

PART VII

Pulse Height Analysis and Gamma Ray Spectroscopy

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SECTION I

Pulse-Height Analyzers

I. Pulse-Height Analyzers

Height of pulse depends on energy of incident radiation.

Discriminator or pulse-height selector (PHS) - excludes pulses below a preselected level.

A. Single-Channel Analyzer

Make successive statistical counts at different "window", PHA settings, called channels, and determine number of pulses by successive subtraction. Then plot pulse-height distribution.

Sample data

PHS setting	Channel	No. of Pulses
0-100	1	
100-200	2	0
200-300	3	2
300-400	4	5
400-500	5	2
		0

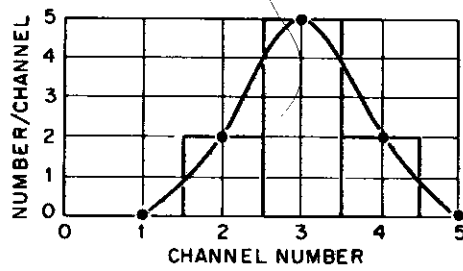


FIG. 1. Pulse-Height Distribution

B. Single-Channel Differential Analyzer

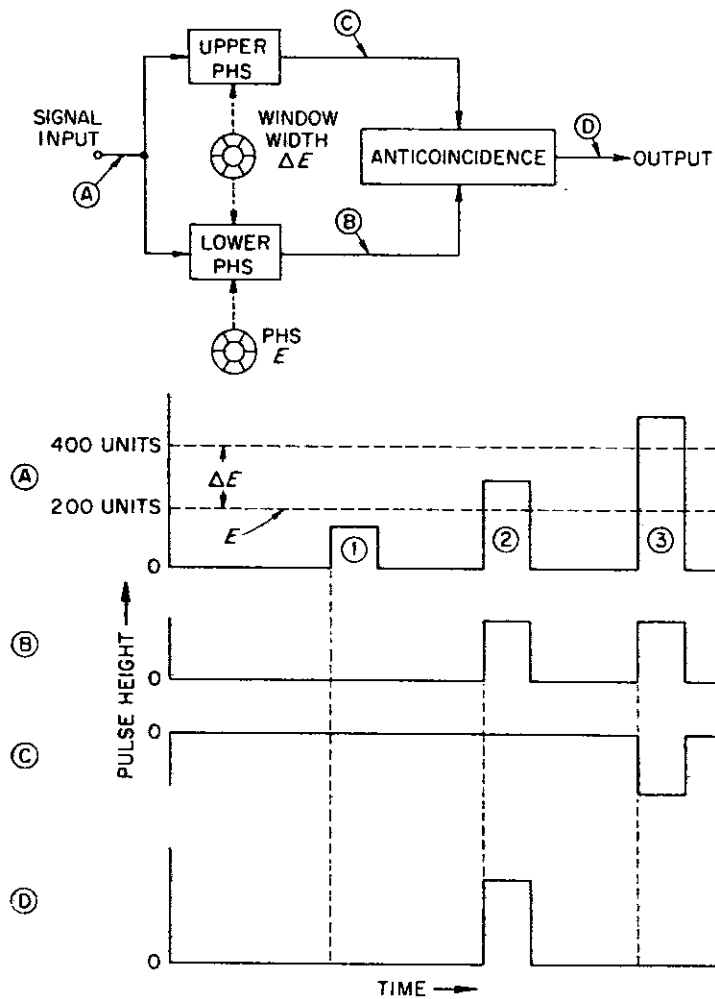


FIG. 2. Functional diagram of a single-channel pulse-height analyzer. Pulse shapes for the different part of the circuit are shown below the block diagram.

C. Multi-Channel Pulse Height Analyzers

Series of single channel analyzers each with a discriminator level slightly different. Used for α , β , and γ energy analysis however more helpful for α and γ where energy is discrete.

1. Pulse-height analysis for α 's:

Problem - thickness of source.

2. Pulse-height analysis for γ 's:

Can simultaneously measure a number of γ emitters.

SECTION II

Gamma Ray Spectroscopy

A. NaI(Tl) Scintillation Spectrometers

NaI crystal doped with Tl

Disadvantage-hygroscopic

Advantage-rather large size crystals are available.

Gamma rays interact with matter by: (Review Part III,
Section IIC)

1. Photoelectric Effect
2. Compton Scattering
3. Pair Production

All above processes occur in NaI(Tl) crystals. In all processes, γ ray interacts with I in NaI.

Note: γ rays are not directly detected - secondary electrons produced by above processes in the crystal give rise to light detected and amplified by phototube.

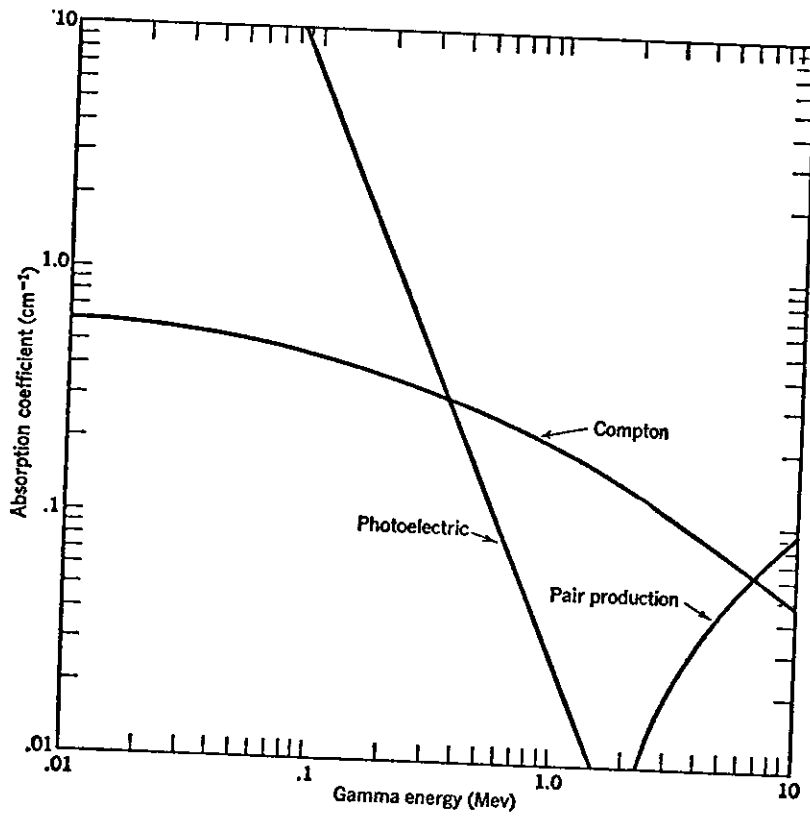


FIG. 3. Dependence of absorption coefficients for sodium iodide on energy.

1. Gamma Ray Interactions in Crystals of Different Sizes:

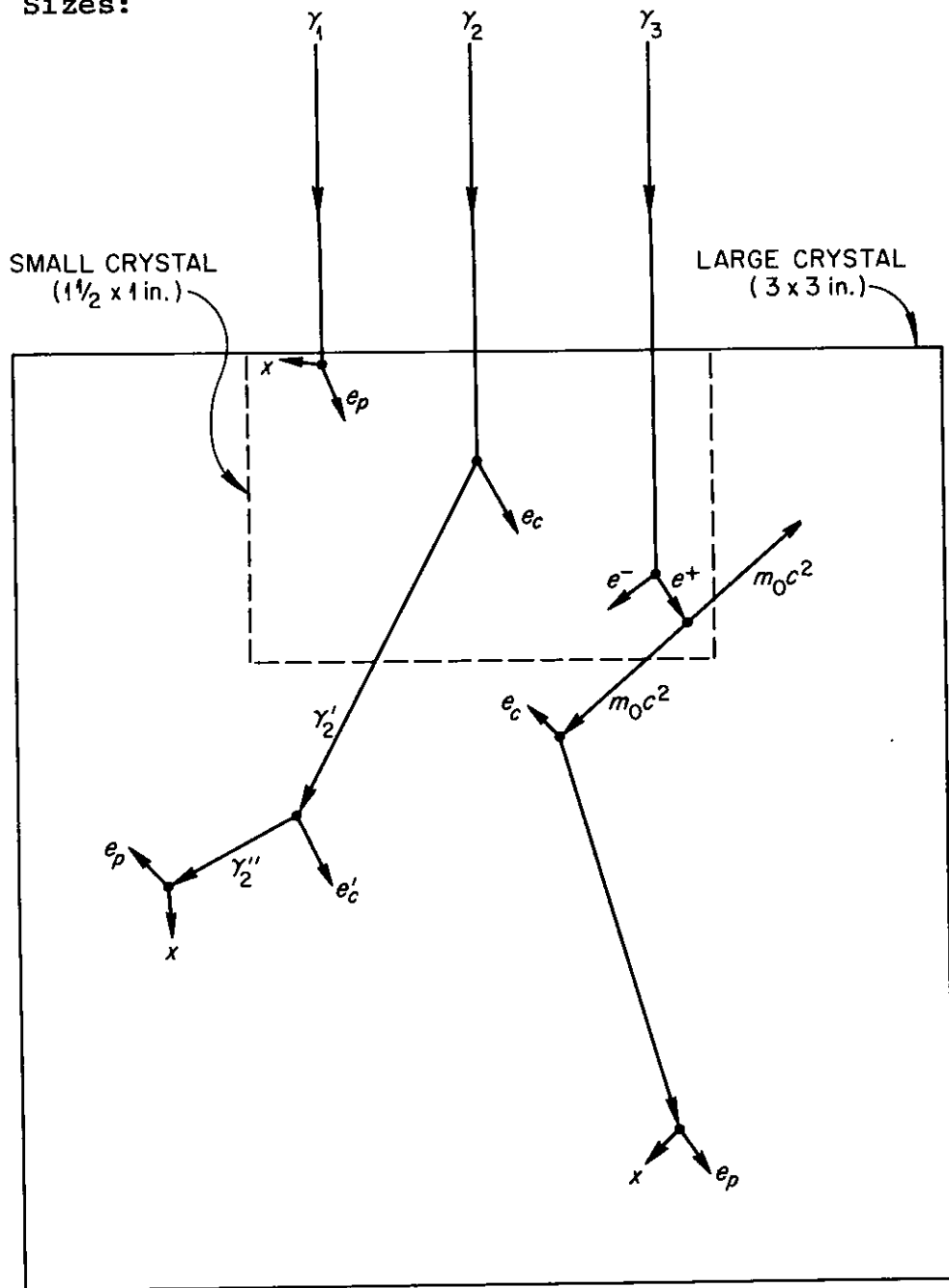


FIG. 4. Schematic representation of gamma-ray interactions within NaI(Tl) crystals of two sizes.

e_p - photoelectron (very short range)

x - x-ray (\sim 28 keV for iodine)

e_c - compton electron

γ' or γ'' - scattered (lower energy) γ rays

e^+ and e^- - ion pair

$m_0 c^2$ - annihilation photons (energy of each = 0.51 MeV)

2. Example of Low Energy γ -ray Interaction

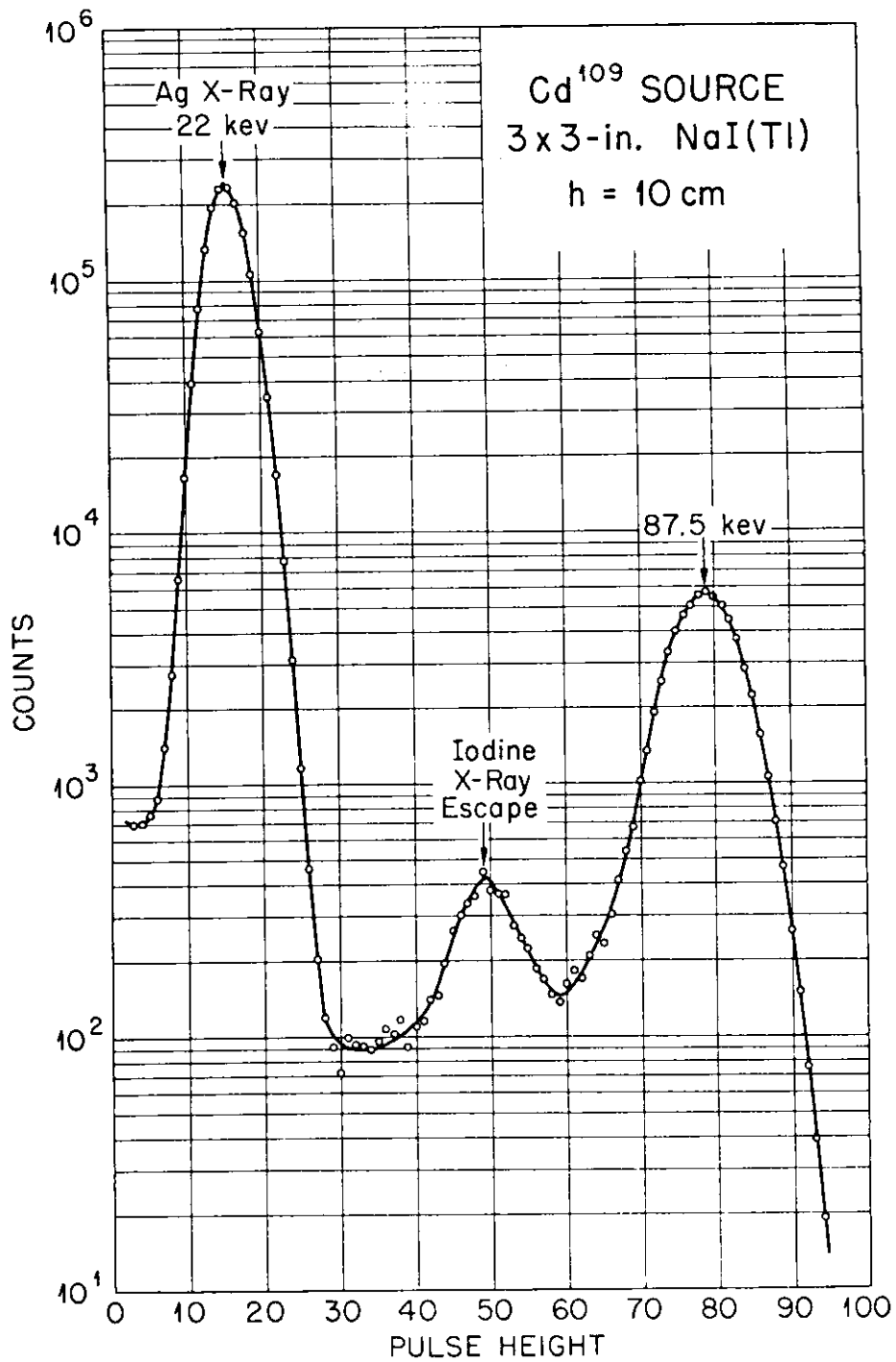


FIG. 5. Spectrum of 87.5 keV gamma rays and 22 keV X rays from a ^{109}Cd source, illustrating the phenomenon of X-ray escape following detection of 87.5 keV gamma rays.

3. Example of Intermediate Energy γ -ray Interaction

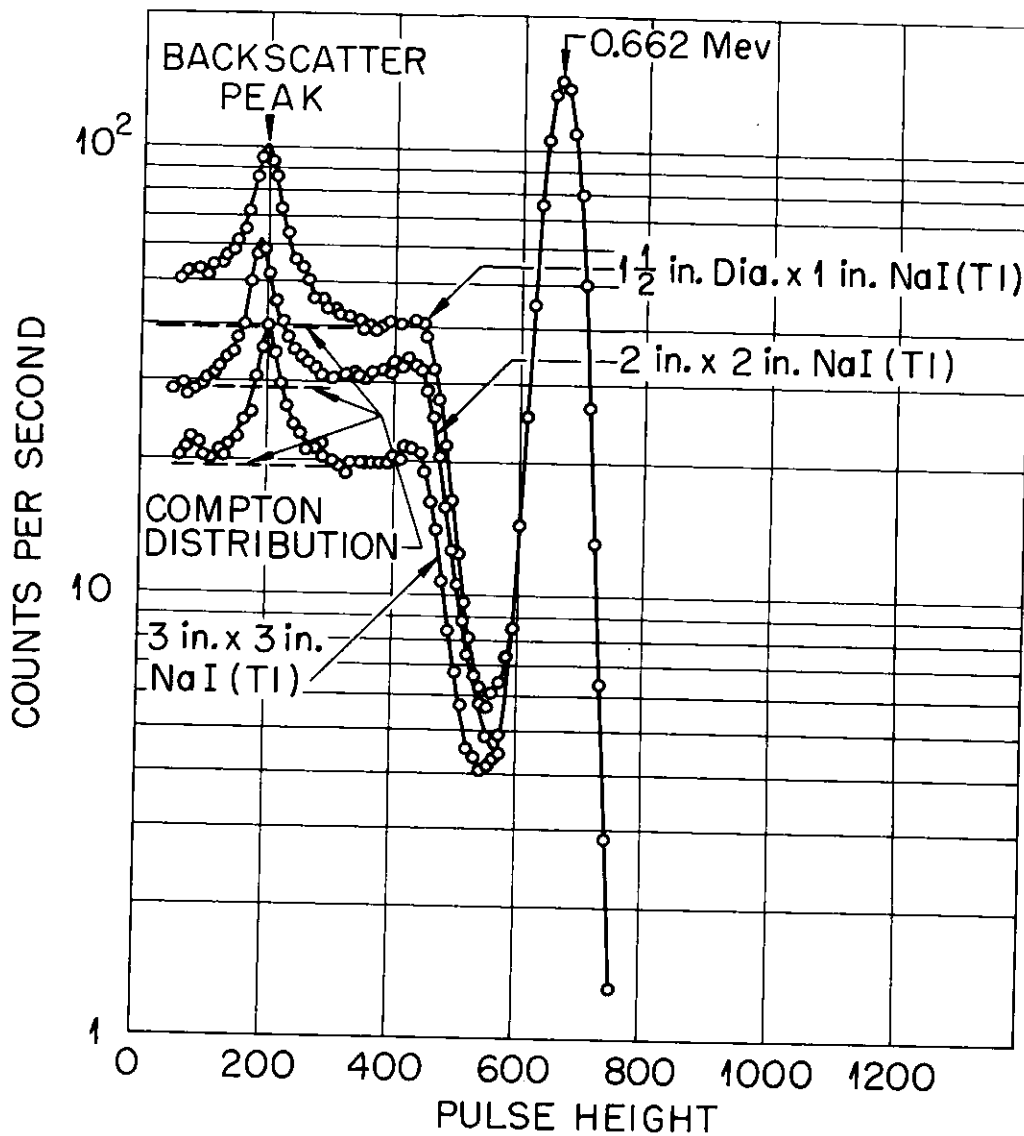


FIG. 6. Spectra obtained by measuring a ^{137}Cs source with NaI(Tl) spectrometers of three crystal sizes.

A - Photo peak

B - Compton peak

C - Backscatter peak - due to scattering of gamma
off of crystal shielding back into crystal -
usually found at ≥ 200 . instrumental problem.

4. Example of High Energy γ -ray Interaction

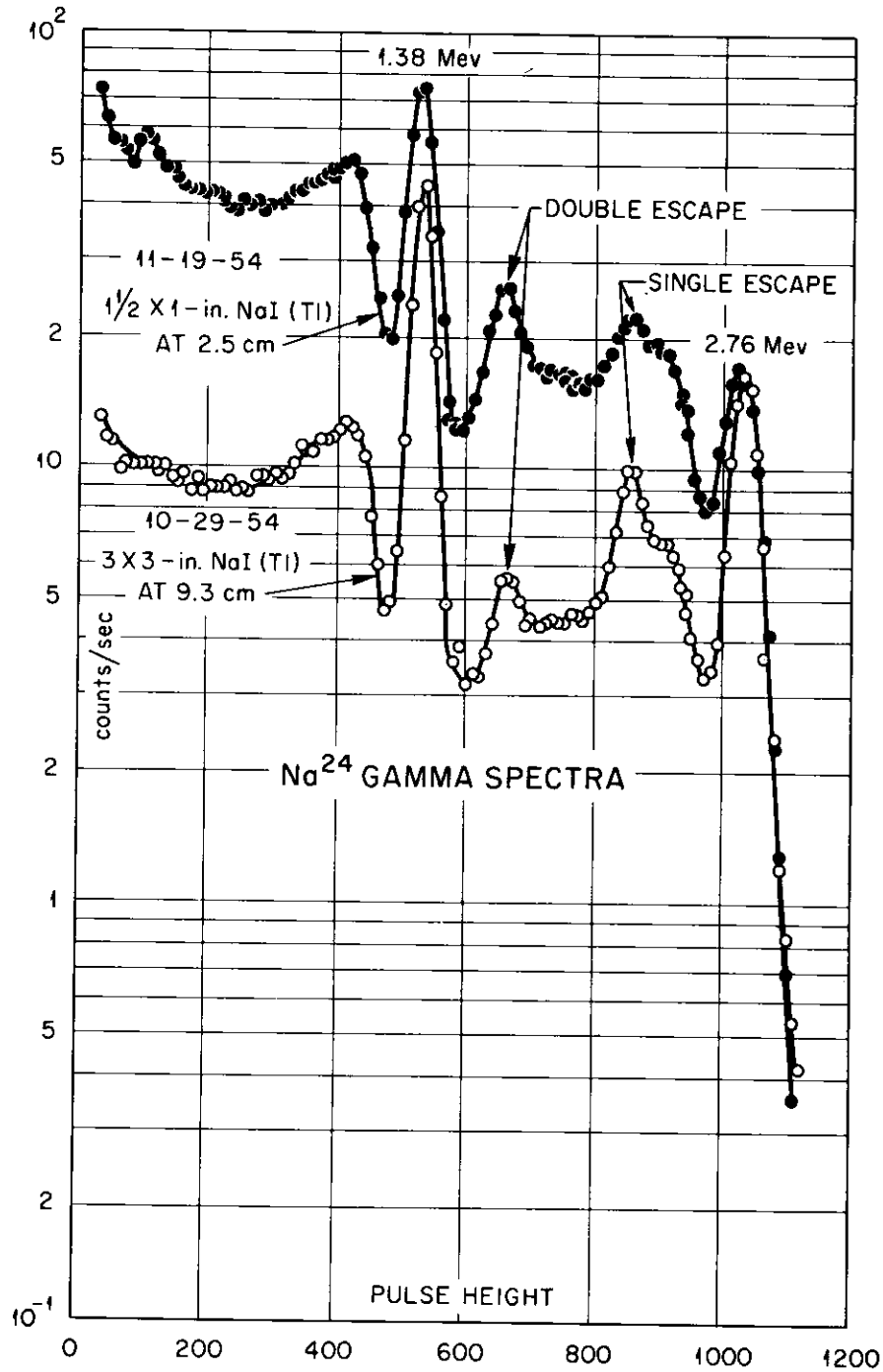


FIG. 7. Gamma ray spectra of ^{24}Na , using $1\frac{1}{2} \times 1$ inch and 3×3 inch NaI(Tl) spectrometers.

^{24}Na -2 γ -rays in this source $\gamma_1 = 2.76 \text{ MeV}$
 $\gamma_2 = 1.38 \text{ MeV}$

Note: Pair production usually not detected for
 γ -ray $< 1.5 \text{ MeV}$.

Summary:

γ_1 - low energy - photoelectric effect; e_p and x-ray

In Spectrum:

- a) Photopeak at energy of γ_1
- b) Iodine x-ray escape peak of energy = $\gamma_1 - \text{x-ray}$
- c) x-ray peak = energy of x-ray

γ_2 - intermediate energy - Compton and photoelectric effects. Size of crystal important.

In Spectrum:

- a) 1.5 x 1 in crystal
If γ_2' is stopped - photopeak at energy of γ_2
If γ_2' escapes - Compton peak - energy $\gamma_2' = \gamma_2 - \gamma_2'$

- b) 3 x 3 in. crystal
One large photopeak at energy of γ_2 (γ_2' captured).

Note: As γ ray energy increases, probability for x-ray escape diminishes.

γ_3 - high energy - pair production - positive and negative electron pair produced.

Energy of pair = $\gamma_3 - 1.02 \text{ MeV}$ ($2 m_{e^-}$)

Positron annihilates forming 2 photons of 0.51 MeV each 180° apart.

Small crystals - probably both annihilation photons escape

Large crystals - probably one annihilation photon and possibly both are stopped.

In spectrum:

3 peaks

- a) Full energy peak - due to multiple processes
- b) Single escape peak - loss of one annihilation photon
- c) Double escape peak - both annihilation photons lost.

5. Diagram of Typical NaI(Tl) Spectrometer

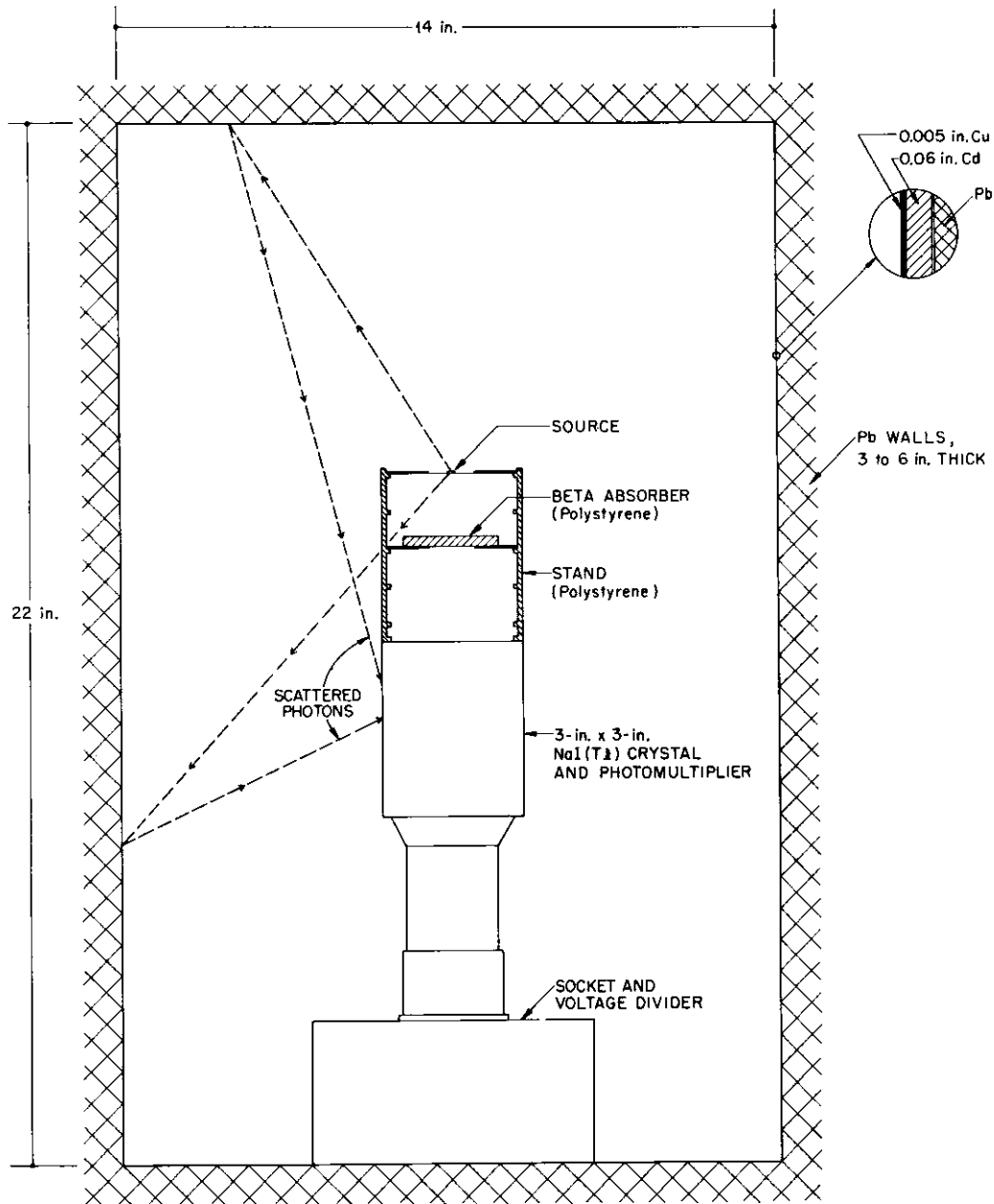


FIG. 8. Cross-section of a typical scintillation spectrometer installation, showing the 3x3 inch NaI (Tl) detector assembly, the lead shielding with "graded" liner, and the use of a low-mass support for the source and beta absorber. The origin of scattered photons is illustrated.

6. Environmental Effects

a. Back Scatter - Results from Compton scattering in the walls of the detector shielding. If E_γ is larger ($E_\gamma > 1/2 mc^2$) the scattered γ will have a minimum energy approaching $1/2 mc^2 - 250$ keV. Thus a backscattering peak often shows up in the spectra at around 250 keV.

b. Bremsstrahlung - Energy lost as radiation by charged particles passing through matter. Although most of the energy goes into excitation and ionization of the interacting medium some bremsstrahlung radiation is produced. It has a continuous energy spectrum from 0 to E_{\max} of the particle.

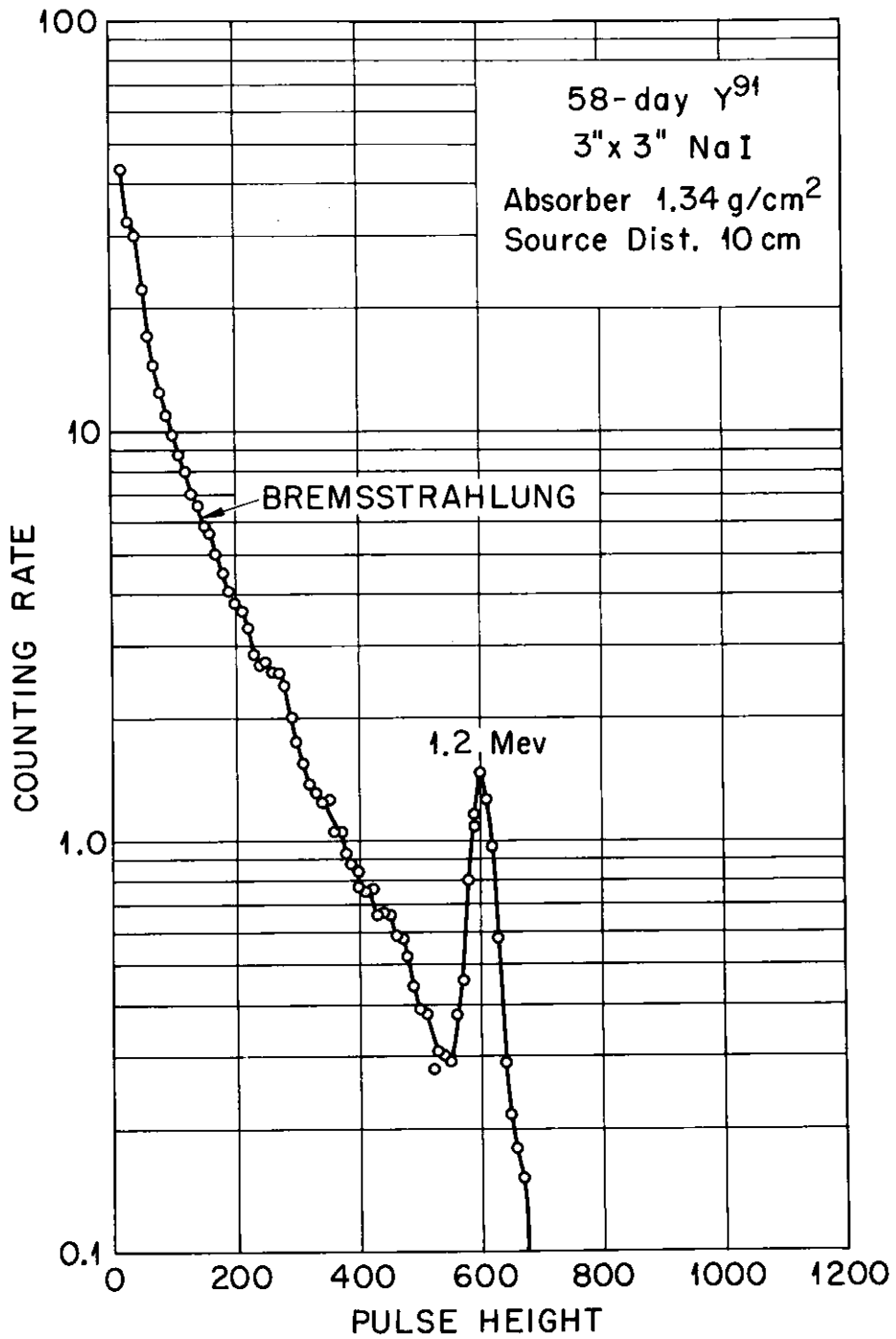


FIG. 9. Gamma-ray spectrum of 58-day Y^{91} , showing the bremsstrahlung spectrum characteristic of a source for which the beta-to-gamma intensity ratio is very large.

7. Sum Peaks

If two gamma rays from a source enter the detector crystal simultaneously, the total energy deposited may be the sum of the energy of the two gamma rays. May be coincident gamma rays or same gamma ray from high intensity source.

$$E_{\text{sum}} = E_{\gamma_1} + E_{\gamma_2} \quad \text{for coincident gammas}$$

$$E_{\text{sum}} = 2E_{\gamma_1} \quad \text{for two identical gammas}$$

Sum peak intensity decreased by increasing distance between sample and detector.

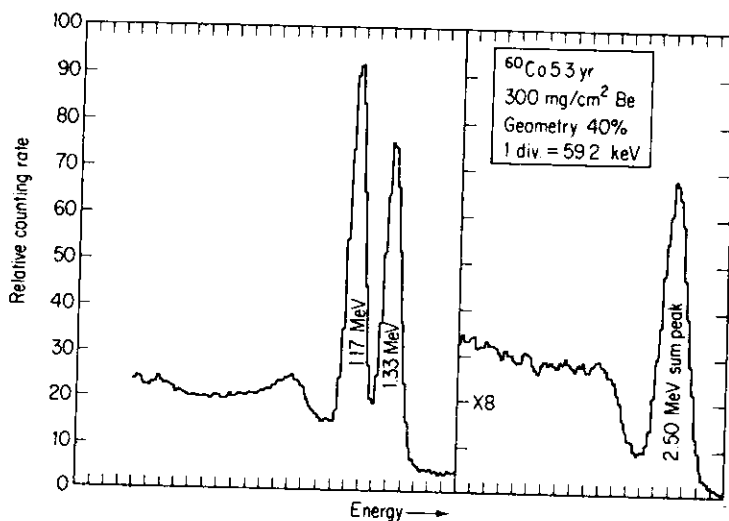


FIG. 10

FIG. 11

Spectra of Co showing sum peak.

8. Contrast of Ideal and Real Spectra

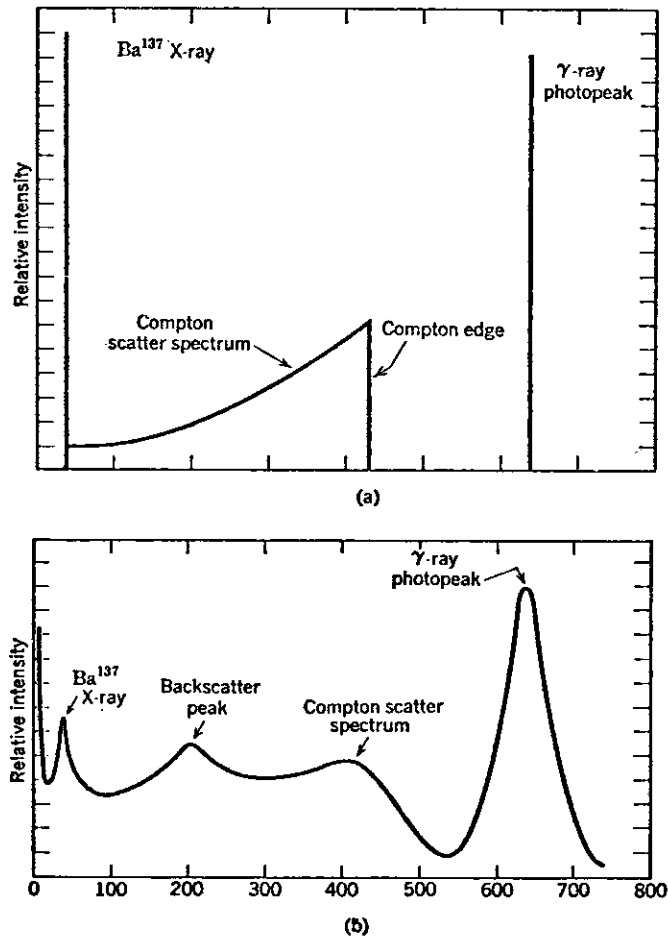


FIG. 12 (a) Gamma Spectrum from an ideal detector.

(b) Gamma spectrum from a real detector.

9. Calculation of the Compton Edge

$$E_e = \frac{4E_\gamma^2}{4E_\gamma + 1} \quad (1)$$

E_e = energy of electron

E_γ = energy of incident γ ray

10. Resolution-measure of ability to differentiate γ rays of similar energies.

$$\text{Resolution} = \frac{\text{FWHM}}{\text{Pulse height (or energy)}} \times 100 \quad (2)$$

FWHM = full width at half maximum in number of channels or of energy.

Ex: Pulse height = 635 keV; FWHM = 75 keV

$$\text{Resolution} = \frac{76 \text{ keV}}{635 \text{ keV}} \times 100 = 12\%$$

11. Calibration Procedure

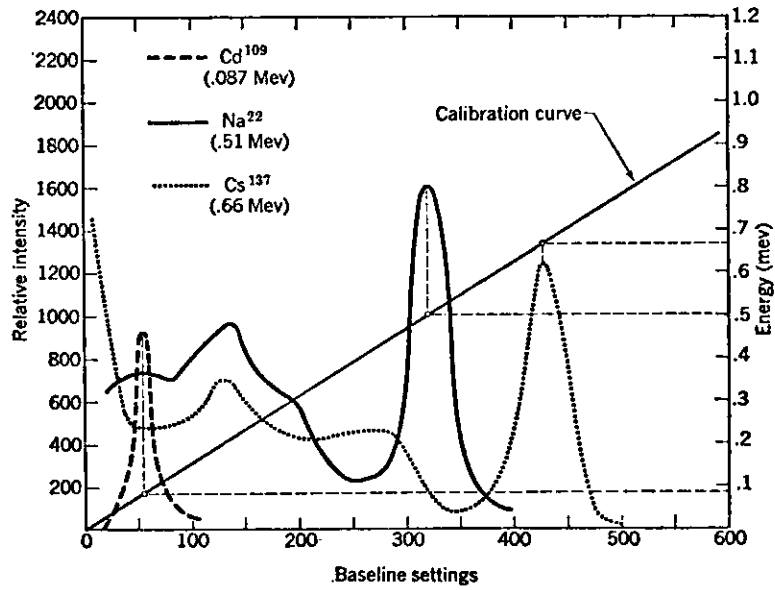


FIG. 13. An illustration of the method of using gamma spectra curves to obtain a calibration curve for the base-line settings as a function of energy. The calibration curve is drawn through the points determined by the base-line settings and the energy of the photopeaks of the standards.

B. Solid State Detectors

1. Gamma Ray Interactions

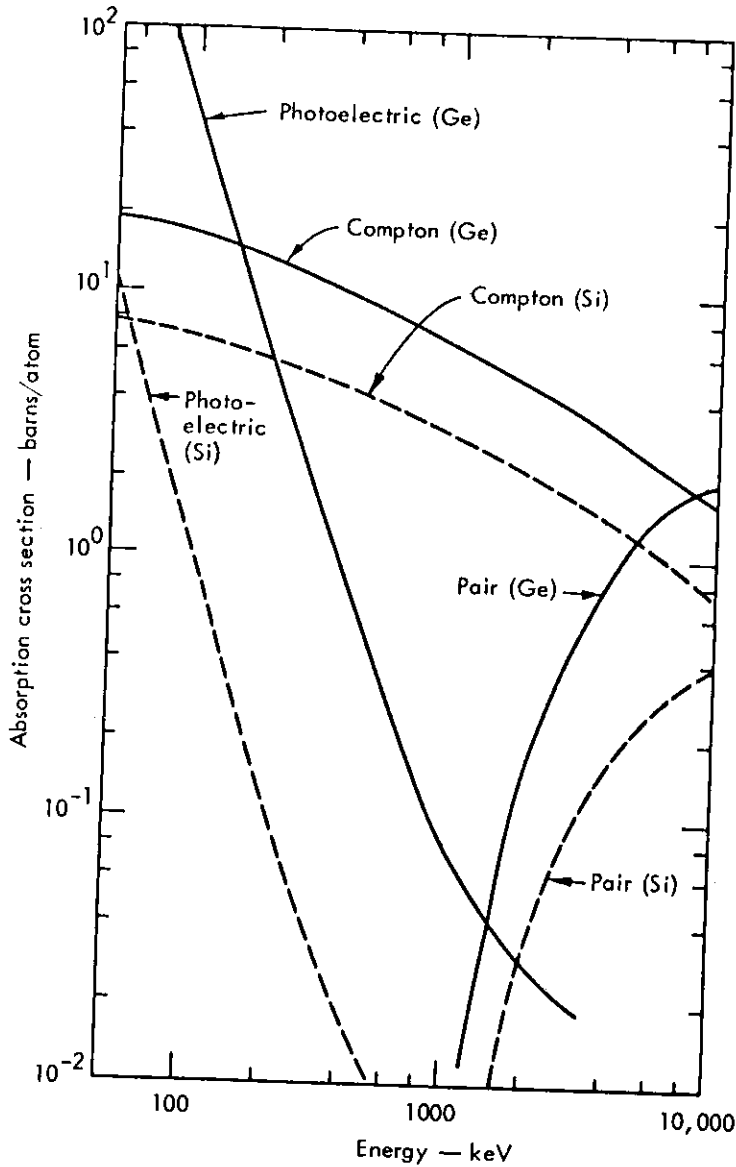


FIG. 14. The variation with energy of the photoelectric, Compton, and pair-production cross sections in silicon and germanium.

2. Absorption Efficiency of Several γ ray Spectrometers

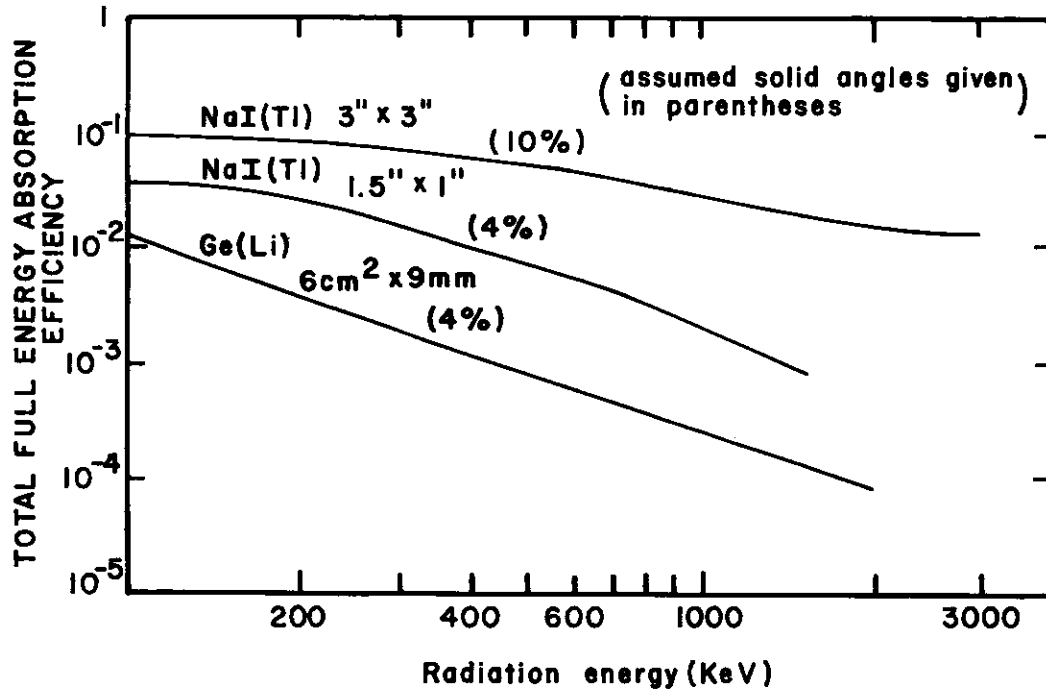


FIG. 15

3. Resolution Characteristics

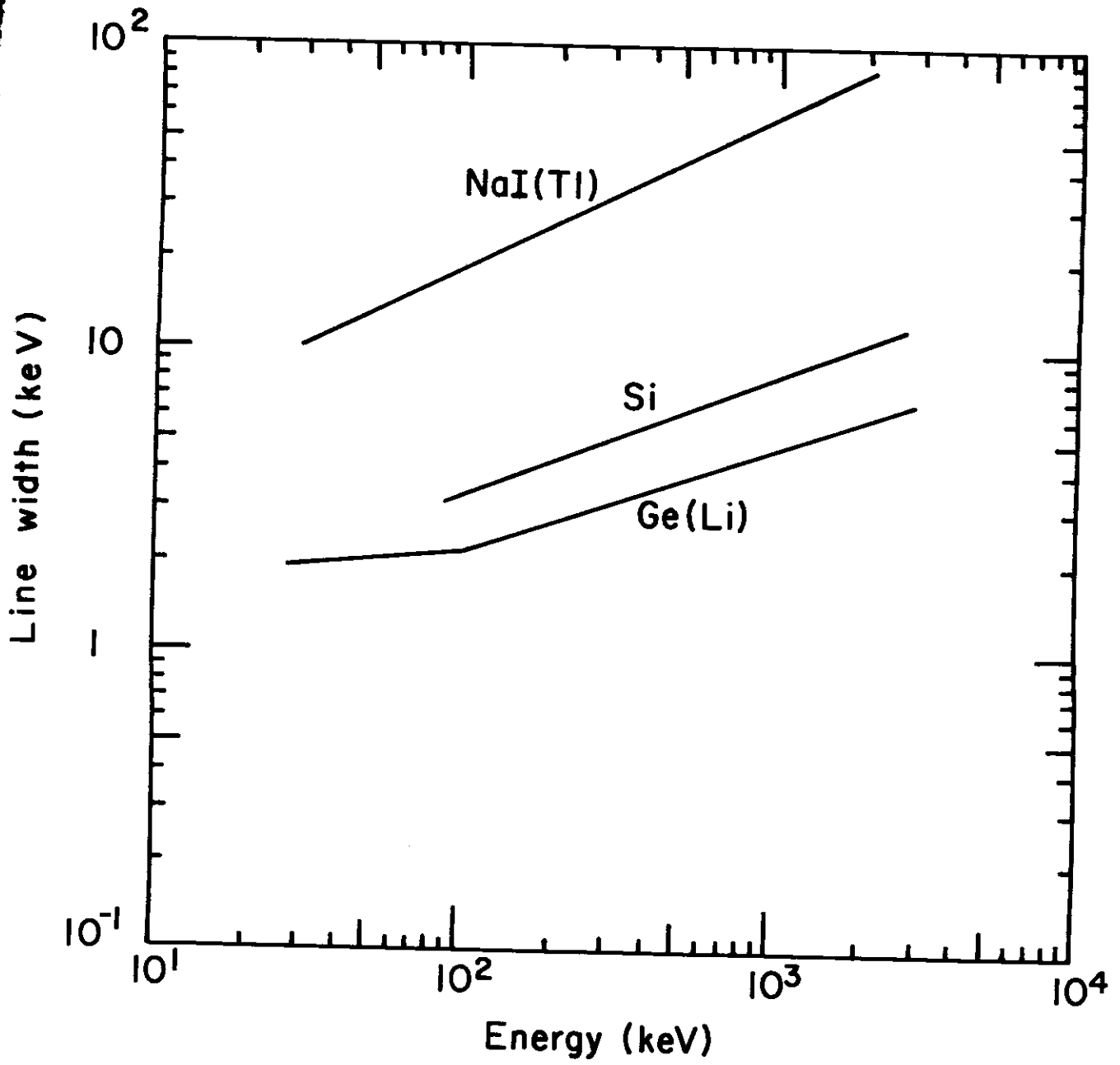


FIG. 16

4. ^{239}Np Spectra in NaI(Tl)

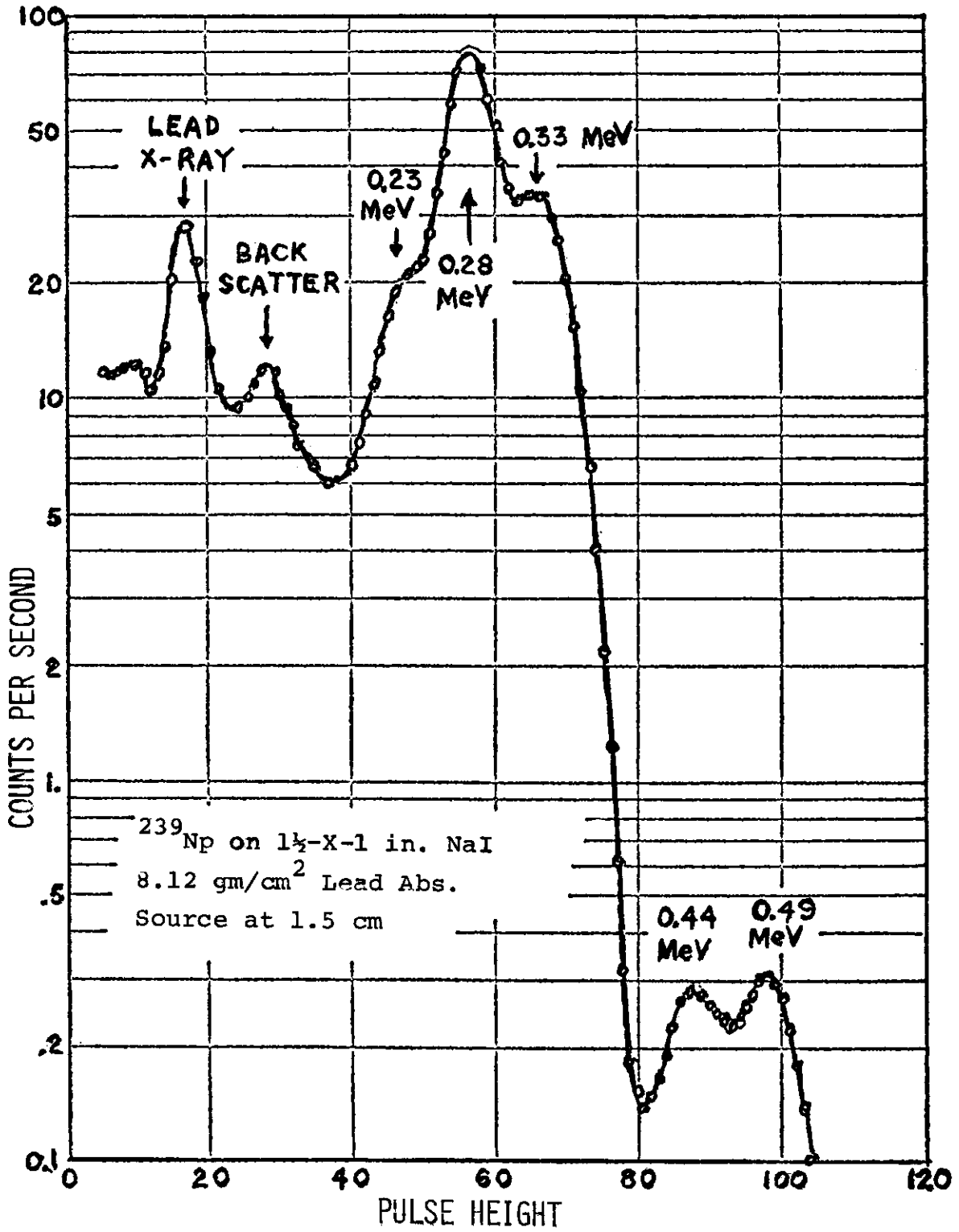


FIG. 17

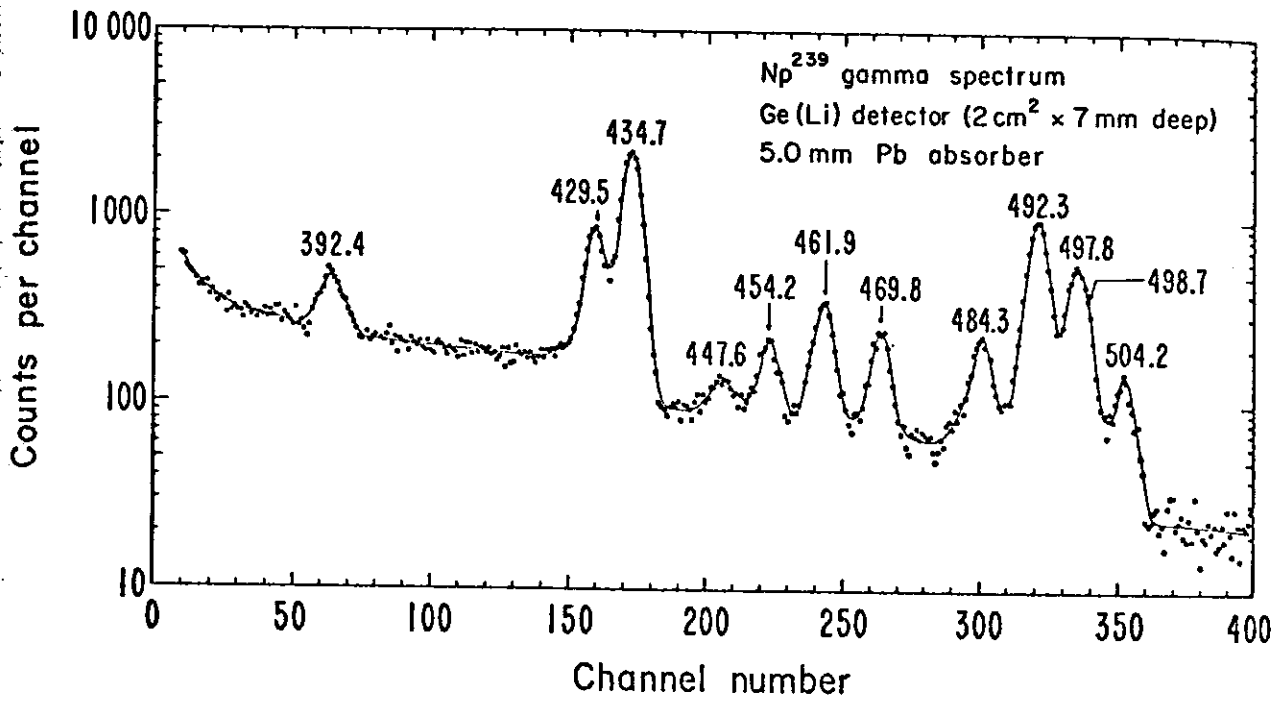


FIG. 18

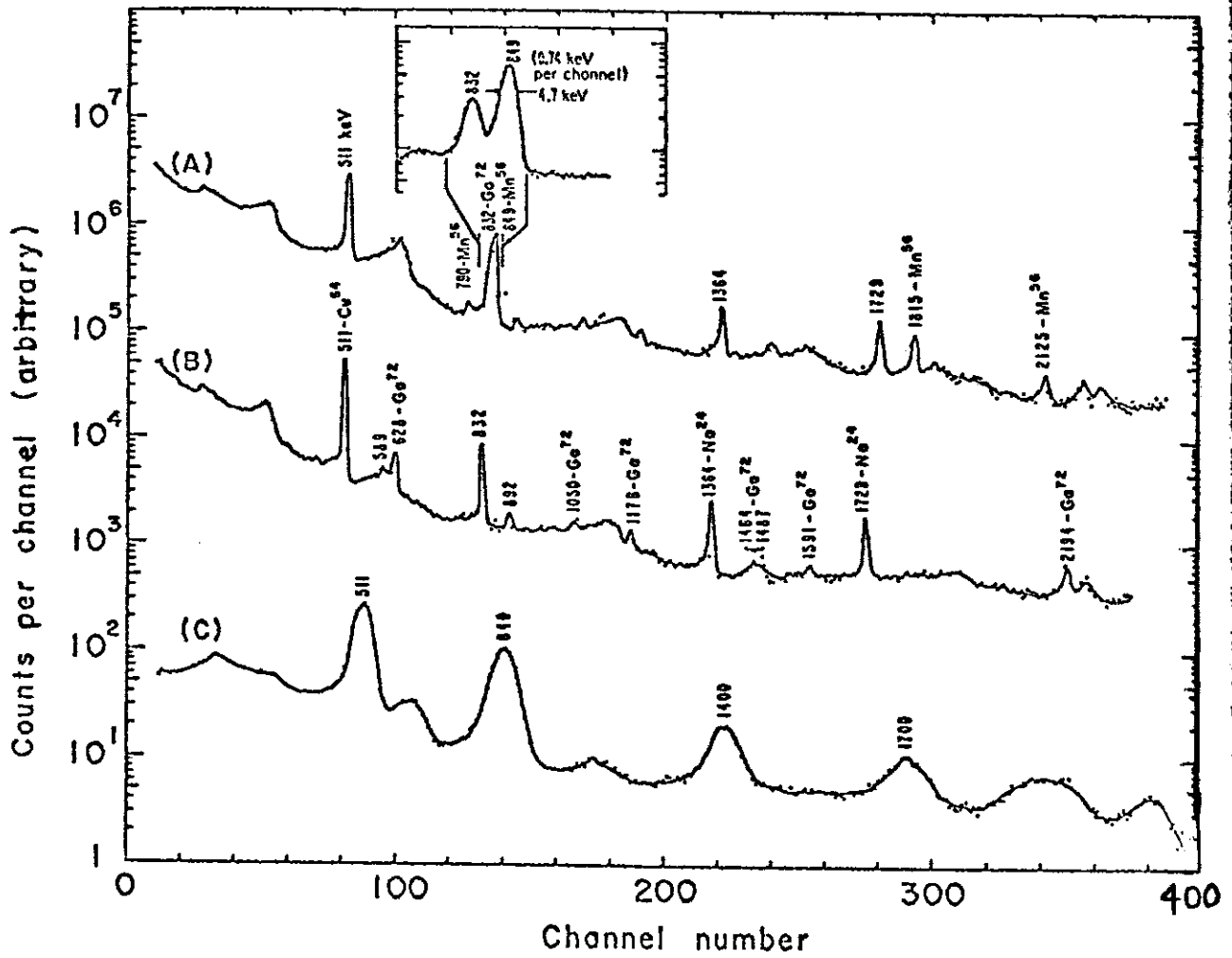


FIG. 19. Neutron Activated Al

- (A) Ge(Li) 2 hr irradiation, 5.2 hr after irradiation
- (B) Ge(Li) 2 hr irradiation, 54.7 hr after irradiation
- (C) NaI(Tl) 3" x 3" 2 hr irradiation, 5.7 hr after irradiation.

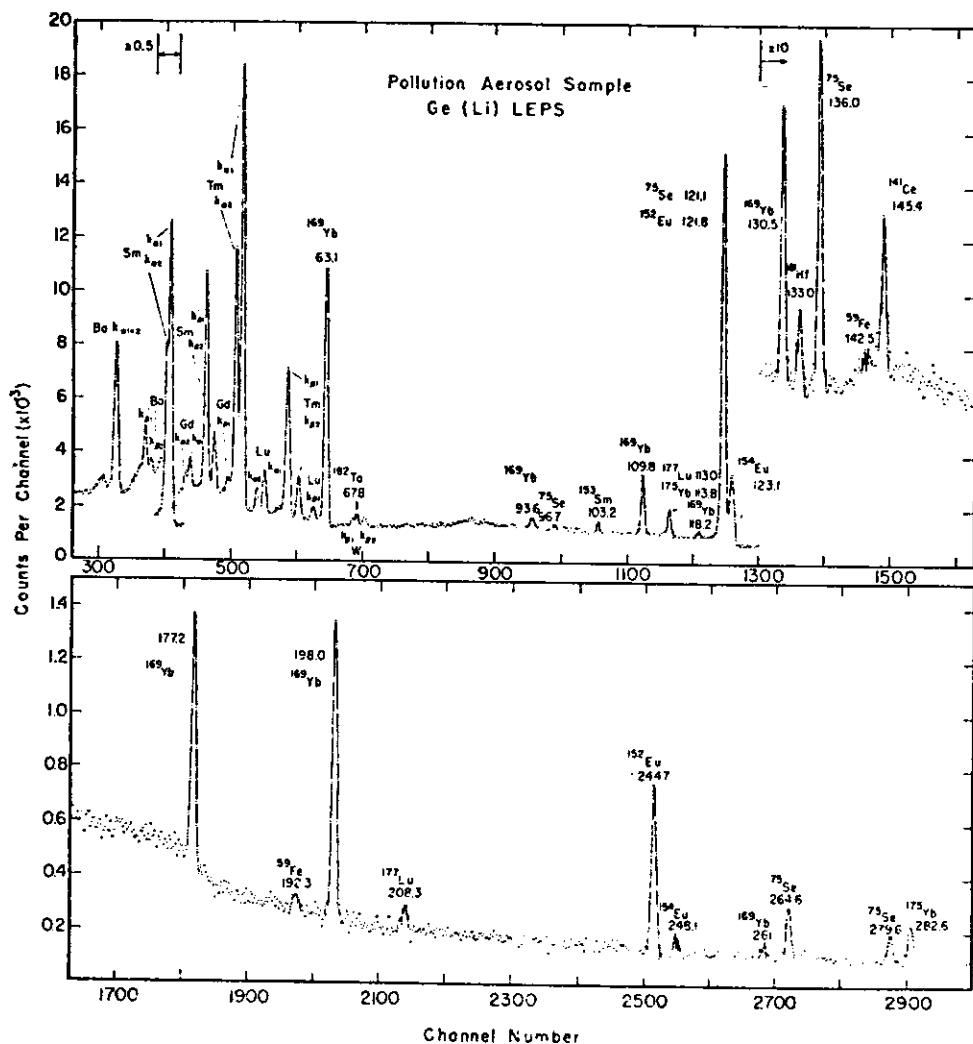


FIG. 20. Low-Energy Portion of the Gamma and X-ray spectrum of an irradiated millipore filter sample observed with the 0.5 cm^3 Ge(Li) detector six days after a 9 hr irradiation. [W.H. Zoller and G.E. Gordon, Anal. Chem. 42 (2), 261 (1970)].

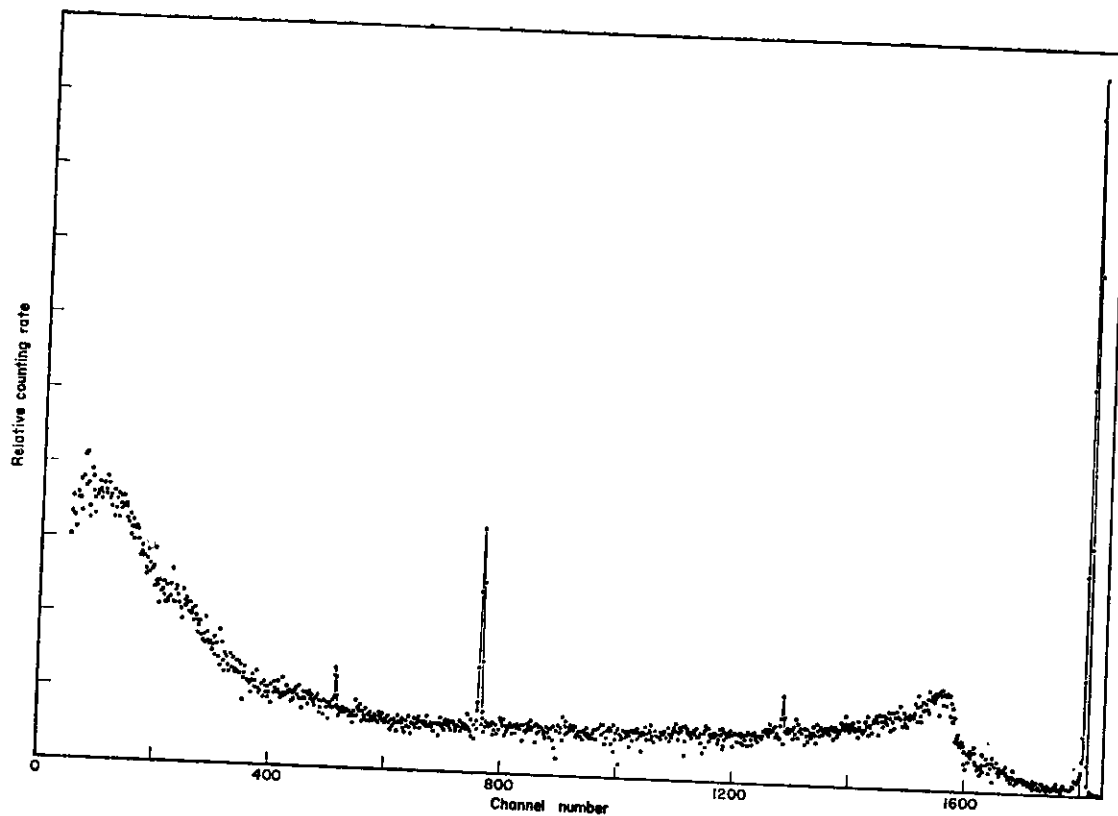
SECTION III

Problems

1. Calculate the Compton edge for the following γ ray emitting nuclides

	E (MeV)
a) ^{46}Sc	0.986, 1.314
b) ^{22}Na	0.51
c) ^{109}Cd	0.087

2. What will be the most probable mode of interaction between matter (i.e., a NaI(Tl) detector) and the γ rays emitted by the nuclides in problem 1? Explain your answers.
3. Figure 21 is a γ ray spectrum of ^{28}Al ($E_\gamma = 1.78$ MeV) obtained on a Ge(Li) detector. What would you expect to be the dominant mode of interaction? Make assignments for peaks a-d. Based on your assignments, at what energies would you expect to find peaks b-d?



4. For a given γ ray what is the effect of the sodium iodide crystal size on the percent of gamma rays completely absorbed? (Assume the crystal is cubic). For a given NaI(Tl) crystal size what is the effect of E_{γ} of the incident γ ray on the percent of gamma rays absorbed?

5. Plot the following NaI(Tl) counting data on semi-log paper to obtain the spectrum for ^{99m}Te ($E_{\gamma}=140$ keV)

<u>Total Count</u>	<u>Pulse Height (keV)</u>
150	40
160	50
180	60
210	70
305	80
560	90
1050	100
800	110
620	120
700	126
1700	130
6000	136
10,000	140
4000	146
1700	150
300	156

What is the resolution based on the 140 keV photopeak? On the low energy side of the photopeak at 100 keV is the I x-ray escape peak. What is the energy of the x-ray?

6. Given below is the γ ray spectrum of ^{60}Co which has two gamma rays. $E_{\gamma_2} = 1.17 \text{ MeV}$ and $E_{\gamma_1} = 1.33 \text{ MeV}$. Identify all the peaks and humps in the spectrum as to energy. Theoretically, the Compton peak associated with a photo-peak has an energy given by the equation 1. Compare the theoretical values with the ones given in the spectrum.

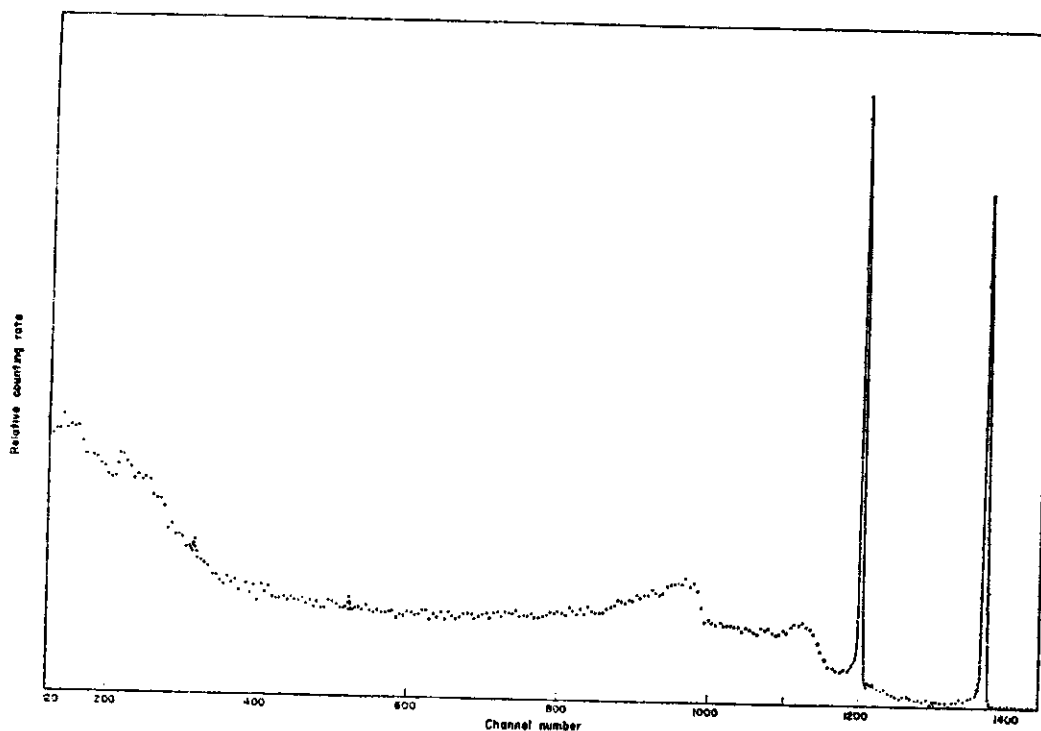


FIG. 22. Gamma spectrum of ^{60}Co