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A CAMAC GAMMA-RAY SCANNING SYSTEM*

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ABSTRACT

A flexible gamma-ray scanning system, based on a LeCroy 3500 multichannel analyzer and CAMAC modules, is described. The system is designed for making simultaneous passive and active scans of objects of interest to nuclear safeguards. The scanner is a stepping-motor-driven carriage; the detectors, a bismuth-germanate scintillator and a high-purity germanium detector. A total of sixteen peaks in the two detector-produced spectra can be integrated simultaneously, and any scan can be viewed during data acquisition. For active scanning, the 2615-keV gamma-ray line from a ^{232}U source and the 4439-keV gamma-ray line from $^{9}Be(\alpha,n)^{12}C$ were selected. The system can be easily reconfigured to accommodate up to seven detectors because it is based on CAMAC modules and FORTRAN. The system is designed for field use and is easily transported. We present and discuss examples of passive and active scans.

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INTRODUCTION

Determining the contents of a container without opening it is a task often faced in nuclear safeguards. We have constructed a gamma-ray scanning system that can scan a container passively and actively to determine the spatial distribution of the radioactive and nonradioactive material. The transmitted intensity in the active scan indicates the material's density.

The scanning system is a versatile, portable instrument that is easy to use and is relatively inexpensive. The system performs simultaneous passive and active scans at multiple gamma-ray energies. It can scan objects as large as 140 cm across and can detect gamma rays with energies greater than 50 keV. The electronics used in the system are commercially available. Total system cost is approximately $50 000.

The system compares favorably with other methods. For example, even though a radiograph is preferable to an active scan, it requires a very intense source; our scanner can operate with a relatively weak source. Another example is an Anger camera, which is much faster than a scanner, but is more expensive and less portable.

SYSTEM DESCRIPTION

Our scanner system is based on a LeCroy 3500 multichannel analyzer (MCA) and three CAMAC modules. As shown in Fig. 1, the LeCroy 3500 system consists of a cathode-ray tube (CRT) with a light pen, a keyboard, a built-in CAMAC crate for eight modules (with possible expansion up to seven external crates), a floppy disk, and a small printer. The memory is expandable to 64 000 channels, with a 16-million count capacity per channel. The LeCroy 3500 contains an Intel 8085 microprocessor with software that supports FORTRAN and assembly language, extensive real-time graphics, CAMAC input/output routines, various analysis routines, and a useful screen dump program. It is relatively easy to combine user-written high-level language programs with system software. An MCA program is resident in the LeCroy's read-only memory. The LeCroy can be transported in a special shipping crate, 61 by 61 by 122 cm. For field use, the LeCroy can be raised 65 cm off the ground by placing it on top of its crate.

A variety of CAMAC modules are available that allow flexibility in controlling the scanner and in acquiring data. The scanning system can support as many as eight 8192-channel analog-to-digital converters (ADCs). System deadtime is small because a 5 μs conversion time for 8000 channels affords a maximum of 150 kHz throughput rate for each ADC, which is equivalent to a Wilkinson-type ADC with a 1600-MHz clock frequency. We use two 8192-channel ADCs (LeCroy model 3511) for two detectors and a pulse generator (Kinetic Systems model 3655) to control the scanner stepping motor. The system could easily accommodate several stepping motor controllers, shaft encoder interfaces, and relay drivers for more elaborate scanners.

The scanner consists of a carriage that supports the detectors and collimators. The carriage rolls along a track that permits the detector to be positioned at a series of points for a scan (Fig. 2). A drive screw, turned by the stepping motor, moves the carriage. The track height is adjustable and can be oriented either horizontally or vertically. The scanner can be easily disassembled and moved to a new location. The stepping motor controller, which is driven by the pulse generator, was custom built.[1]

Many types of gamma-ray detectors can be used in the scanning system. We chose a 7.62-cm diameter by 7.62-cm-long bismuth-germanate detector and a efficient high-purity germanium detector with a small all-attitude Dewar, supplied by Princeton Gamma-Tech. The system can be easily expanded to accommodate more detectors by using additional ADCs or multiplexers. The bismuth-germanate crystal is very efficient at high energies,[2] but sufficiently compact that the mass of shielding required is relatively small. The high-purity germanium detector has excellent resolution--1.76 keV FWHM (full width at half maximum) at 1.33 MeV--for resolving peaks in complex spectra.

SYSTEM OPERATION

The scanning system operates in two modes: active and passive. In passive scanning, the object under examination must be radioactive. Passive scans of objects of interest to nuclear safeguards use the gamma-ray lines shown in the Table. In active transmission scanning, a suitable gamma-ray source must be provided; we have investigated numerous possibilities. There are very few sources not involving a reaction that yield a high-energy gamma-ray line and have a lifetime of at least several years. The 2615-keV gamma-ray line from ^{208}Tl fed by ^{232}U ($T_{1/2}$ = 71.9 years)[4] is the most convenient line we have found. However, the 2615-keV line is also produced by the ^{232}U contaminant in fissionable material and is present in background. Therefore, unless a moderately intense source is used, the precision of the scan is reduced.

Among reaction sources, we have found the 4439-keV gamma-ray line from ^{9}Be $(\alpha,n)^{12}$ C in an ^{241}Am/Be source to be the most convenient. Our bare ^{241}Am/Be source emits 10^5 neutrons/s and the corresponding 4.439 MeV gamma-ray rate in the full energy and first escape peaks in our bismuth-germanate detector at 50 cm is 16 counts/s. The ratio of gamma rays to neutrons can be indefinitely increased by adding borated polyethylene shielding.[5] The 60-keV gamma-ray line from ^{241}Am is easily shielded with a few millimeters of lead. The 4.439-keV line is Doppler-broadened, but this is not significant when the detector is bismuth germanate because its resolution is approximately 7% FWHM at this energy.[2] The background at this high energy is low and is produced mainly by cosmic rays, neutron capture gamma rays, and summing of lower energy gamma rays.

The operator types in the number of positions the scanner is to measure, the dwell time at each position, and the distance between positions. He also indicates which peaks in the acquired spectra are to be integrated and the regions to be used to define the background continua under the peaks. The background continuum we use is a step function.[6] A total of 16 peaks in the two spectra can be integrated. An option allows a previously acquired background scan without a transmission source present to be subtracted point by point. The LeCroy integrates the peaks after acquiring spectra at each position and subtracts a background if this option was selected. Scans on each peak can be viewed during data acquisition.

RESULTS

Using an arrangement with polyethylene and lead for active scans (Fig. 3), we calculated the expected scans for a point detector first for just the polyethylene at 4.439, 2.615, and 0.662 MeV; the results appear in Fig. 4. The point source and point detector define a straight line through the object. The calculation involves determining the chord lengths through the material and calculating the attenuation[7] and the $1/R^2$ correction. The rises in the center of the graph are caused by the void. Figure 5 shows the results for polyethylene and iron. The intensities are strongly attenuated by the iron, but the void can still be seen with 2.615- and 4.439-MeV gamma rays.

Figure 6 compares an experimental active scan and the calculated scan. The object was identical to that shown in Fig. 3, except that the polyethylene was replaced by a composite material of density 1.62 g/cm^3 and attenuation coefficient 0.300 cm^2/g at 4.439 MeV. The gamma-ray energy was 4.439 MeV. The detector was the bismuth-germanate crystal with only side shielding to reduce background. The agreement between the data and the calculated curve is good. The data go slightly negative in the void because the background scan subtracted was too large. The slope outside the object is not quite correct because a point detector was assumed in the calculation. We ignored the finite size of the detector, the side shielding, and the fact that the detector was not always aimed at the source. A Monte Carlo calculation at each scanner position could take into account these effects but it would require additional computer time.

Figure 7 shows a passive scan, using a high-purity germanium detector, on the 356-keV line from a point source of ^{133}Ba placed in the center of the object used for the active scan. Because of the good resolution, the contribution from scattered gamma rays was insignificant. The geometry was defined by a lead collimator 33.0 cm long by 4.44 cm i.d. by 7.62 cm o.d. Our calculated spatial resolution W_r is 7.8 cm, which agrees with the measured value of 8 cm shown in Fig. 7. For a spatially extended object of dimension W_o, the measured response W_m is roughly given by $W_m = \left(W_o^2 + W_r^2\right)^{1/2}$. More precisely, the measured response is a convolution of the spatial distribution of the radioactivity in the object and the point spread-function of the system. Once again, a Monte Carlo calculation could be applied.

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TABLE

MAJOR GAMMA-RAY LINES FROM THE FISSIONABLE ISOTOPES[3]

Isotope	Energy (keV)	Intensity $(g\text{-}s)^{-1}$
^{235}U	185.72	4.3×10^4
^{238}U (^{234m}Pa)	1001.10	1.0×10^2
(^{234m}Pa)	766.40	3.9×10^1
^{238}Pu	766.40	1.5×10^5
	152.77	6.5×10^6
^{239}Pu	413.69	3.4×10^4
	129.28	1.4×10^5
^{241}Pu (^{237}U)	207.98	2.0×10^7
(^{237}U)	164.59	1.8×10^6
	148.60	7.5×10^6
^{241}Am	59.54	4.6×10^{10}

FIGURE CAPTIONS

Fig. 1. A LeCroy 3500 system with printer/plotter and diskette drive unit.

Fig. 2. The scanner consists of a track, a carriage that supports a high-purity germanium detector and collimator, and a stepping motor controller. The drum is the object being scanned. The ^{241}Am/Be source is supported on the ringstand in the foreground. The amplifier and high-voltage power supply are behind the detector.

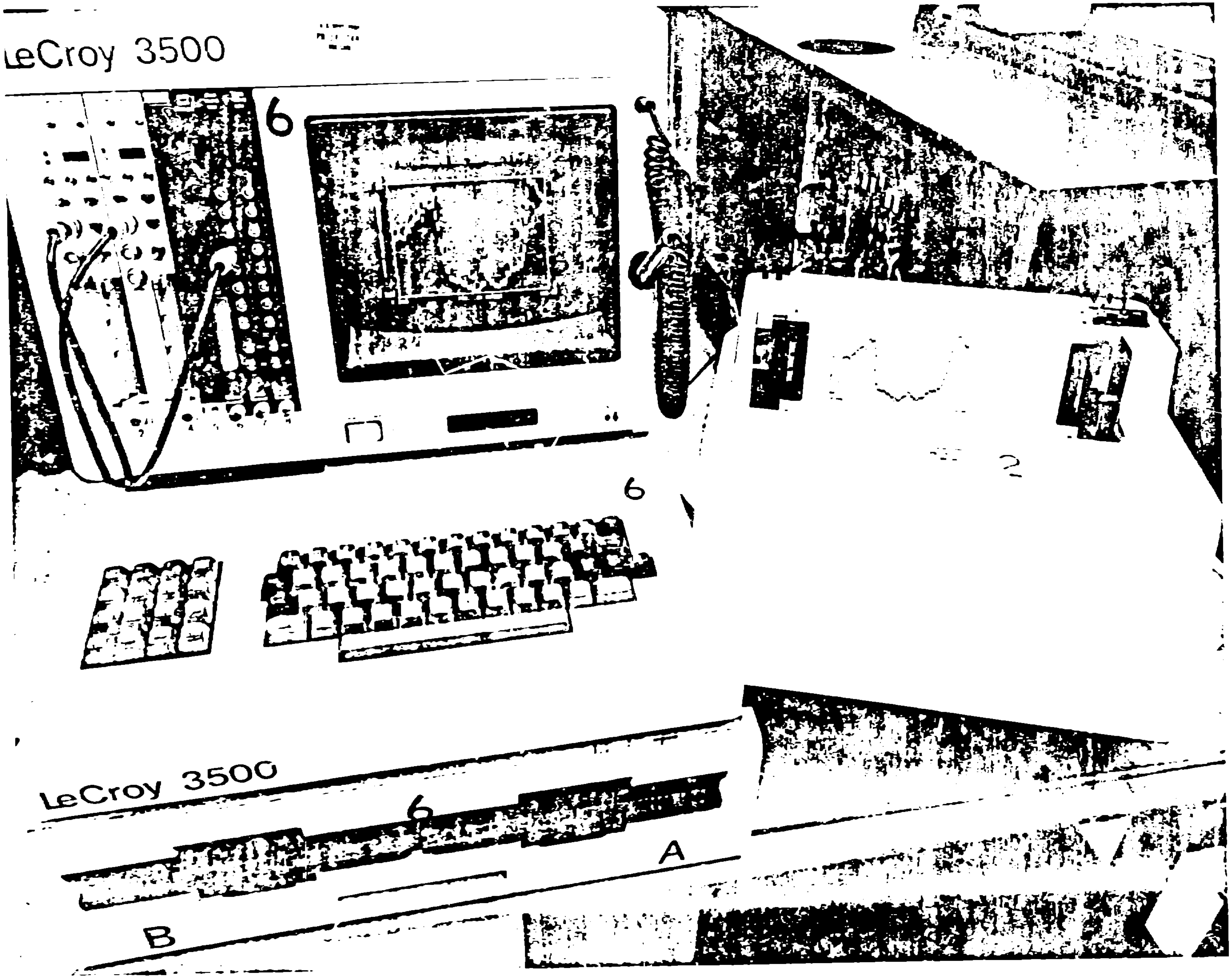
Fig. 3. This arrangement is used for active scans. The detector is a bismuth-germanate crystal shielded by a lead annulus that travels horizontally on a track to view the source through an interposed object.

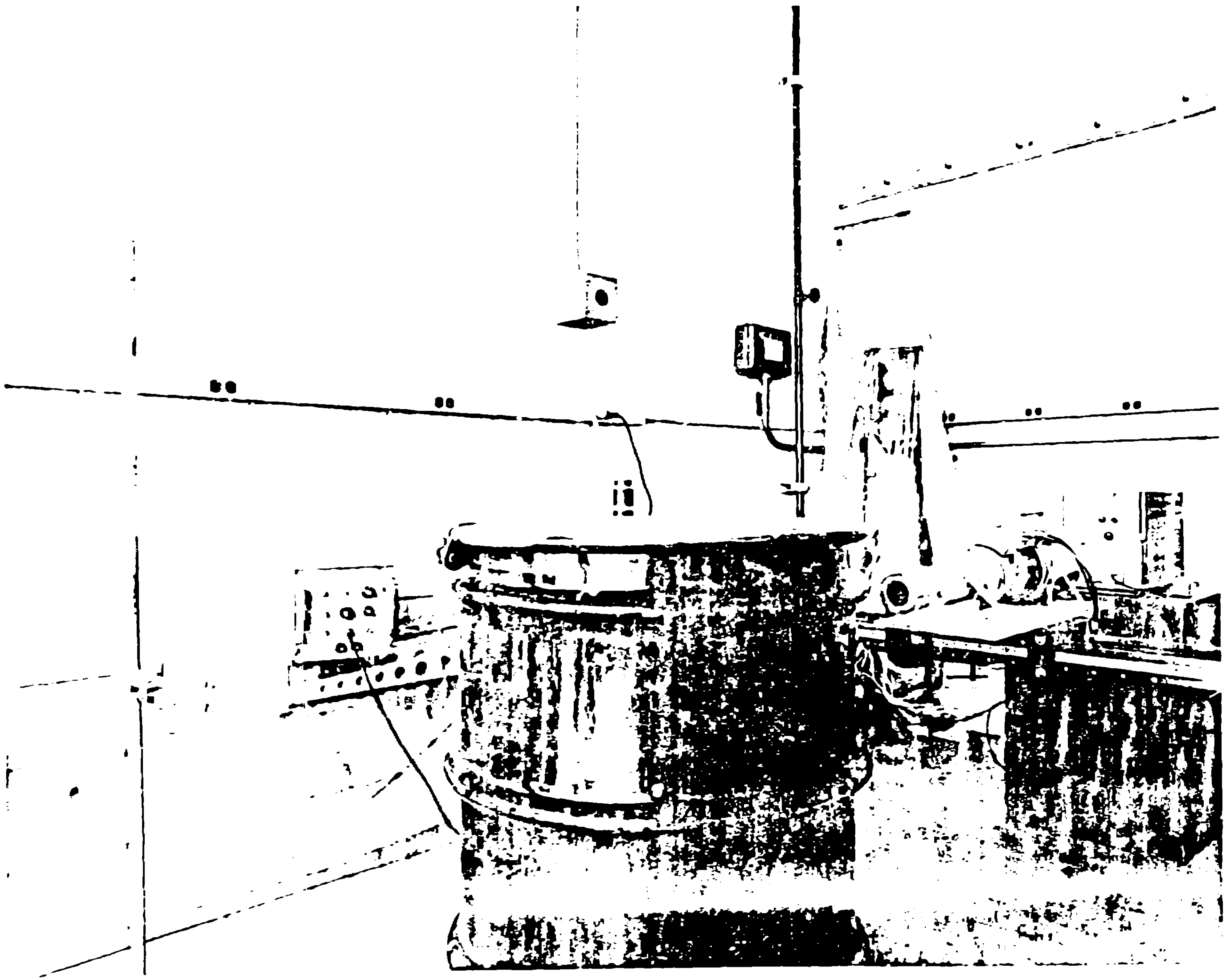
Fig. 4. Plot of the calculated scans for just the polyethylene (Fig. 3 configuration) for three different gamma-ray energies. The rises in the middle are caused by the center void. The arrows indicate where the gamma rays are tangent to the inner or outer surfaces.

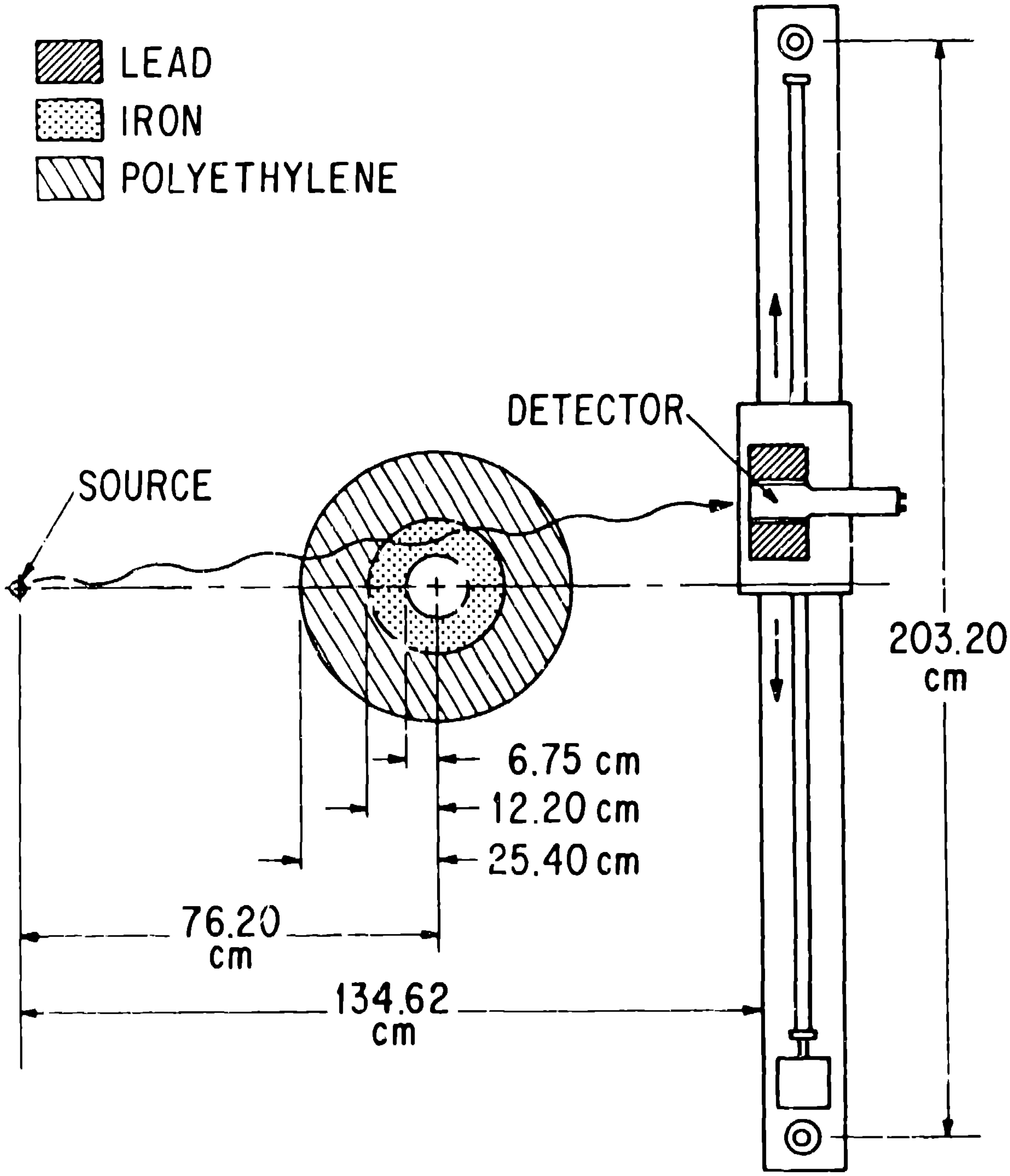
Fig. 5. Calculated scans for polyethylene and iron (Fig. 3 configuration).

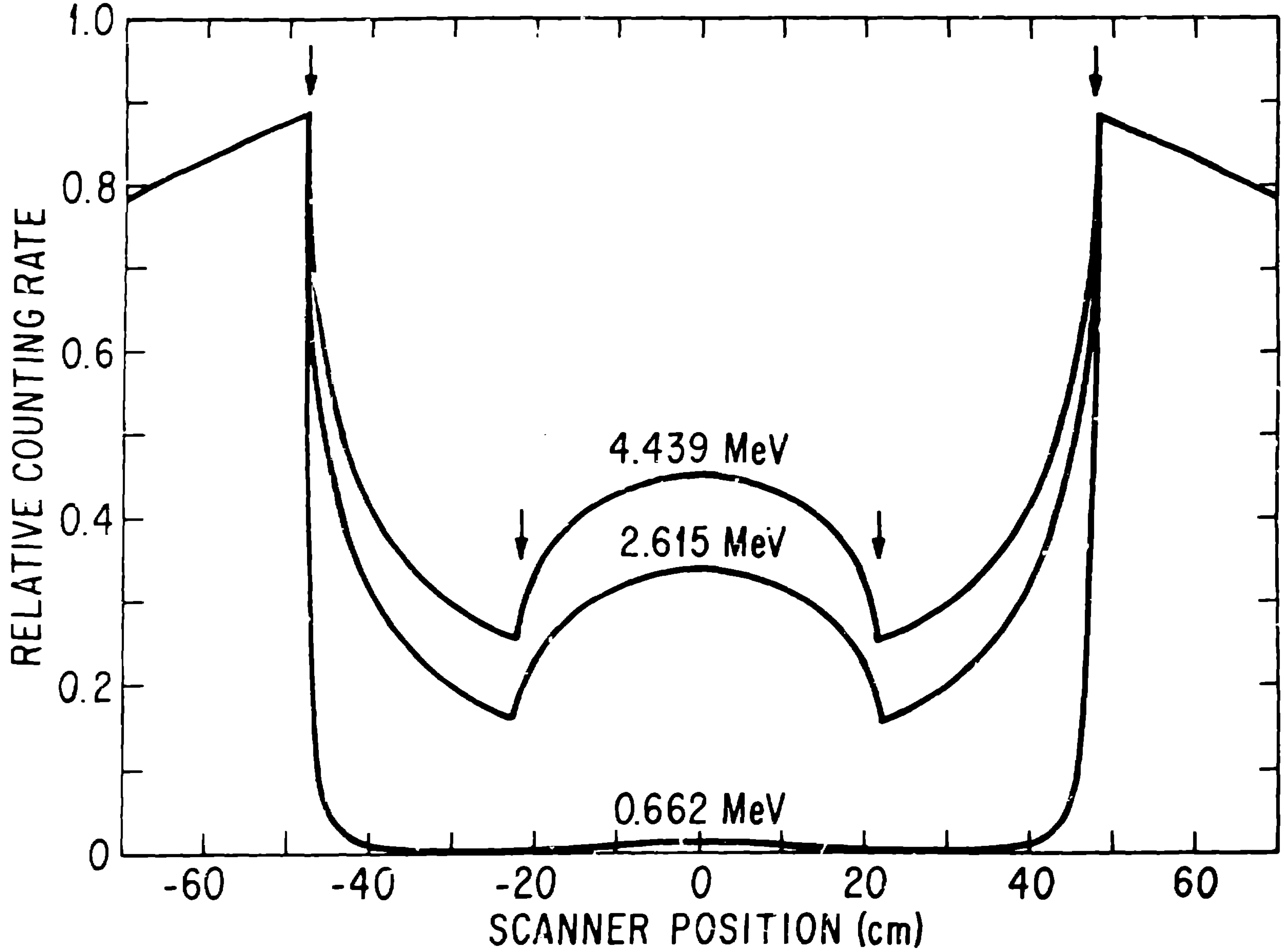
Fig. 6. Experimental and calculated active scan with 4.439-MeV gamma rays.

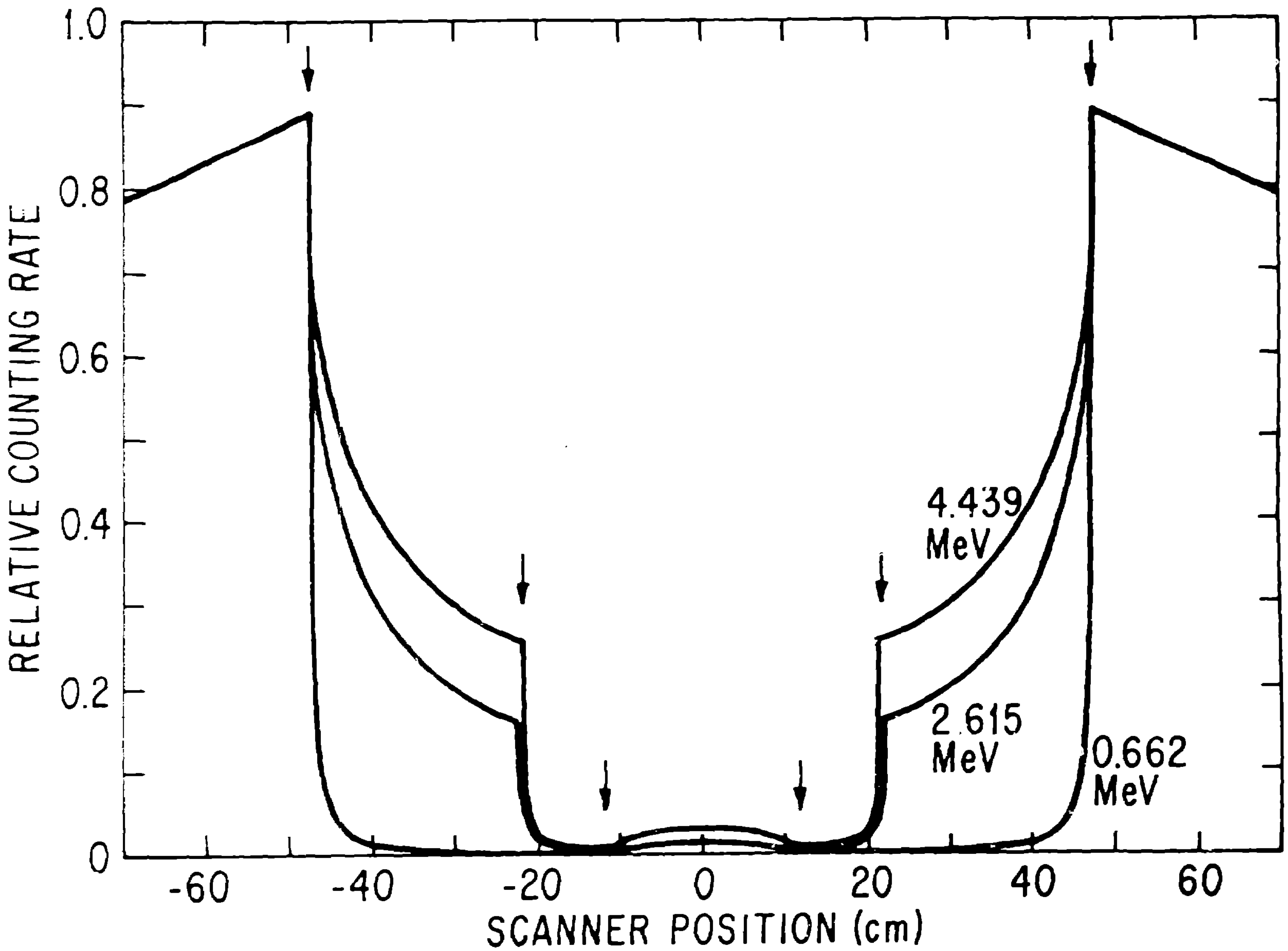
Fig. 7. A passive scan on the 356-keV line from a point source of ^{133}Ba, placed in the center of the object that was used for the active scan in Fig. 6.


LeCroy 3500
6
6
2
LeCroy 3500
6
A
B

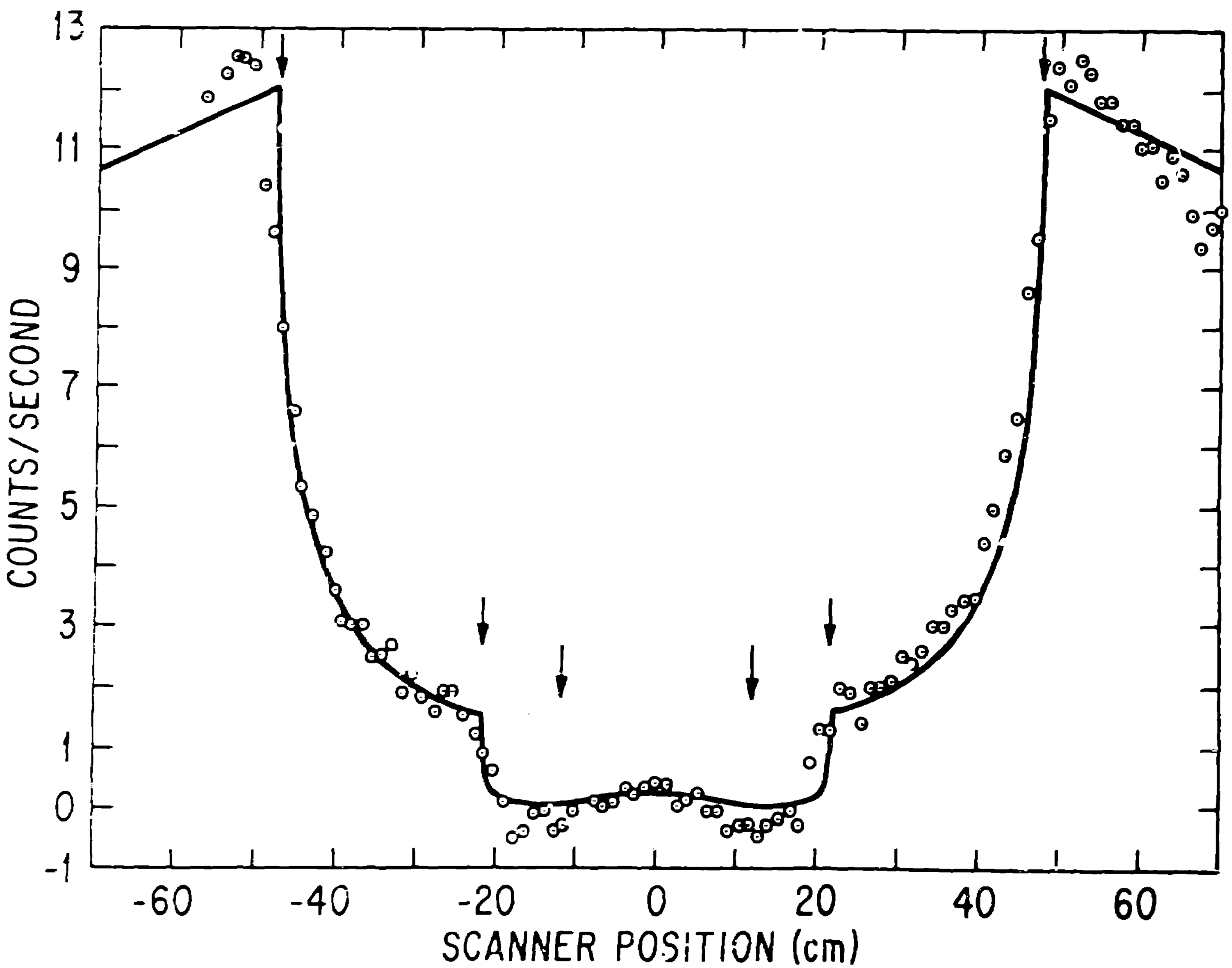



LEAD
IRON
POLYETHYLENE
DETECTOR
SOURCE
203.20 cm
6.75 cm
12.20 cm
25.40 cm
76.20 cm
134.62 cm

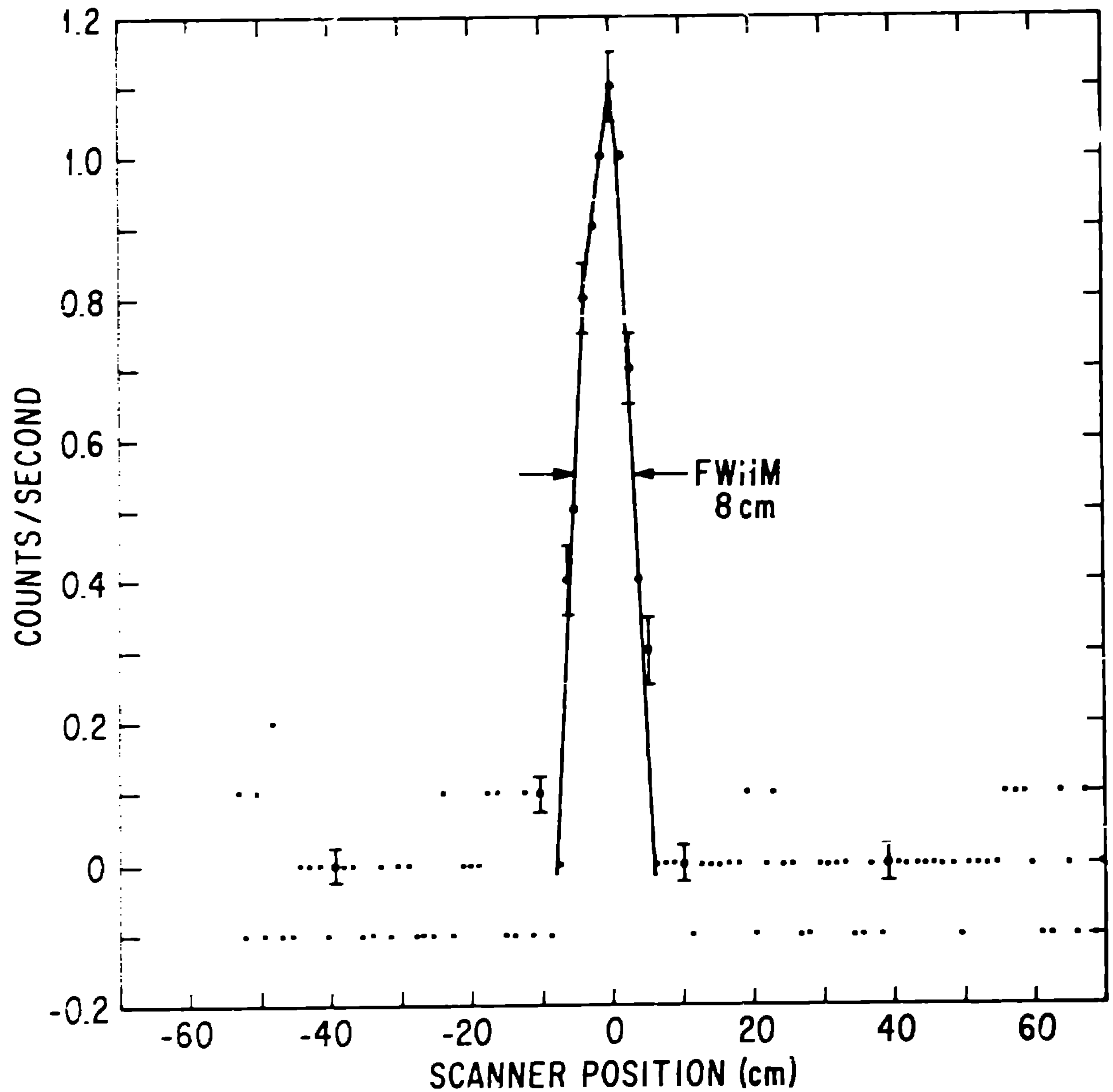

1.0
0.8
0.6
0.4
0.2
0
RELATIVE COUNTING RATE
4.439 MeV
2.615 MeV
0.662 MeV
-60
-40
-20
0
20
40
60
SCANNER POSITION (cm)



1.0
0.8
0.6
0.4
0.2
0
RELATIVE COUNTING RATE
-60
-40
-20
0
20
40
60
SCANNER POSITION (cm)
4.439 MeV
2.615 MeV
0.662 MeV



COUNTS/SECOND
13
11
9
7
5
3
1
0
-1
-60
-40
-20
0
20
40
60
SCANNER POSITION (cm)



1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
COUNTS/SECOND
FWiiM
8 cm
-60
-40
-20
0
20
40
60
SCANNER POSITION (cm)