x-ray region, however, it was evident (see Figure 4) that scattered radiation was making a sizable contribution to the counting rate observed. This contribution was probably offset by the total absorption of x rays in the rib cage. However, an exact method of determining the contribution of scattered radiation to this region remains to be developed.

Since americium deposited in the rib cage and sternum lies much closer to the counter than that distributed throughout the lung (and possibly thoracic lymph nodes), a sizeable fraction of the thoracic content present

FIGURE CAPTIONS

Fig. 1. Seven-position scans of the subject. The counting rate from the upper crystal is shown by the symbol (X), and the counting rate from the lower crystal by (O).

Fig. 2. Longitudinal profile scan of the subject. These measurements were made with a 2.54-cm wide aperture on the lower crystal.

Fig. 3. Transverse profile scan of the subject at 40 cm from the vertex. The positions are left and right of the median line of the body.

Fig. 4. The spectrum of ^{241}Am obtained with the proportional counter centered over mid-sternum of the subject. The solid line was obtained by smoothing the experimental points over eleven-channel intervals; this results in considerable loss of resolution in the region below 35 keV.

TABLE I: The effective depth of ^{241}Am deposited in various regions of the body.

Location	Skull	Thorax	Liver	Left side	Knees
Effective depth, cm (±10%)	0.75	4.86	11.8	12.3	2.47

TABLE II: Correlation of observed counts in the profile scan with bone surface area. $\rho = +0.94$.

Region	Portions of skeleton	% total surface area[a]	% total counts (less lung content)
I	Skull 4 cervical vert.	12	14
II	3 cervical ert. Thoracic vert. Chest cage Humeri	26	23
III	Lumbar vert. Pelvis Proximal femurs Radii Ulnae Hands	33	26
IV	Distal femurs Proximal tibiae Proximal fibulae	17	22
V	Distal tibiae Distal fibulae Feet	12	15

[a]Derived from the distribution of cortical and trabecular bone by mass for reference man (ICRP Publication 23, 1975, p. 67).

in the rib cage would result in an estimated total thoracic content much lower than that given above. Such a lower content would be inconsistent with the results of the profile scans presented in section 2.2.

4. CONCLUSIONS

A strong correlation between the distribution of activity measured in the longitudinal profile scan and the available bone surface areas may be obtained if two assumptions are made: first, the lungs contain some 25% of the total body burden and second, the calibration factor for ^{241}Am does not vary markedly from one position of the profile scan to another. The distributions of counting rate and surface area are presented in Table II. The correlation between the two distributions is +0.94, which is significant at the 99% level.

There are four major conclusions which may be drawn from our measurements on this subject:

1. Chelation therapy has resulted in the removal of more than one-half the initial body burden.

2. There is little activity in the liver—presumably due to removal of ^{241}Am by the chelation therapy.

3. Some 10% of the initial body burden remains in the lungs.

4. Distribution of the remaining activity is consistent with deposition on bone surfaces.

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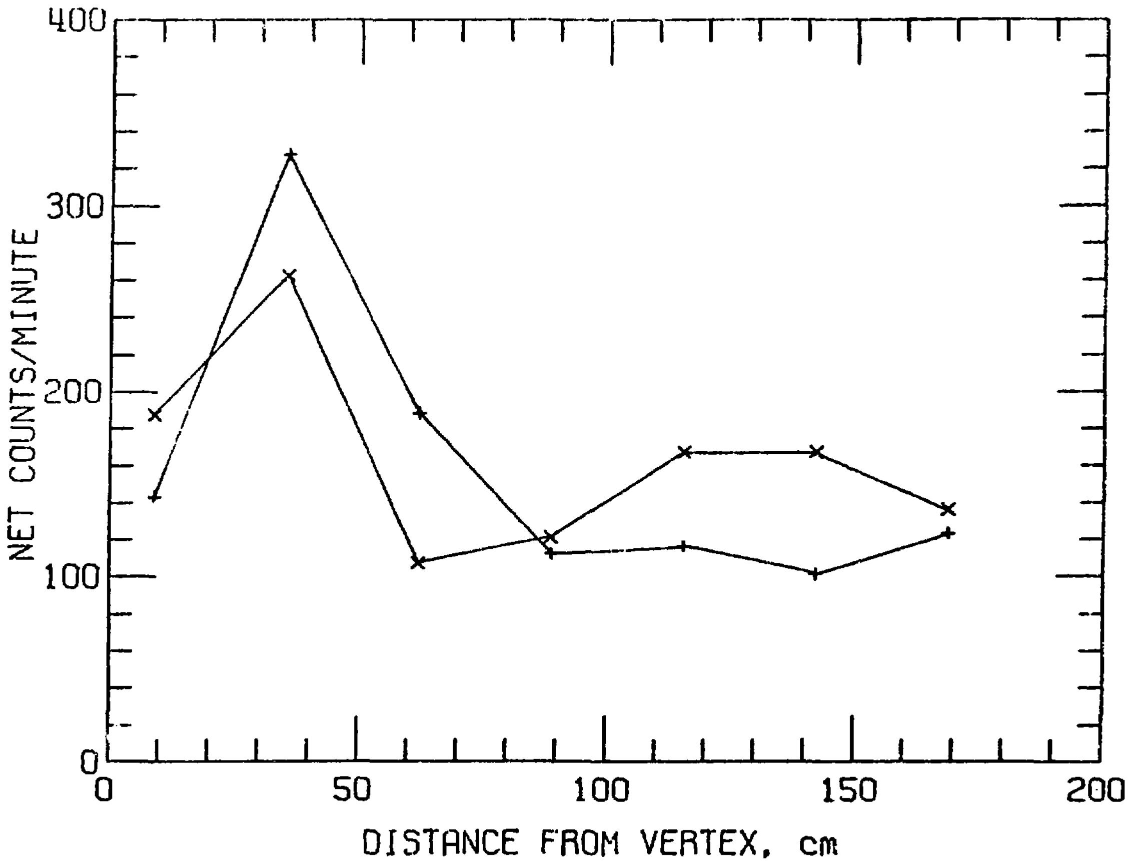

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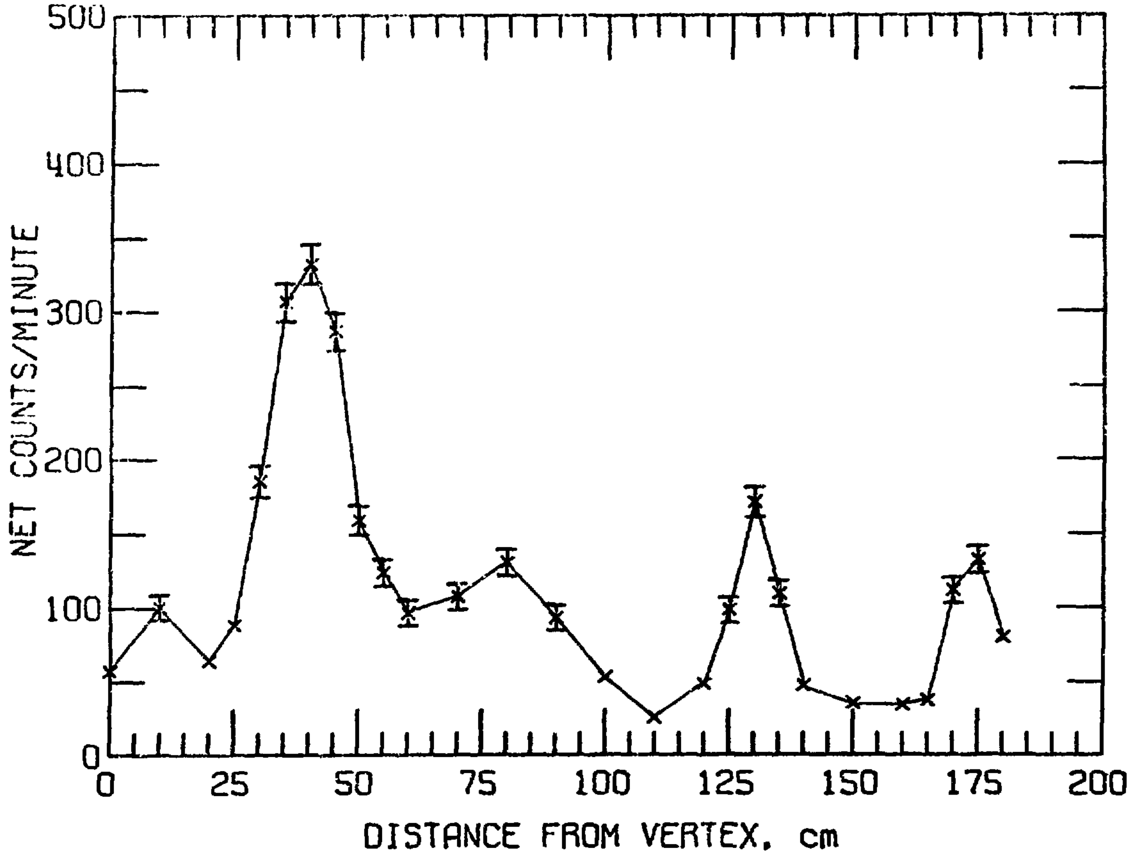

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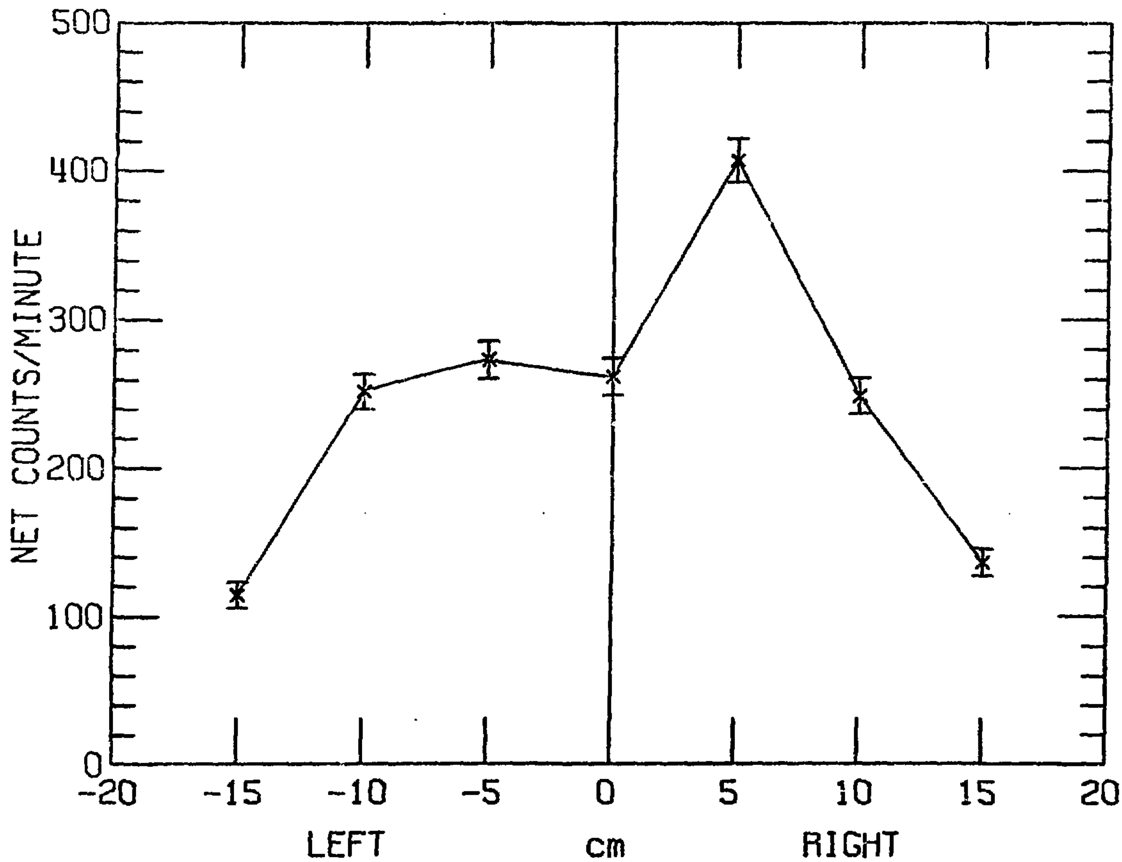

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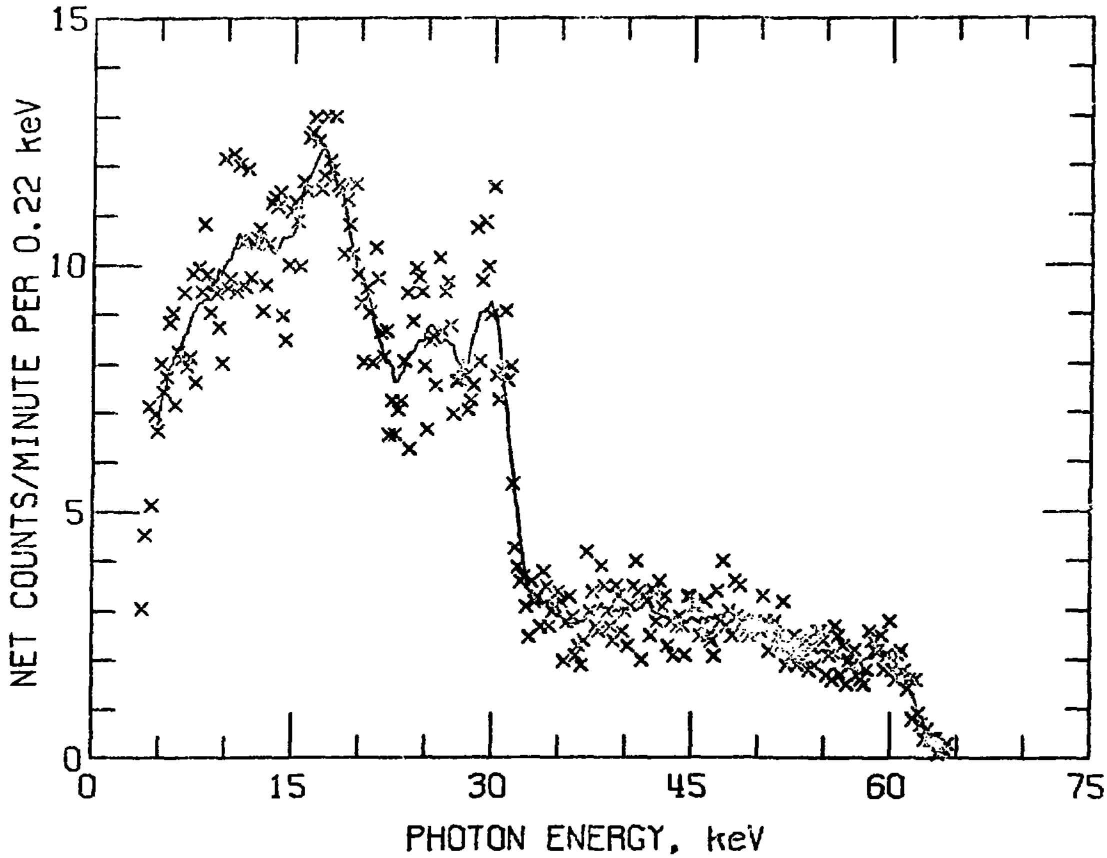

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