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TITLE: MASTER LTI-ENERGY GAMMA-RAY AUTOMATED SCANNING SYSTEM

AUTHOR(S): Hsiao-Hua Hsu, Group Q-2
John C. Pratt, Group Q-2
Edward R. Shunk, Group Q-2

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MULTI-ENERGY GAMMA-RAY AUTOMATED SCANNING SYSTEM

H. H. Hsu, J. C. Pratt, and E. R. Shunk

Los Alamos National Laboratory
Los Alamos, New Mexico, 87545, USA

ABSTRACT

A CAMAC-based gamma-ray scanning system was used to measure the transmission through stacked attenuators for up to 16 different gamma rays. For each measurement, we obtained the transmission for gamma rays ranging in energy from 77 to 2614 keV. These transmission measurements were used to produce a set of linear equations that may be solved for either thickness or density of the discrete attenuators comprising a given stacked assembly.

INTRODUCTION

A CAMAC gamma-ray scanning system[1] was used for multi-energy transmission measurements. These measurements allowed us to estimate the densities or separate thicknesses of stacked discrete attenuators.

EXPERIMENTAL SETUP

The gamma-ray detector used in this experiment was an [illegible] purity germanium detector, positioned some [illegible] from a selected gamma-ray source. A scanner carriage transported the attenuating materials along a line normal to the detector source axis, as illustrated in Fig. 1. The scanner carriage is positioned by a drive screw turned by stepping motor that is controlled by the data acquisition system.

A LeCroy 3500 multichannel analyzer was used to acquire and store the data for subsequent analysis. The LeCroy 3500 has a built-in CAMAC minicrate, keyboard, and cathode-ray tube display (Fig. 2). It runs a CP/M® operating system that supports FORTRAN programs. LeCroy supplied both a FORTRAN-callable CAMAC program and plotting libraries that were used to develop the data-acquisition software employed in making these measurements.

The LeCroy 3500 also has special CAMAC data acquisition modules that can iniate direct memory access (DMA) to the 24-bit data memory. One such module is the LeCroy 3511 analog-to-digital converter that detects and digitizes the gamma-ray detector pulses. The digitizing time for 13 bits is 5 μs; the DMA time is 1 μs. With this module programmed to deliver its data by direct memory access, the gamma spectra acquisition continues without impact on the computation.

We acquired a transmitted gamma-ray spectrum for each horizontal point considered, then controlled the stepping motor to position the carriage to the next point. At the end of the operator-specified acquisition time for each of those points, we read the data memory and extracted the net photopeak area for each of up to 16 separate gamma rays. The ratio of each transmitted gamma ray's count rate to the count rate with the object (or stack of attenuators) removed, is the transmission of the material(s) at that point.

EXPERIMENTAL METHOD

Specific probe monoergetic gamma rays were chosen as widely separated in energy as possible in order to have a suitably large range of material attenuation coefficients. A ^{238}Th-^{208}Tl source comes very close to these requirements, decays with a long half-life, and is readily available. On occasion, a ^{60}Co source was incorporated for acquiring better statistics in the middle of the energy range employed.

One gamma-ray transmission scan of a multiple-component/multiple-layer attenuating assembly appears in Fig. 3. The arrangement of the attenuating materials is shown in Fig. 4. The scan shows a series of irregular steps as the scanner transports the attenuator assembly through the gamma-ray beam. The boundaries between materials appear on the plot. The measured transmission occasionally increases markedly at boundary points where poor joints allow a straight-through path for source gamma rays. One such spatial scan was recorded for each gamma ray.

If we denote

$I_0(k)$ = intensity of gamma-ray k without absorber,

$I(k)$ = intensity of gamma-ray k with absorber,

ρ_i = density of absorber i, in g/cm^3,

$\mu_i(k)$ = attenuation coefficient of absorber i at the energy of gamma ray k, in cm^2/g, and

t_i = thickness of absorber i, in cm,

then the transmission ratio $I(k)/I_0(k)$ is given for the materials present by

$$I(k) = I_0(k) \exp -\sum_i \mu_i(k)\, \rho_i t_i \tag{1a}$$

or

$$\ln \frac{I_0(k)}{I} = \sum_i \mu_i(k) \rho_i t_i \, . \tag{1b}$$

One such equation, relating the material thicknesses (or densities) to observed gamma-ray intensities, is obtained for each gamma ray.

EXAMPLE

Consider the following seven gamma rays of ^{228}Th-^{208}Tl, ^{133}Ba, and ^{60}Co: 238, 356, 583, 860, 1332, 1620, and 2614 keV. Imagine these gamma rays impinging upon some composite structure made up of the materials shown in Table I.

If we take the densities and attenuation coefficients as known, the thickness of each material remains unknown on the right-hand side of equation (1b), which when expanded produces the following set of seven equations in six unknowns:

$$\ln \frac{I_0(238)}{I(238)} = 7.08\, t_1 + 1.90\, t_2 + 0.959\, t_3 + 0.303\, t_4 + 0.121\, t_5 + 0.218\, t_6 \tag{2a}$$

$$\ln \frac{I_0(356)}{I(356)} = 3.10\, t_1 + 1.10\, t_2 + 0.7[illegible]\, t_3 + 0.261\, t_4 + 0.105\, t_5 + 0.188\, t_6 \tag{2b}$$

$$\ln \frac{I_0(583)}{I(583)} = 1.61\, t_1 + 0.761\, t_2 + 0.[illegible]\, t_3 + 0.21[illegible]\, t_4 + 0.08[illegible]\, t_5 + 0.15[illegible]\, t_6 \tag{2c}$$

$$\ln \frac{I_0([illegible])}{I([illegible])} = 0.897\, t_1 + 0.[illegible]\, t_2 + 0.[illegible]\, t_3 + 0.178\, t_4 + [illegible]\, t_5 + 0.128\, t_6 \tag{2d}$$

$$\ln \frac{I_0([illegible])}{I([illegible])} = 0.[illegible]\, t_1 + 0.[illegible]\, t_2 + 0.[illegible]\, t_3 + 0.1[illegible]\, t_4 + [illegible]\, t_5 + 0.10[illegible]\, t_6 \tag{2e}$$

$$\ln \frac{I_0(1620)}{I(1620)} = 0.[illegible]\, t_1 + 0.[illegible]\, t_2 + 0.[illegible]\, t_3 + 0.1[illegible]\, t_4 + [illegible]\, t_5 + 0.09[illegible]\, t_6 \tag{2f}$$

$$\ln \frac{I_0(2614)}{I(2614)} = 0.[illegible]\, t_1 + 0.[illegible]\, t_2 + [illegible]\, t_3 + 0.1[illegible]\, t_4 + [illegible]\, t_5 + 0.0[illegible]\, t_6 \tag{2g}$$

where t_1, t_2, t_3, t_4, t_5, t_6 are the thicknesses (in centimeters) of lead, cadmium, iron, aluminum, polyethylene, and mock high explosive, respectively. One such set of linear equations occurs at each point in a typical scan, relating the thicknesses of the materials at that point to the transmission of the gamma rays at that point.

We can find these unknown thicknesses $t_1 \ldots t_6$ by solving the set of six linear equations exactly, or finding the t_i by a least-squares method where there are more equations than unknowns. The results of a test run appear in Table II.

Inferred attenuator thickness values were, in general, lower than the actual thickness for each specific attenuating material. The observed difference can be attributed to the fact that the employed theoretical attenuation coefficients for these materials were derived from narrow beam considerations, an ideal situation not too well realized in the actual measurements.

REFERENCE

1. C. E. Moss, J. C. Pratt, and I. K. Shunk, "A CAMAC Gamma-Ray Scanning System," Fifth Symposium on X- and Gamma Ray Sources and Applications, Ann Arbor, Michigan, June 10-12, 1981.

TABLE I

LINEAR ATTENUATION COEFFICIENTS AT VARIOUS GAMMA ENERGIES

Gamma-ray energy (keV)	Material: Lead ρ=11.3 (cm^{-1})	Cadmium ρ=8.65 (cm^{-1})	Iron ρ=7.86 (cm^{-1})	Aluminum ρ=2.70 (cm^{-1})	Polyethylene ρ=0.92 (cm^{-1})	Mock High Explosive ρ=1.84 (cm^{-1})
238.6	7.08	1.90	0.959	0.303	0.121	0.218
311.0	4.25	1.35	0.831	0.278	0.112	0.200
356.0	3.10	1.10	0.765	0.261	0.105	0.188
511.7	1.70	0.776	0.647	0.225	0.0907	0.163
583.2	1.41	0.701	0.609	0.216	0.0857	0.154
727.3	1.07	0.604	0.549	0.193	0.0777	0.139
860.5	0.897	0.545	0.506	0.178	0.0719	0.128
1173.2	0.669	0.458	0.433	0.153	0.0618	0.111
1332.5	0.628	0.429	0.407	0.144	0.0579	0.104
1620.6	0.560	0.390	0.369	0.130	0.0523	0.0938
2614.7	0.478	0.327	0.300	0.120	0.0403	0.0726

TABLE II

ACTUAL AND EXPERIMENTAL ATTENUATOR THICKNESSES

	Lead (cm)	Cadmium (cm)	Iron (cm)	Aluminum (cm)	Polyethylene (cm)	Mock High Explosive (cm)
Actual	1.9	0.32	2.5	1.9	5.4	6.6
Measured	1.9 ±0.3	0.28 ±0.3	2.3 ±0.3	1.7 ±0.3	5.0 ±0.5	5.9 ±0.7

FIGURE CAPTIONS

Fig. 1. High-purity germanium detector, source, and attenuation materials mounted on scanner carriage.

Fig. 2. LeCroy 3500 multichannel analyzer.

Fig. 3. Attenuation profile, multi-component/multi-layer transmission test object.

Fig. 4. Top view of transmission test object shown in Fig. 3.

$$\ln \frac{I_0(235)}{I(236)} = 7.08\ t_1 + 1.90\ t_2 + 0.959\ t_3 + 0.303\ t_4 + 0.121\ t_5 + 0.218\ t_6 \qquad (2a)$$

$$\ln \frac{I_0(356)}{I(356)} = 3.10\ t_1 + 1.10\ t_2 + 0.765\ t_3 + 0.261\ t_4 + 0.105\ t_5 + 0.188\ t_6 \qquad (2b)$$

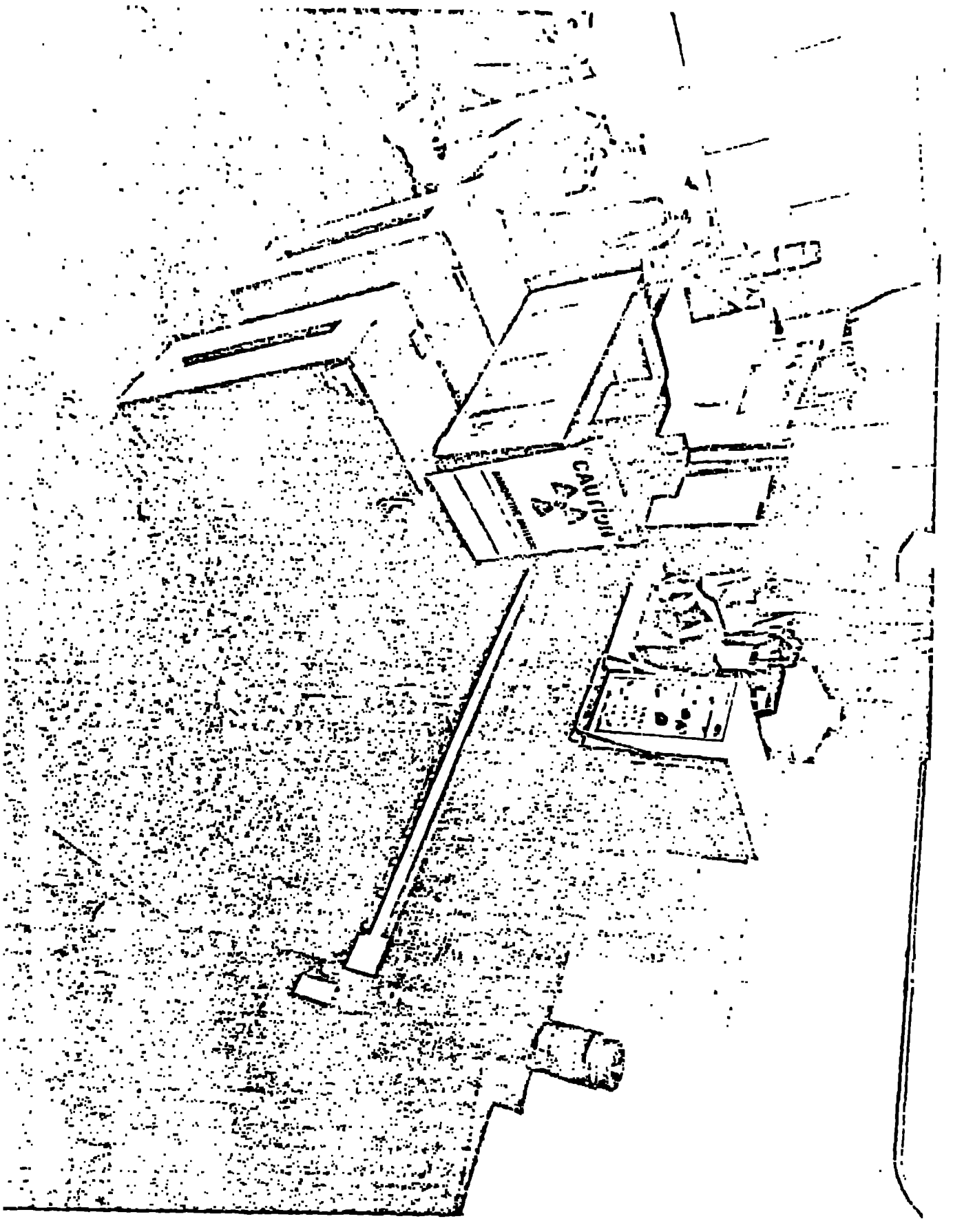
$$\ln \frac{I_0(563)}{I(563)} = 1.[illegible]1\ t_1 + 0.701\ t_2 + 0.609\ t_3 + 0.216\ t_4 + 0.085\ t_5 + 0.154\ t_6 \qquad (2c)$$

$$\ln \frac{I_0(569)}{I(569)} = 0.697\ t_1 + 0.545\ t_2 + 0.506\ t_3 + 0.178\ t_4 + 0.0719\ t_5 + 0.128\ t_6 \qquad (2d)$$

$$\ln \frac{I_0(1332)}{I(1332)} = 0.526\ t_1 + 0.429\ t_2 + 0.407\ t_3 + 0.144\ t_4 + 0.0579\ t_5 + 0.104\ t_6 \qquad (2e)$$

$$\ln \frac{I_0(1620)}{I(1620)} = 0.561\ t_1 + 0.390\ t_2 + 0.369\ t_3 + 0.130\ t_4 + 0.0523\ t_5 + 0.0938\ t_6 \qquad (2f)$$

$$\ln \frac{I_0(2614)}{I(2614)} = 0.476\ t_1 + 0.327\ t_2 + 0.300\ t_3 + 0.102\ t_4 + 0.0403\ t_5 + 0.0726\ t_6 \qquad (2g)$$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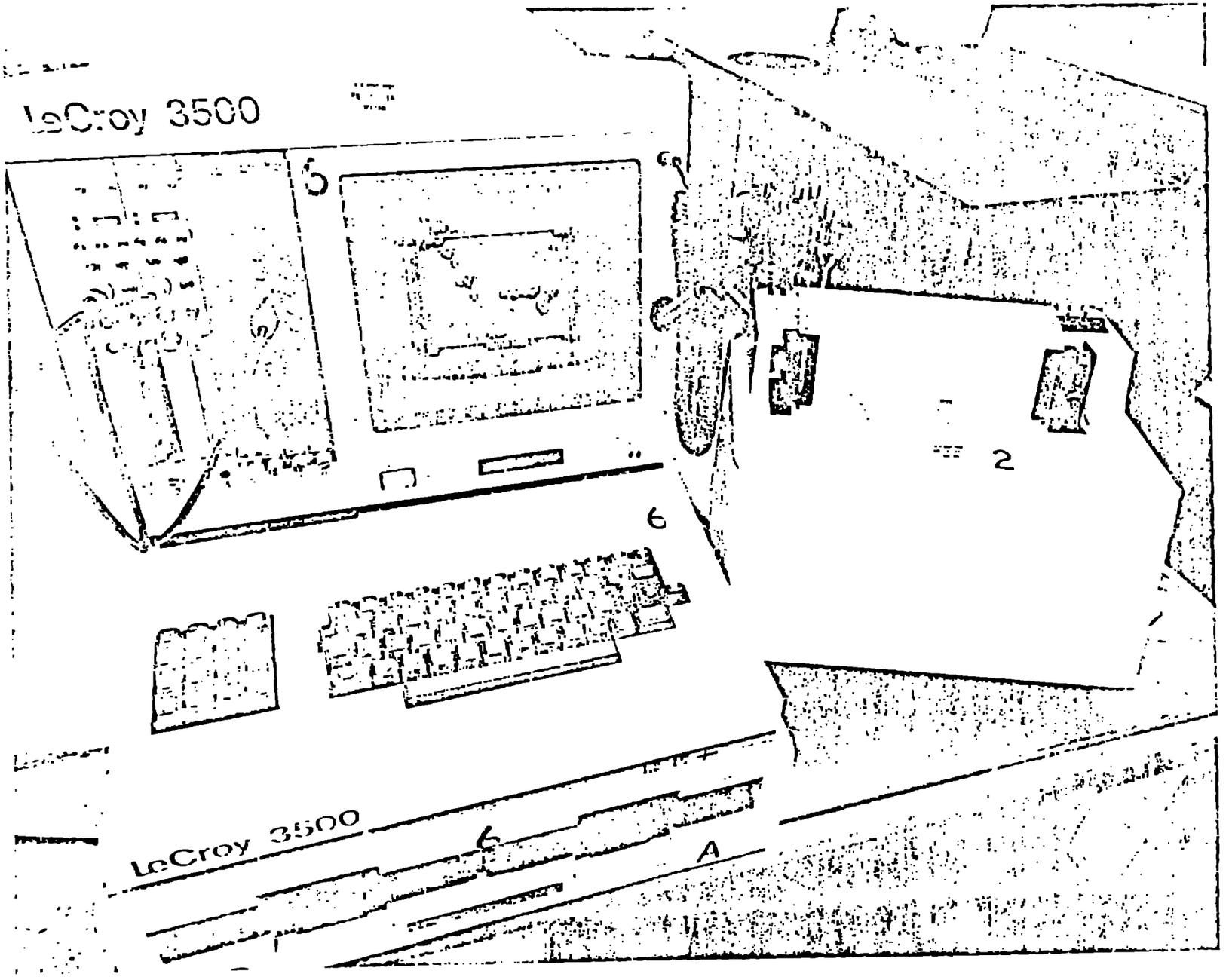
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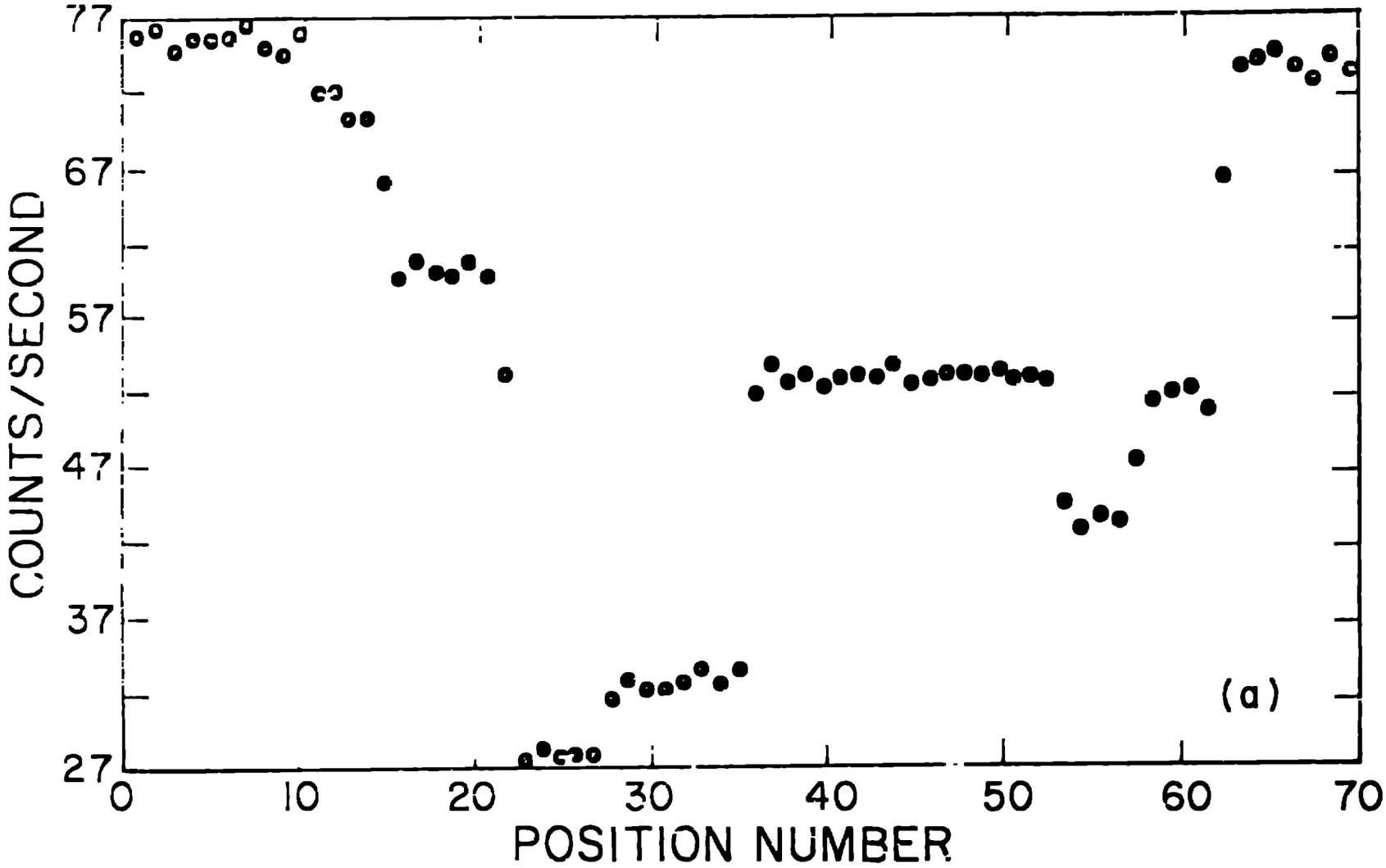
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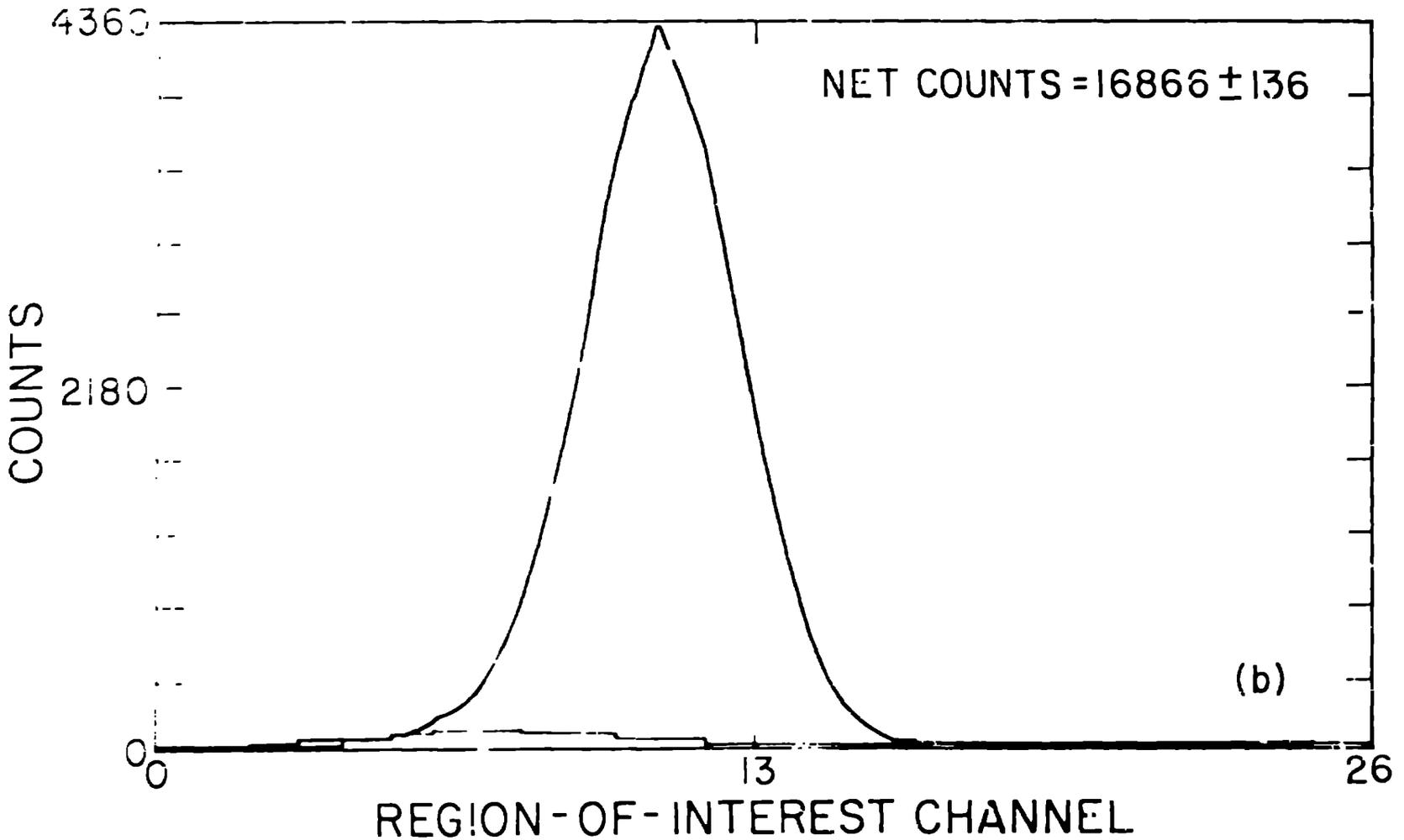
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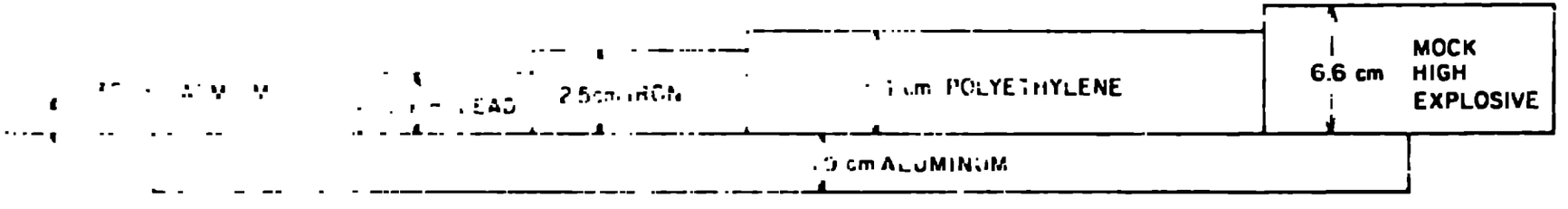
13
26
REGION-OF-INTEREST CHANNEL


LEAD
POLYETHYLENE
6.6 cm
MOCK
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