CONF-900563--13

DE90 013681

NUCLEAR SPECTROSCOPY WITH Si PIN DIODE DETECTORS AT ROOM TEMPERATURE*

I. AHMAD, R.R. BETTS, T. HAPP, D.J. HENDERSON, F.L.H. WOLFS and A.H. WUOSMAA

Physics Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439, USA

The characteristics of PIN diodes have been determined. These diodes have lower leakage currents and noise than other types of Si radiation detectors. The energy resolutions (FWHM) of a 1 cm^2 x 0.5 mm PIN diode measured with a pulser, 122.0 keV gamma rays, 193 keV electrons, and 5.5-MeV alpha particles were 2.6, 2.8, 2.9, and 11.0 keV, respectively. For a 6 mm x 6 mm x 0.2 mm PIN diode, the resolutions (FWHM) for a pulser, 60 keV γ-rays, 193 keV electrons, and 5.5-MeV α-particles were 2.1, 2.2, 2.4, and 10.8 keV, respectively.

1. Introduction

High resolution electron spectroscopy has in the past been carried out with cooled lithium-drifted silicon detectors, which are usually 3 mm thick. These cooled detectors, when coupled to preamplifiers with cooled FET's in their first stage, can give energy resolutions (FWHM) of 1.0 keV or better for 100 keV electrons [1]. The full width at half maximum slightly increases with energy because of the statistical spread in the signal. Typical performance of such detectors, as measured in ref. [1], is given in table 1. By subtracting the contribution of the electronic and detector noise from the total width, one can determine the contribution of the statistical fluctuations in the number of electron-hole pairs produced by the radiation. These numbers are included in the table.

*This work was supported by the US Department of Energy, Nuclear Physics Division, under contract No. W-31-109-ENG-38.

In the past few years, there have been significant improvements in the fabrication of low-noise Si detectors for nuclear spectroscopic measurements. One type of such detectors is the passivated ion-implanted Si detector [2] which exhibits leakage currents of less than 10 nanoamperes. These detectors give excellent energy resolutions [3] for alpha particles and electrons. Small, 0.2 cm^2 area, detectors of this type, coupled to a low-noise preamplifier, have given resolutions (FWHM) of 1.5 keV for low energy X-rays [4]. Since the mechanism for the electron-hole pair production is the same for photons and electrons, one expects similar resolutions (~1.5 keV) for electrons.

Another type of Si detector has recently been used for nuclear spectroscopic measurements. These Si detectors, called PIN diodes, are mainly used for the detection of light from scintillation crystals. Because of their small size, PIN diodes have been used in place of photomultiplier tubes in experimental apparatus where space is limited. Several investigations have been carried out with PIN diodes, which show that these detectors have extremely low leakage currents and low noise. In a recent article [5], a resolution (FWHM) of 2.0 keV was obtained for low energy γ rays and electrons with a 13.2 mm^2 (4.1 mm diameter) x 0.1 mm PIN diode. The periphery of the detector was protected against breakdown by coating it with silicone rubber [6]. Although the performance of this 0.1 mm thick detector shows the excellent quality of PIN diodes, thicker and larger area detectors are required for useful electron spectroscopy. Since the bulk leakage current depends on the detector volume and the surface leakage current depends on the overall fabrication of the detector, it is difficult to extrapolate the properties of larger PIN diodes from the performance of such small detectors. For this reason, we have measured the characteristics of larger and thicker detectors with the aim of using them in our accelerator based research. In this report we present the results of these measurements.

2. Experimental methods and results

Silicon PIN diodes of various dimensions were used in the present measurements. Since the PIN diodes come from the manufacturers unmounted, holders were constructed for the mounting of these detectors. We have tested various preamplifiers and found the best performance with the Canberra [7] 2001A preamplifier, which had a load resistor of 10 GΩ. The amplifier time constant was 2 μs and the spectra were measured with a computer based multichannel analyzer. A pulser was used to measure the electronic noise of the system. The capacitance of each detector was measured at the bias voltage of operation. The noise of this preamplifier at 0 pf input capacitance was measured to be 1.0 keV. The noise was also measured at several values of capacitance.

2.1. Electron spectroscopy

The detector and the source were placed in a small chamber which was evacuated to 30 millitorr with a mechanical pump. For electron spectroscopy a thin electroplated source was used. The spectrum of a ^{203}Hg source measured with a 1 cm^2 x 0.5 mm PIN diode, HAMAMATSU S1723-09N [8], is displayed in fig. 1. This detector can stop electrons up to 400 keV energy. The detector was operated at 90 volts and at this voltage the leakage current was 1 nA and the detector capacitance was 39 pf. A resolution (FWHM) of 2.6 keV was obtained for the test pulse and the 279.2 K line had a FWHM of 2.9 keV. A spectrum of ^{57}Co gamma rays, measured with the same setup, is shown in fig. 2. The FWHM of the 122 keV γ-ray is 2.8 keV.

Similar tests were performed with a 6 mm x 6 mm HAMAMATSU S2620 PIN diode. This detector was 0.2 mm thick and could stop electrons up to 200 keV energy. The detector was operated at 70 volts and at this bias, the leakage current was less than 1 nA and the detector capacitance was 30 pf. Spectra of ^{203}Hg electrons and ^{241}Am γ rays measured with this detector are shown in figs. 3 and 4. A pulser peak is included in the electron spectrum to show the noise in the system. The resolutions (FWHM) for the pulser, 60 keV γ rays and 279.2 K electrons are measured to be 2.1 keV, 2.2 keV, and 2.4 keV, respectively.

In order to detect electrons with energy greater than 500 keV, and x-rays efficiently, PIN diodes with thickness greater than 0.5 mm are required. Such PIN diodes are, however, not currently available commercially. We have obtained some custom-made 1 cm^2 x 1 mm PIN diodes from MICRON [9] and have tested them. At room temperature these detectors have typical resolutions of 6 keV for electrons. Detectors with a guard ring connected so as to short the surface currents had a leakage current of 12 nA through the active volume and gave pulser and electron resolutions (FWHM) of 4.0 and 4.2 keV, respectively.

2.2. Alpha spectra

The PIN diodes were also used to measure the spectrum of alpha particles. Since the detector noise is extremely low (as shown by the pulser noise) and the detector entrance window is extremely thin [5], one should obtain excellent resolution for alpha particles. We used a TENNELEC [10] TC170 preamplifier so that the large pulses produced by the alpha particles do not saturate. This preamplifier has a factor of 5 lower gain than the Canberra 2001A preamplifier, and a load resistor of 250 MΩ. Using this preamplifier and the HAMAMATSU S2620 PIN diode, with a 3-mm collimator, we measured alpha spectra of ^{238}Pu and ^{249}Cf. These sources were produced by an isotope separator and were extremely thin. With this setup the pulser width was 2.5 keV and the resolution (FWHM) of ^{238}Pu alpha peaks was 10.8 keV. The alpha spectrum was also measured with a 1 cm^2 x 0.5 mm HAMAMATSU S1723-09N detector, with a 6-mm collimator in front, and it is displayed in fig. 5. A resolution of 11.0 keV was obtained. This resolution is among the best measured resolutions with 1 cm^2 area detectors. Also this resolution is better than the value of 12.0 keV measured with a 13 mm^2 x 0.1 mm detector in ref. [5].

3. Discussion

The resolutions of γ rays and electron lines depend on three factors: the electronic noise of the system, noise in the Si detector, and the statistical fluctuations in electron-hole pair production. The electronic noise of the setup was measured by replacing the detector with a capacitance of the same value as that of the detector. Thus with a 39 pf at the input of the Canberra 2001A preamplifier, the electronic noise was measured to be 2.0 keV. The width of the pulser with a 1 cm^2 x 0.5 mm PIN diode connected was 2.6 keV. This width has the electronic contribution as well as the noise in the detector and these add in quadrature to give the measured resolution of 2.6 keV. From these measurements we deduce the detector noise as 1.7 keV. Using similar analysis we deduce the noise of the 6 mm x 6 mm x 0.2 mm PIN diode as 1.1 keV. The width of the γ-ray peak and electron peak is somewhat larger than the pulser width because of the statistical spread in the number of electron-hole pairs produced by the radiation. This can be calculated [11] or taken from table 1.

4. Conclusion

The present study and previous investigations show that the PIN diodes have potential for high resolution alpha, electron and x ray spectroscopy. These PIN diodes have extremely low leakage current and low noise, better than any known

Si detector of comparable dimension. They also have extremely thin entrance windows. Thus, in principle, these detectors should give resolutions of less than 10 keV for alpha particles when coupled to low noise preamplifiers.

These PIN diodes are, however, mounted such that the edges are unshielded and consequently show edge effects. For example, when used without a collimator the alpha spectra show satellite peaks about 25 keV below the main peaks. Thus a collimator should be used for electron and alpha particle spectra. Alternatively, the edge can be covered with silicone rubber so that the edges are insensitive to α-particles and electrons. The resolutions of the PIN diodes can be improved by selecting preamplifiers with very low noise and by placing the PIN diode and the first stage of the preamplifier directly in contact with each other, as has been done with the Enertec [4] detectors. With such improvements it is possible to achieve resolutions of 2.0 keV for the 6 mm x 6 mm x 0.2 mm PIN diode and 2.5 keV for the 1 cm^2 x 0.5 mm PIN diode at 200 keV electron energy.

Acknowledgments

The authors acknowledge helpful discussions with the members of the APEX collaboration, which consists of scientists from Argonne National Laboratory, Florida State University, Michigan State University, Princeton University, University of Rochester, University of Washington and Yale University. We would also like to thank Tom Moog for his assistance in setting up the computer system for data acquisition.

References

[1] I. Ahmad and F. Wagner, Nucl. Instr. and Meth. 116 (1974) 465.

[2] J. Kemmer, Nucl. Instr. and Meth. 226 (1984) 89.

[3] I. Ahmad, Nucl. Instr. and Meth. A242 (1986) 395.

[4] INTERTECHNIQUE, Enertec Nuclear Instruments, Lingolsheim, France.

[5] H. Yamamoto, S. Hatakeyama, T. Norimura and T. Tsuchiya, Nucl. Instr. and Meth. A281 (1989) 128.

[6] H. Yamamoto, Y. Mori, Y. Wakuta and M. Sonoda, Nucl. Instr. and Meth. 134 (1976) 119.

[7] CANBERRA Industries, Inc., One State Street, Meriden, Connecticut 06450.

[8] HAMAMATSU Corporation, 360 Foothill Road, P.O. Box 6910, Bridgewater, N.J. 08807-0910.

[9] MICRON Semiconductor Ltd, 1 Royal Buildings, Marlborough Road, Churchill Industrial Estate, Lancing, Sussex, BN15 8UN, England.

[10] TENNELEC, 601 Oak Ridge Turnpike, P. O. Box 2560, Oak Ridge, Tennessee 37831.

[11] G. F. Knoll, Radiation Detection and Measurement (Wiley & Sons, 1989) p. 400.

Figure Captions:

Fig. 1. Electron spectrum of a ^{203}Hg source measured with a 1 cm^2 x 0.5 mm HAMAMATSU S1723-09N PIN diode. The detector was operated at 90 volts and at that bias, the leakage current was 1 nA. A 6-mm diameter collimator was used to avoid edge effects. The energy scale is 90.0 eV per channel.

Fig. 2. ^{57}Co γ-ray spectrum measured with a 1 cm^2 x 0.5 mm PIN diode. The energy scale is 90.0 eV per channel.

Fig. 3. ^{203}Hg electron spectrum measured with a 6 mm x 6 mm x 0.2 mm HAMAMATSU S2620 PIN diode. The detector was operated at 70 volts and at that bias the leakage current was less than 1 nA. A 3-mm diameter collimator was used to avoid edge effects. A pulser peak is also included. The energy scale is 89.5 eV per channel.

Fig. 4. ^{241}Am γ-ray spectrum measured with a 6-mm x 6-mm X 0.2-mm HAMAMATSU S2620 PIN diode. The energy scale is 89.5 eV per channel.

Fig. 5. ^{238}Pu alpha spectrum measured with a 1-cm^2 x 0.5-mm HAMAMATSU S1723-09N PIN diode. The detector bias was 90 volts and at that bias the leakage current was 1 nA. An aluminum collimator with a 6-mm hole was used to avoid edge effects of the detector. The energy scale is 1.00 keV per channel.

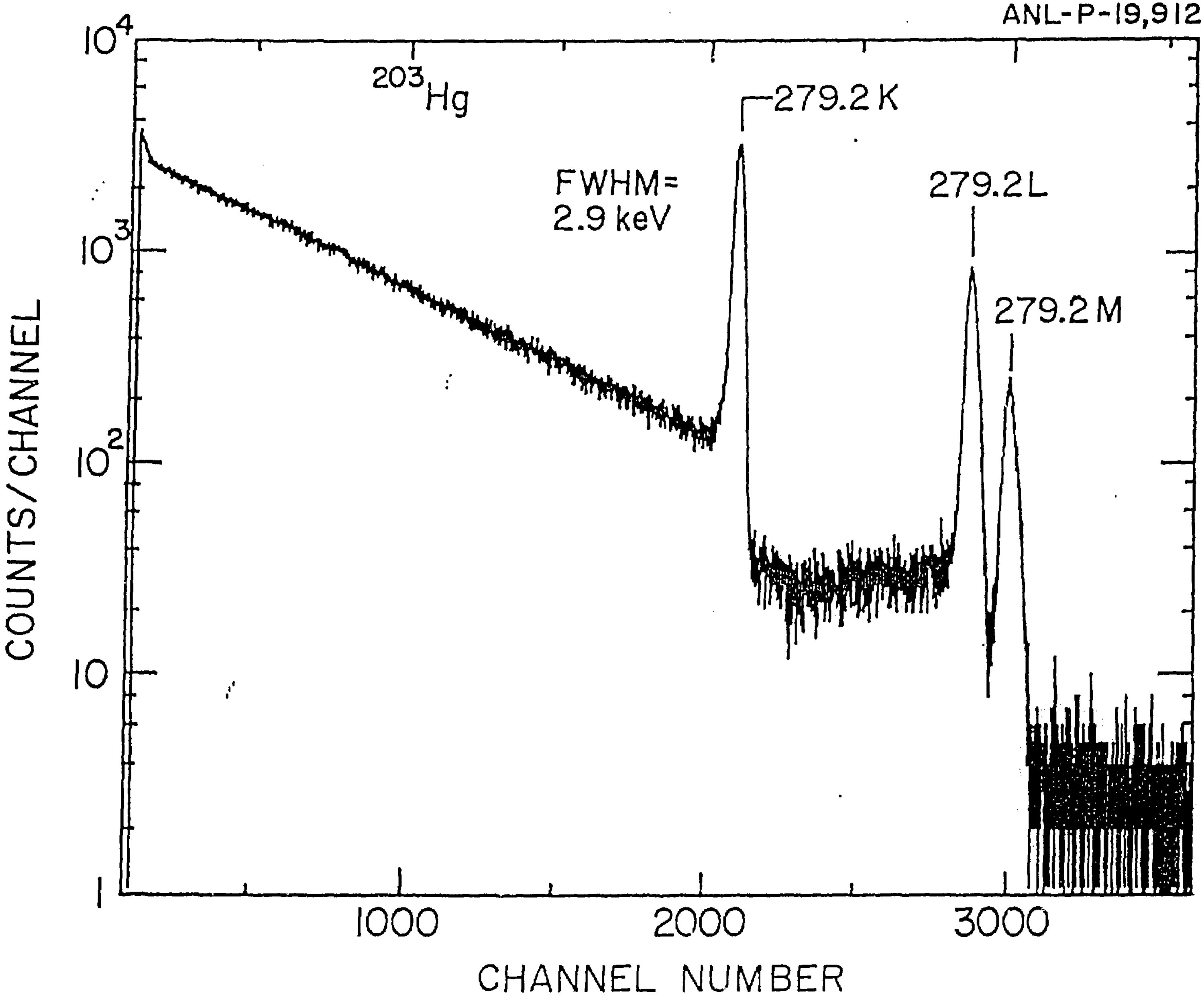
Table 1

Resolution of the cooled Si(Li) spectrometer at different energies (from ref. [1]).

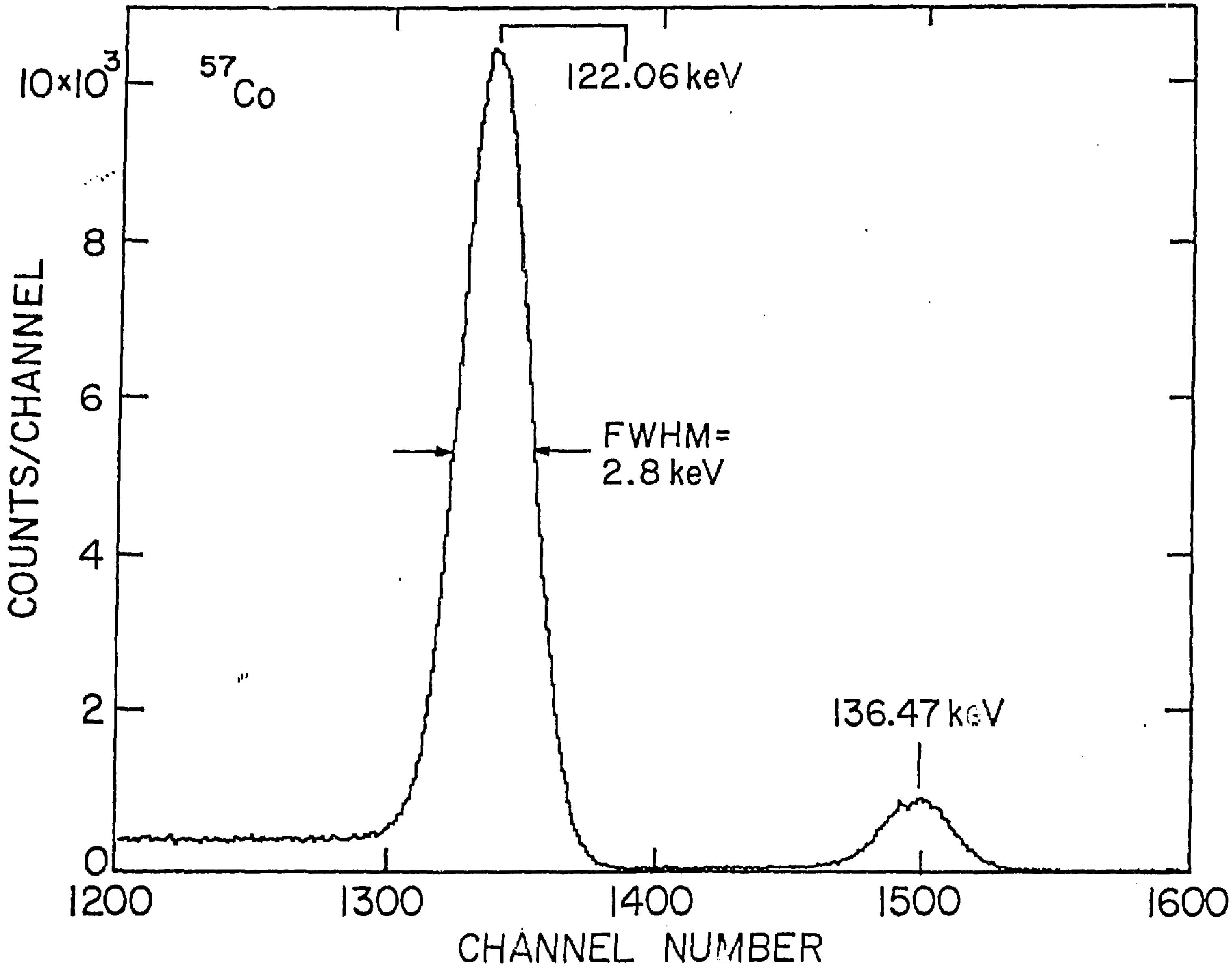
Sample	Energy	Measured full width at half maximum (FWHM)	Contribution[a] from statistical effects
Pulser	-	0.64 keV	-
^{57}Co 14.4 γ	14.413 keV	0.68 keV	0.23 keV
^{241}Am 59.5 γ	59.537 keV	0.73 keV	0.35 keV
^{57}Co 122.0 γ	122.061 keV	0.83 keV	0.53 keV
^{57}Co 122.0 K electron	114.95 keV	0.88 keV	0.60 keV
^{203}Hg 279.2 K electron	193.64 keV	1.06 keV	0.84 keV
^{137}Cs 661.6 K electron	624.15 keV	1.50 keV	1.36 keV
^{244}Cm α	5.805 MeV	12.0 keV	12.0 keV

[a] $(\Delta E)_{statistical} = [(\Delta E^2_{measured} - (\Delta E)_{pulser}]^{1/2}$

ANL-P-19,912

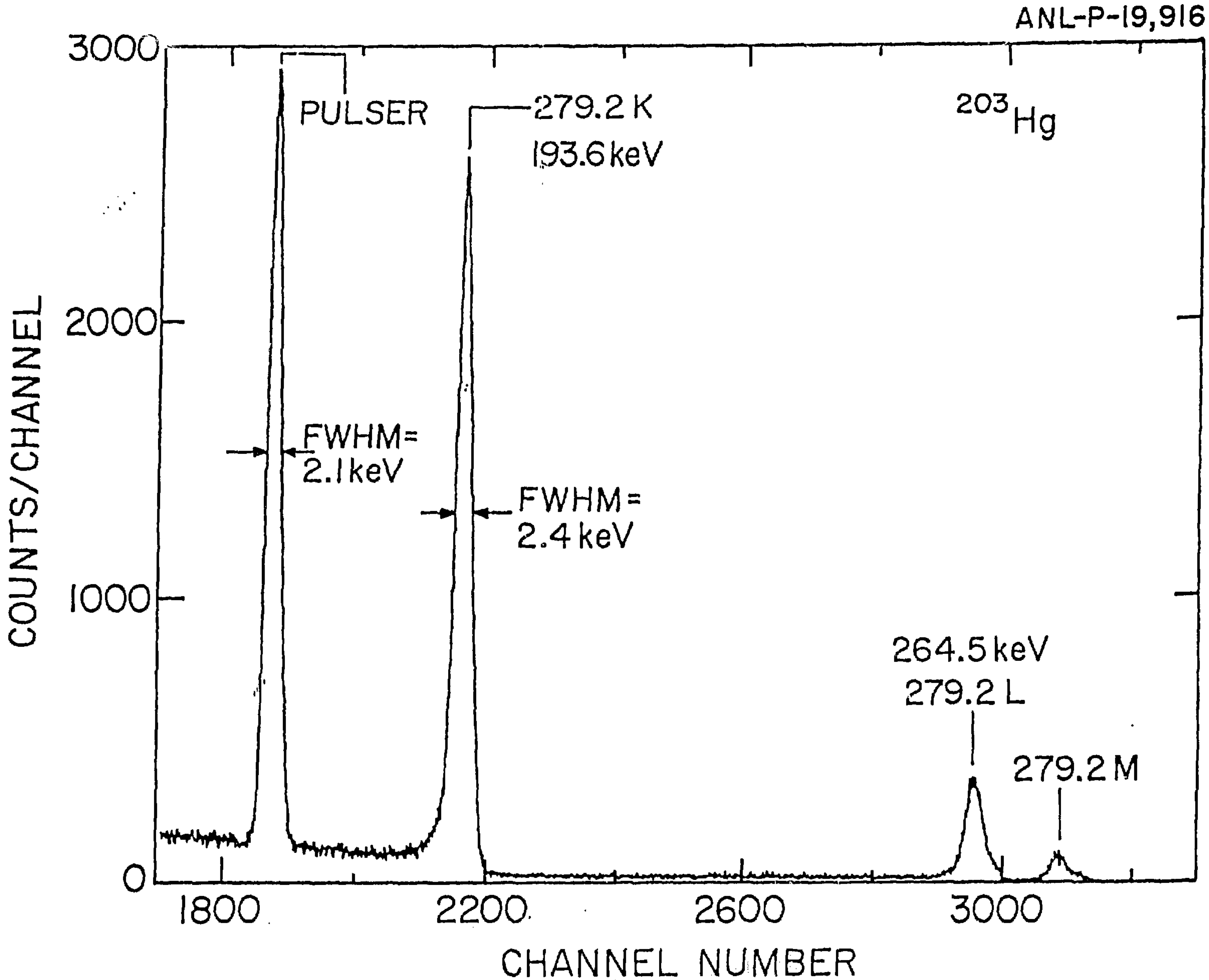


Fi...

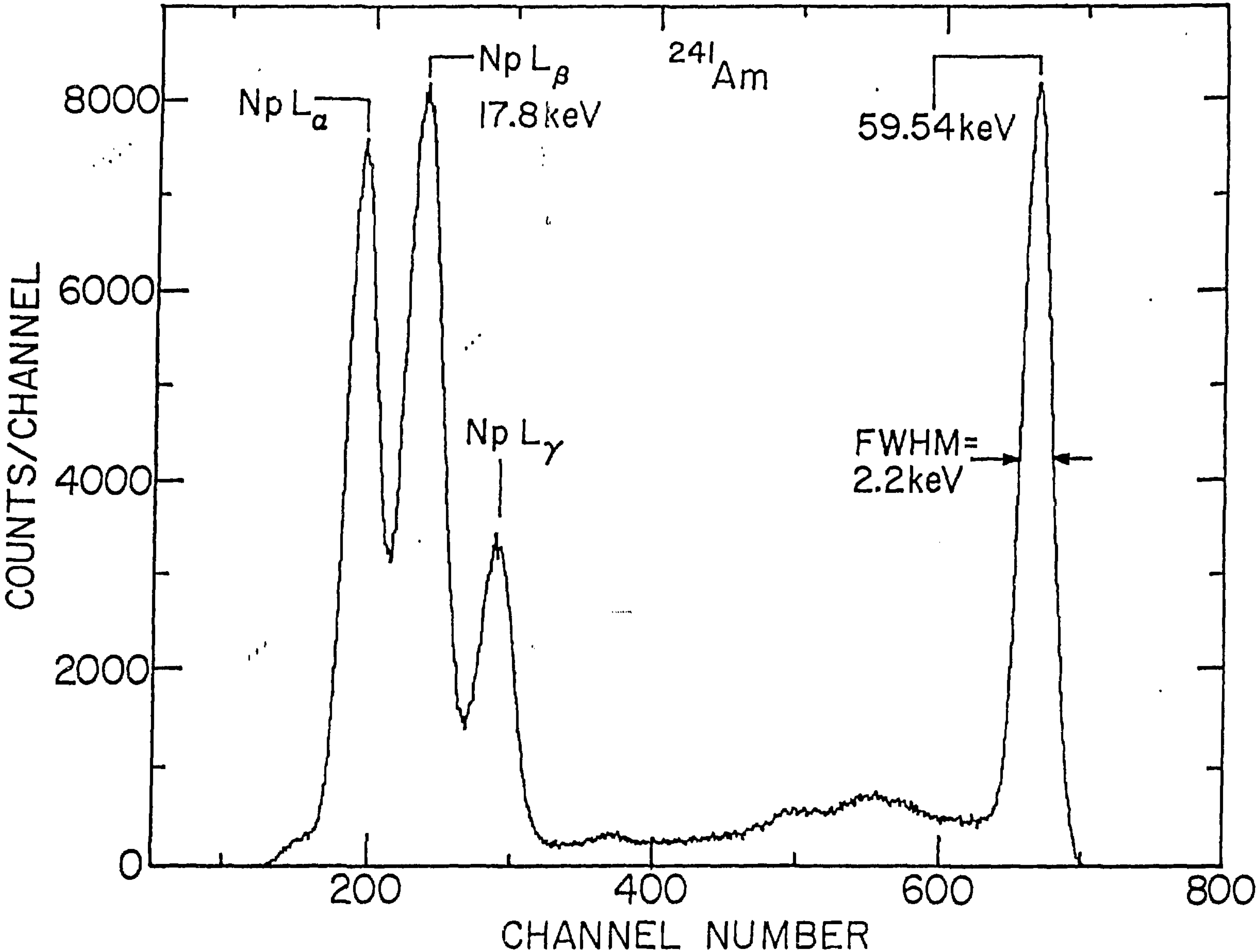


10×10³
⁵⁷Co
122.06 keV
8
6
4
2
0
COUNTS/CHANNEL
FWHM=
2.8 keV
136.47 keV
1200
1300
1400
1500
1600
CHANNEL NUMBER

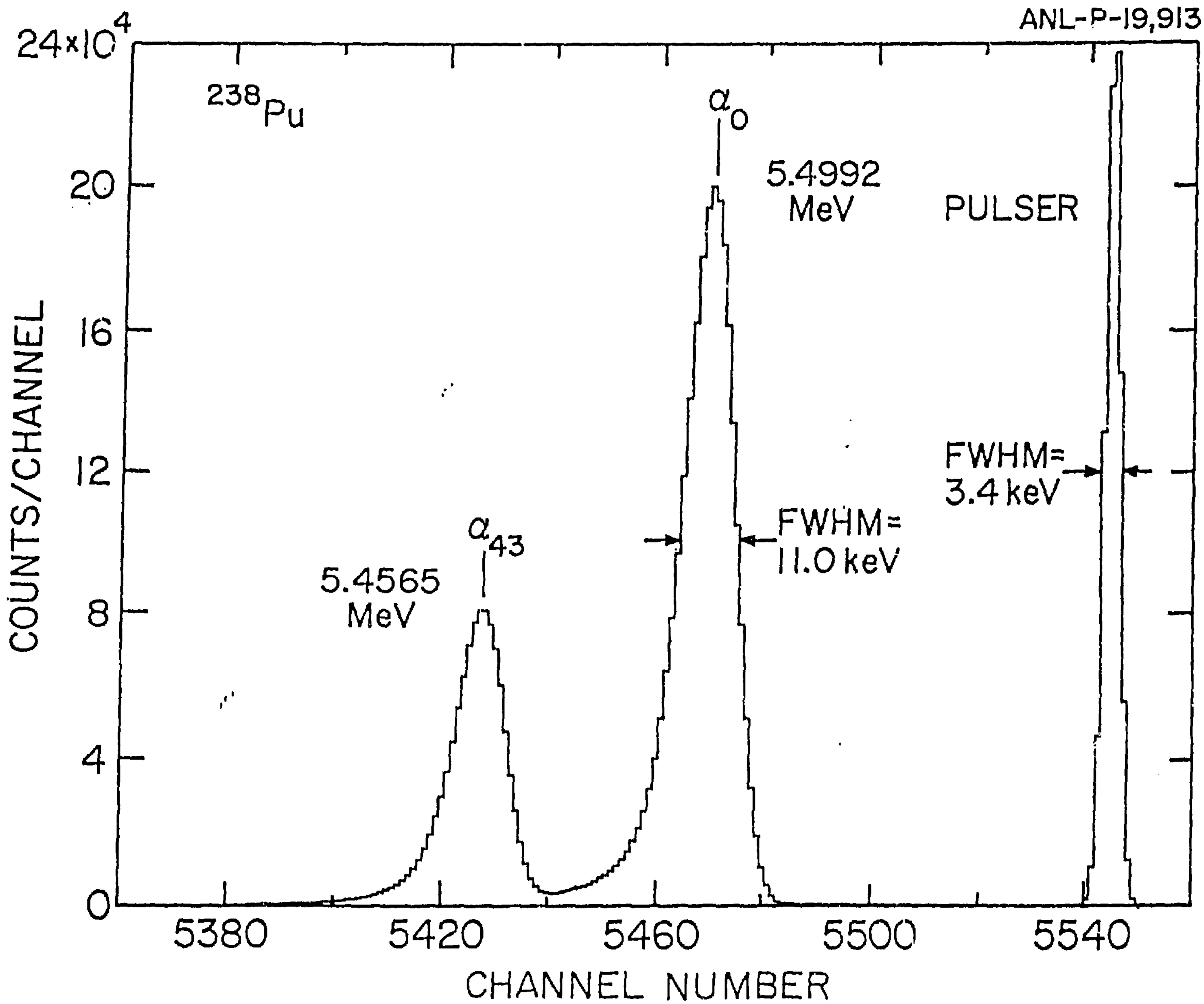
Fig. 2


ANL-P-19,916
3000
2000
1000
0
COUNTS/CHANNEL
PULSER
279.2 K
193.6 keV
^{203}Hg
FWHM=
2.1 keV
FWHM=
2.4 keV
264.5 keV
279.2 L
279.2 M
1800
2200
2600
3000
CHANNEL NUMBER

ANL-P-19,917



Np L_α
Np L_β
17.8 keV
^{241}Am
59.54 keV
Np L_γ
FWHM=
2.2 keV
8000
6000
4000
2000
0
COUNTS/CHANNEL
200
400
600
800
CHANNEL NUMBER


ANL-P-19,913
238Pu
24x10^4
20
16
12
8
4
0
COUNTS/CHANNEL
α0
5.4992 MeV
PULSER
FWHM= 3.4 keV
FWHM= 11.0 keV
α43
5.4565 MeV
5380
5420
5460
5500
5540
CHANNEL NUMBER