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ABSTRACT

Lithium-drifted silicon surface-barrier detectors have been fabricated which exhibit stable electrical and α-particle characteristics under conditions of prolonged aging and repeated exposure to thermal-vacuum environments. The detectors will operate at a temperature of 85°C and high vacuum for several days and at a temperature of 100°C and high vacuum for several hours, with no evidence of noise instability.

The operating characteristics of such detectors have been studied over a period of fourteen months. These studies included measurements of their electrical and α-particle characteristics taken before, during, and after extended thermal-vacuum testing at 50°C and 85°C, and short-term testing at 100°C. Degradation in electrical and α-particle characteristics resulting from such testing and aging was found to be negligible over the fourteen month time period. The α-particle measurements at 100°C indicate that the fractional change in the mean energy per ion pair in going from room temperature to 100°C is approximately -1.8%. The results of these studies are reported.

1. INTRODUCTION

The need for charged-particle detectors which exhibit stable characteristics for prolonged periods of time both under ordinary laboratory conditions and under conditions of high vacuum and elevated temperature continues to be of importance in the space sciences. In our laboratory, this need has led to a continuing study of the effects of aging in the laboratory and environmental testing on the electrical and charged-particle characteristics of the lithium-drifted silicon surface-barrier detector[1-4]).

It was shown earlier[3]) that lithium-drifted silicon surface-barrier detectors made from high resistivity material (~ 1000 ohm-cm) have much more stable α-particle characteristics than detectors made from low resitivity material (~ 100 ohm-cm), and that detectors given a boiling-water treatment (consisting of completely immersing the detector in boiling deionized water for 15 minutes immediately after fabrication) have lower initial leakage current and slightly higher initial charge-collection-efficiency than detectors not given this treatment. From the data available at that time[3]), it was not possible to decide to what extent the boiling water (BW) treatment was responsible for the long-term detector stability observed and to what extent the use of high resistivity material was responsible. This paper presents the results of a study of the effects of aging and thermal-vacuum environments on the

characteristics of surface-barrier detectors made from high resistivity material. Results will be given for detectors which were given the BW treatment (BW detectors) as well as for those not given the boiling-water treatment (NBW detectors). The aim of the present work was to study the relative importance of the BW treatment and material resistivity on detector behavior under environmental testing and aging and to extend the thermal-vacuum tests to higher temperatures than previously used[2,3]).

2. SURFACE-BARRIER DETECTORS

2.1 DETECTOR FABRICATION

The general techniques used in the fabrication of the surface-barrier detectors were identical to those described elsewhere[1-3]). Single crystals of p-type silicon with electrical resistivities in the range 1000 to 1500 ohm-cm were used as the starting material. The detectors were fabricated as described earlier[3]) and some of the detectors were given the BW treatment.

2.2 ELECTRONIC EQUIPMENT

The amplifier system used for most of the measurements was a transistorized charge-sensitive amplifier-post-amplifier combination designed at this laboratory. This amplifier had an integrating and differentiating time constant of 2μs. An ORTEC Model 204 charge-dumping pulser was used

to provide data on electrical resolution and to provide an energy calibration for the system. The pulser was calibrated by making use of conventional gold-silicon surface-barrier detectors[5]) operated at high bias and Po^{210} sources. The output from the post amplifier was analyzed on an RIDL Model 32-12B 400-channel pulse-height analyzer. Detector currents were monitored with a Keithley Model 410 micro-microammeter. The detector load resistor used throughout the experiment was $10^5 \Omega$.

2.3 DETECTOR CHARACTERIZATION

The depth of the lithium diffusion and the intrinsic depth was determined by making use of internal conversion electrons from Cs^{137} and Bi^{207} sources and capacitance measurements, as described earlier[2]). Such measurements were made periodically during the aging and environmental testing of detectors to determine whether any changes in n- or intrinsic-region depths had occurred.

2.4 SOURCES

It was found that the Po^{210} sources which had been obtained commercially "leaked" under conditions of high vacuum and elevated temperatures. To avoid this contamination problem, an Am^{241} source was fabricated by the following procedure. A sheet of thoroughly cleaned mylar with a thickness of 750 μinches was mounted on a frame and a diluted solution of

the Am^{241} isotope in HCL + H_2O was deposited on the mylar film with a micro-pipette and allowed to dry. A second piece of mylar, 250 μinches thick, was prepared and cleaned. The thickness of this second mylar film controls the peak energy of the α-particles emitted by the completed source. The first mylar film with the Am^{241} is placed on a glass plate, and a small amount of epoxy is deposited over the face containing the Am^{241}. The second mylar sheet is then placed on top and the excess epoxy is rolled out with a soft roller. A second piece of plate glass is placed on top of the assembly and a pressure of 10^4 lb/in^2 is applied. Pressure is maintained until polymerization of the epoxy is complete. The source is then removed from the press and cut to the desired size. The thickness of the epoxy film has been measured to be ~5 to 10 μinches. A spectrum (shown in Figs. 4 and 10) obtained with this "sandwiched" source showed a fairly well defined peak with a sharp high energy cutoff and serious straggling at energies less than the peak energy. Although the straggling made it difficult to locate the peak precisely, repeated spectra taken at room temperature, 85°C, and 100°C showed that changes in the peak position with temperature greater than about 0.4% could be detected. This source was calibrated by making use of a conventional surface-barrier detector operated at high bias[5]) and a calibrated pulser. The energy corresponding to the peak was found to be 4.37 MeV. Repeated

environmental testing showed that this source was mechanically rugged and was stable at 100°C and high vacuum.

2.5 THERMAL-VACUUM TEST

The aging and thermal-vacuum (t-v) testing procedure consisted of the following:

1. Detectors were allowed to age at room temperature with no bias applied for approximately two months following fabrication.

2. They were then placed in a vacuum chamber and maintained at a temperature of 50°C and a vacuum of approximately 3×10^{-5} mm Hg for four to seven days, with the bias voltage applied continuously.

3. The detectors were removed from the vacuum chamber and allowed to stand with no bias applied for ten weeks to one year, depending upon the detector.

4. They were then placed in the vacuum chamber and maintained at a temperature of 85°C and a vacuum of approximately 3×10^{-5} mm Hg for five days with the bias voltage applied continuously. During this 85°C t-v test, the temperature was raised to 100°C and maintained at this temperature for several hours and then returned to 85°C. For some detectors, this excursion to 100°C was carried out twice. At both 85°C and 100°C, the uncertainty in detector temperature was about 5°C.

5. The detectors were removed from the vacuum chamber and allowed to stand in the laboratory with no bias applied.

The following detector characteristics were measured: a) current-voltage characteristic; b) n-region depth and intrinsic depth; c) capacitance *vs.* bias voltage; d) electrical resolution *vs.* bias voltage; e) charge-collection-efficiency and resolution *vs.* bias voltage for Po^{210} α-particles; f) charge-collection efficiency for Am^{241} α-particles *vs.* bias voltage. Six detectors were studied in this manner. Four of the six detectors were BW detectors and the remaining two were NBW detectors. The experimental results are presented in the following section.

3. EXPERIMENTAL RESULTS AND DISCUSSION

All six of the detectors studied had sensitive areas of 1.2 cm^2, lithium-diffused depths in the range 125 to 150μ, and intrinsic depths ranging from 300 to 350μ.

Using the definition of charge-collection-efficiency (CCE) given earlier[3]), the CCE as measured in this experiment at the temperature T may be written

$$CCE = Q_L(T)/Q_L = \epsilon/\epsilon(T) , \qquad (1)$$

where $Q_L(T)$ is the charge liberated at the temperature T, Q_L is the charge liberated at room temperature, ϵ is the mean energy per ion pair at room

temperature[6-8]), and $\epsilon(T)$ is the mean energy per ion pair at the temperature T. For Eq. (1) to be valid, the operating bias voltage must be high enough so that the transit times[9]) of the carriers are sufficiently less than the amplifier time constant[10]), and high enough to insure that the effects of carrier loss through recombination or trapping[11]) are negligible. For all detectors studied, an applied bias of 15 volts (~ 450V/cm) was sufficient to satisfy both requirements at all temperatures used.

In measurements of the CCE for Po^{210} α-particles, it was possible to detect a change in CCE of about 0.1%. For the case of Am^{241} α-particles from the "sandwiched" source, a change in CCE of about 0.4% could be detected. The calibrated pulser set at 5.7 MeV was used to determine the CCE and the electrical noise spread. The contribution to the noise line-width from the amplifier alone was about 44 keV. All α-particle spectra were obtained with uncollimated sources. Although the charged particles used throughout the measurements were α-particles (~ 5 MeV), the degradation in detector response for charged particles producing lower ionization density should be less than any degradation observed with the α-particles[2,3]).

The experimental results found for the two NBW detectors were very similar in all respects and will be illustrated for one of them, hereafter referred to as NBW-1. Also, the results found for the four BW detectors were essentially identical and will be illustrated for one of them, hereafter

referred to as BW-2. Because of the bulk of experimental data, the results are presented in table form. To illustrate any differences in behavior of NBW-1 and BW-2 more clearly, spectra are shown corresponding to selected entries in the tables. The characteristics of NBW-1 and BW-2 before, during, and after the t-v tests are shown in Tables 1 and 2 and Figures 1 - 13.

Tables 1 and 2 show that, soon after fabrication, detector BW-2 had a much lower leakage current than NBW-1, in agreement with earlier results[3]). Typically, BW detectors have initial currents from 0.1 to 0.2 $\mu A/cm^2$, whereas NBW detectors have initial currents in the range from 1 to $5\mu A/cm^2$. Figure 1 shows the response of NBW-1 to Po^{210} α-particles after aging 49 days and Figure 8 shows the initial response of BW-2 to Po^{210} α-particles. During the two-month aging period, the CCE for Po^{210} α-particles remained $\geq$ 99.8% for both BW and NBW detectors. During this time interval, the leakage current of BW-2 remained essentially constant whereas the current of NBW-1 steadily improved, attaining a value close to that of BW-2. This steady decrease in leakage current for NBW-1 with time has been found to be a characteristic common to all NBW detectors[3]).

After the two-month aging period, the detectors were mounted in a vacuum chamber and maintained at a temperature of 50°C and a pressure

of 3×10^{-5} mm Hg for from four to seven days with the bias voltage applied continuously. For all BW and NBW detectors studied, the leakage current was < 5μA and the electrical line width < 60 keV at all times during this test. A Po^{210} spectrum obtained on NBW-1 just after the test is shown in Figure 2, where the CCE was 100.0%, showing that the 50°C t-v test slightly improved the particle characteristics of this detector. The same improvement was found for both NBW detectors studied.

The detectors were removed from the vacuum chamber and allowed to stand in the laboratory with no bias applied. Tables 1 and 2 show that after aging for a period of approximately ten weeks, the Po^{210} CCE for NBW-1 decreased to 99.8%, whereas the Po^{210} CCE for BW-2 remained at 100.0%. A Po^{210} spectrum obtained at this time for BW-2 is shown in Figure 9. At this time, both NBW detectors had a Po^{210} CCE of 99.8% and all four BW detectors had a Po^{210} CCE of 100.0%. To further study the effects of long-term aging, the NBW detectors were allowed to age for an additional eight months. Since all our previous experience had shown that any degradation occuring in BW detectors would be less than that occurring in NBW detectors (under identical conditions of aging and environmental testing), no long term aging of the BW detectors was carried out. The long term aging data for the NBW detectors would then indicate the upper limit of degradation which might be found for BW detectors over the same aging period. Table 1 shows that during this eight month aging period (no applied bias), there was no degra-

dation in the electrical or α-particle characteristics of NBW-1 other than an increase in the Po^{210} linewidth from ~ 60 to ~ 72 keV. Figure 3 shows the response of NBW-1 to Po^{210} α-particles at the end of this aging period. This same behavior was found for both NBW detectors and hence, a change no greater than this would be expected for BW detectors aged for this same period of time.

The detectors were then mounted in the vacuum chamber and maintained at a temperature of 85°C and a pressure of 3×10^{-5} mm Hg for five days with the bias voltage applied continuously. During this 85°C t-v test, the temperature was raised to 100°C and maintained at this temperature long enough (~ few hours) to obtain α-particle spectra and electrical data. Tables 1 and 2 give the electrical and α-particle characteristics of NBW-1 and BW-2 during this test. Figures 4 and 10 give the response of NBW-1 and BW-2 to the Am^{241} source at room temperature before the test. The slight difference at this time in the CCE of NBW-1 (99.8%) and BW-2 (100.0%) for Po^{210} α-particles (Figures 3 and 9, respectively) could not be detected in their response to the Am^{241} source, and within experimental error (~ 0.4% for the Am^{241} source), the CCE for the Am^{241} α-particles was 100.0% for both detectors.

Tables 1 and 2 show that the leakage current for both NBW-1 and BW-2 was < 25μA at 85°C at all times during the test and the electrical linewidth for both was < 150keV. For the remaining four detectors studied (one NBW and three BW detectors) the currents were in the range 9.3μA to 60μA, with corresponding pulser resolutions in the range 93 - 250 keV, at 85°C during the five day test. At 100°C, the current for both NBW-1 and BW-2 was < 53μA and the electrical linewidth < 217 keV for an applied bias up to 29V. For the remaining four detectors, the currents were in the range 22μA to 97μA, with corresponding pulser resolutions in the range 137 - 290 keV at 100°C. Figures 5 and 12 show the response of NBW-1 and BW-2 to the Am^{241} source at 85°C, and Figures 6 and 11 show the response of NBW-1 and BW-2 to Am^{241} at 100°C. Tables 1 and 2 show that at 85°C and 100°C, no dependence of the Am^{241} CCE on applied bias (up to 29V) could be measured (within experimental error). Repeated determinations of the Am^{241} CCE at 100°C for both NBW-1 and BW-2 gave an average value of 101.8%. This value for the CCE and the use of Eq. (1) gives a value for the fractional change in the mean energy per ion pair of -1.8% in going from room temperature to 100°C. Similar determinations of the Am^{241} CCE at 85°C gave an average value of 101.5%, yielding a value for the fractional change in the mean energy per ion pair of -1.5%. The uncertainty in the Am^{241} CCE determinations made it difficult to determine the difference in CCE at 85°C and 100°C. In

addition, at the elevated temperatures, the detector temperature was uncertain to about 5°C. However, the indicated difference in CCE at 85° and 100°C is felt to be real. The measured fractional change in ϵ at both 85°C and 100°C is larger than expected from eralier measurements of $\delta\epsilon/\epsilon$ at 50°C and 65°C[3]). However, any comparison of the values of $\delta\epsilon/\epsilon$ measured at 85°C and 100°C with values obtained at lower temperatures[3,6-8]) or with a calculation of the mean energy per ion pair by Shockler[12]) would be premature in view of the uncertainty in the measurements reported here.

After the 85°C t-v test the detectors were removed from the chamber and allowed to stand with no bias applied for a few days. Figures 7 and 13 show the response of NBW-1 and BW-2 to Po^{210} α-particles at this time. At this final stage, all six detectors studied had a CCE of 100.0% for Po^{210} α-particles. As was the case for the 50°C t-v test, the 85°C t-v test produced a very slight improvement in the Po^{210} CCE for both NBW detectors (99.8% to 100.0%). Measurements of the n-region depths and detector capacitance taken before, during, and after the repeated t-v testing and aging indicated that the overall change in intrinsic depth for all detectors studied was < 5%.

A comparison of the data given in Tables 1 and 2 shows that, other than the high initial current of NBW detectors and the very slight

degradation (~ 0.2%) they exhibit during aging, the electrical and charged-particle characteristics of NBW detectors under conditions of environmental testing and aging are essentially identical to those of BW detectors. The above data and the results of earlier studies[3]) show that the use of high resistivity material is of prime importance for obtaining detectors with high ($\geq$ 99.8%) CCE which exhibit long-term electrical and α-particle stability under conditions of prolonged aging and environmental testing. The BW treatment will yield detectors with lower initial current and slightly higher (0.1% - 0.2%) CCE, but does not seem to be of significant importance in determining the long term α-particle stability.

4. CONCLUSIONS

Detectors made from p-type silicon with electrical resistivity in the range 1000 ohm-cm to 1500 ohm-cm and having a sensitive area of 1.2 cm^2, an intrinsic depth in the range 300 to 350μ, and operated at a bias of 15V, exhibit stable electrical and Po^{210} α-particle characteristics under conditions of aging and t-v testing over a period of fourteen months. Values of the CCE for Po^{210} α-particles at room temperature were in the range 99.8% to 100.0% throughout this period. The detectors will operate at 85°C for several days and at 100°C for several hours with no evidence of noise instability. Detectors given the BW treatment have initial currents in the range 0.1 to 0.2

$\mu A/cm^2$. NBW detectors have initial currents in the range 1 to $5\mu A/cm^2$. The current of NBW detectors steadily improves with time, attaining a value close to that characteristic of BW detectors. The high CCE and long-term α-particle stability observed is determined primarily by the material resistivity rather than a BW treatment.

The data at 85°C and 100°C indicates that the fractional change in the mean energy per ion pair in going from room temperature to 85°C and to 100°C is approximately -1.5% and -1.8%, respectively. For all detectors studied, the overall change in intrinsic depth resulting from the environmental testing and aging was < 5%. Hopefully, the environmental behavior exhibited by the detectors studied here will serve as a guide to the behavior which might be expected from a typical surface-barrier detector of the type described here in applications requiring operating temperatures in the neighborhood of 100°C. To what extent the behavior shown by the detectors studied in this present work might be expected for detectors having much deeper intrinsic depths must await further experiment.

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FIGURE CAPTIONS

Figure 1. Room temperature response of detector NBW-1 to Po^{210} α-particles. Detector age was 49 days.

Figure 2. Room temperature response of detector NBW-1 to Po^{210} α-particles. Detector age was 62 days.

Figure 3. Room temperature response of detector NBW-1 to Po^{210} α-particles. Detector age was 385 days.

Figure 4. Room temperature response of detector NBW-1 to the Am^{241} source. Detector age was 385 days.

Figure 5. Response of detector NBW-1 to the Am^{241} source during thermal-vacuum test. Temperature was 85°C and pressure 3×10^{-5} mm Hg. Detector age was 391 days.

Figure 6. Response of detector NBW-1 to the Am^{241} source during thermal-vacuum test. Temperature was 100°C and pressure 3×10^{-5} mm Hg. Detector age was 395 days.

Figure 7. Room temperature response of detector NBW-1 to Po^{210} α-particles. Detector age was 405 days.

Figure 8. Room temperature response of detector BW-2 to Po^{210} α-particles. Detector age was 2 days.

Figure 9. Room temperature response of detector BW-2 to Po^{210} α-particles. Detector age was 150 days.

Figure 10. Room temperature response of detector BW-2 to the Am^{241} source. Detector age was 152 days.

Figure 11. Response of detector BW-2 to the Am^{241} source during thermal-vacuum test. Temperature was 100°C and pressure 3×10^{-5} mm Hg. Detector age was 152 days.

Figure 12. Response of detector BW-2 to the Am^{241} source during thermal-vacuum test. Temperature was 85°C and pressure 3×10^{-5} mm Hg. Detector age was 157 days.

Figure 13. Room temperature response of detector BW-2 to Po^{210} α-particles. Detector age was 159 days.

Characteristics of detector NBW-1 (Table 1) and BW-2 (Table 2), before, during, and after thermal-vacuum (t-v) tests. Column 1 gives the detector age in days. Column 2 gives the detector temperature in ^{o}C, where r.t. denotes room temperature. Columns 3 and 4 give the applied bias in V and the leakage current in μA, respectively. Columns 5 and 6 give the resolutions (fwhm) expressed in keV for a calibrated pulser set at 5.7 MeV and Po^{210} α-particles, respectively. Columns 7 and 8 give the CCE for Po^{210} α-particles and Am^{241} α-particles, respectively. The detector was at room temperature except during the thermal-vacuum tests. No bias was applied during the time intervals between successive room temperature measurements. The bias voltage was applied continuously during the thermal-vacuum tests. Test conditions were the same for NBW-1 and BW-2.

Table 1

	1	2	3	4	5	6	7	8	
	Age of Detector (d)	Temp. (^{o}C)	V (V)	I (μA)	5.7MeV Pulser (keV)	Po^{210} (keV)	Po^{210} CCE (%)	Am^{241} CCE (%)	
	1	r.t.	15	1.2	46	--	---	---	
	49	r.t.	15	0.15	44	48	99.8	---	(Fig. 1)
	55	r.t.	15	0.19	41	50	99.8	---	
	58	50	15	3.3	--	--	---	---	
t-v	59	50	15	3.8	--	--	---	---	
test	60	50	15	3.9	--	--	---	---	
	61	50	15	4.1	54	--	---	---	
	62	r.t.	15	0.43	50	59	100.0	---	(Fig. 2)
	74	r.t.	15	0.30	50	56	100.0	---	
	88	r.t.	15	0.14	47	59	99.9	---	
	97	r.t.	15	0.12	53	61	99.8	---	
	151	r.t.	15	0.10	47	61	99.8	---	
	360	r.t.	15	0.10	57	72	99.8	---	
	385	r.t.	15	0.13	53	72	99.8	---	(Fig. 3)
	385	r.t.	15	0.13	47	--	---	100.0	(Fig. 4)
	390	r.t.	15	0.10	53	--	---	100.0	
	390	85	15	14.0	107	--	---	101.6	
	391	85	25	10.9	101	--	---	101.6	(Fig. 5)
	392	85	15	18.0	144	--	---	101.8	
t-v	392	100	15	35.3	186	--	---	101.8	
test	392	100	29	41.5	216	--	---	101.5	
	392	85	15	17.5	126	--	---	101.4	
	395	85	15	22.0	132	--	---	101.6	
	395	100	15	44.3	206	--	---	102.0	(Fig. 6)
	395	100	19.7	47.0	206	--	---	102.0	
	399	r.t.	15	0.37	40	49	100.0	---	
	404	r.t.	15	0.32	42	47	100.0	---	
	405	r.t.	15	0.19	42	50	100.0	---	(Fig. 7)

Table 2

1	2	3	4	5	6	7	8	
Age of Detector (d)	Temp. (^{o}C)	V (V)	I (μA)	5.7 MeV Pulser (keV)	Po^{210} (keV)	Po^{210} CCE (%)	Am^{241} CCE (%)	
1	r.t.	15	0.28	40	--	--	--	
2	r.t.	15	0.24	54	66	100.0	--	(Fig. 8)
t-v test 74	r.t.	15	0.22	--	--	--	--	
t-v test 75	50	15	1.85	--	--	--	--	
t-v test 76	50	15	2.07	--	--	--	--	
t-v test 77	50	15	2.31	--	--	--	--	
t-v test 78	50	15	2.44	55	--	--	--	
t-v test 78	r.t.	15	0.23	--	--	--	--	
150	r.t.	15	0.27	36	51	100.0	--	(Fig. 9)
t-v test 152	r.t.	15	0.20	48	--	--	100.0	(Fig. 10)
t-v test 152	100	15	49.0	180	--	--	101.6	
t-v test 152	100	20	52.0	198	--	--	102.0	(Fig. 11)
t-v test 153	85	15	20.0	124	--	--	101.4	
t-v test 156	85	15	23.0	120	--	--	101.1	
t-v test 157	85	20	24.0	125	--	--	101.4	(Fig. 12)
159	r.t.	15	0.40	47	52	100.0	--	(Fig. 13)

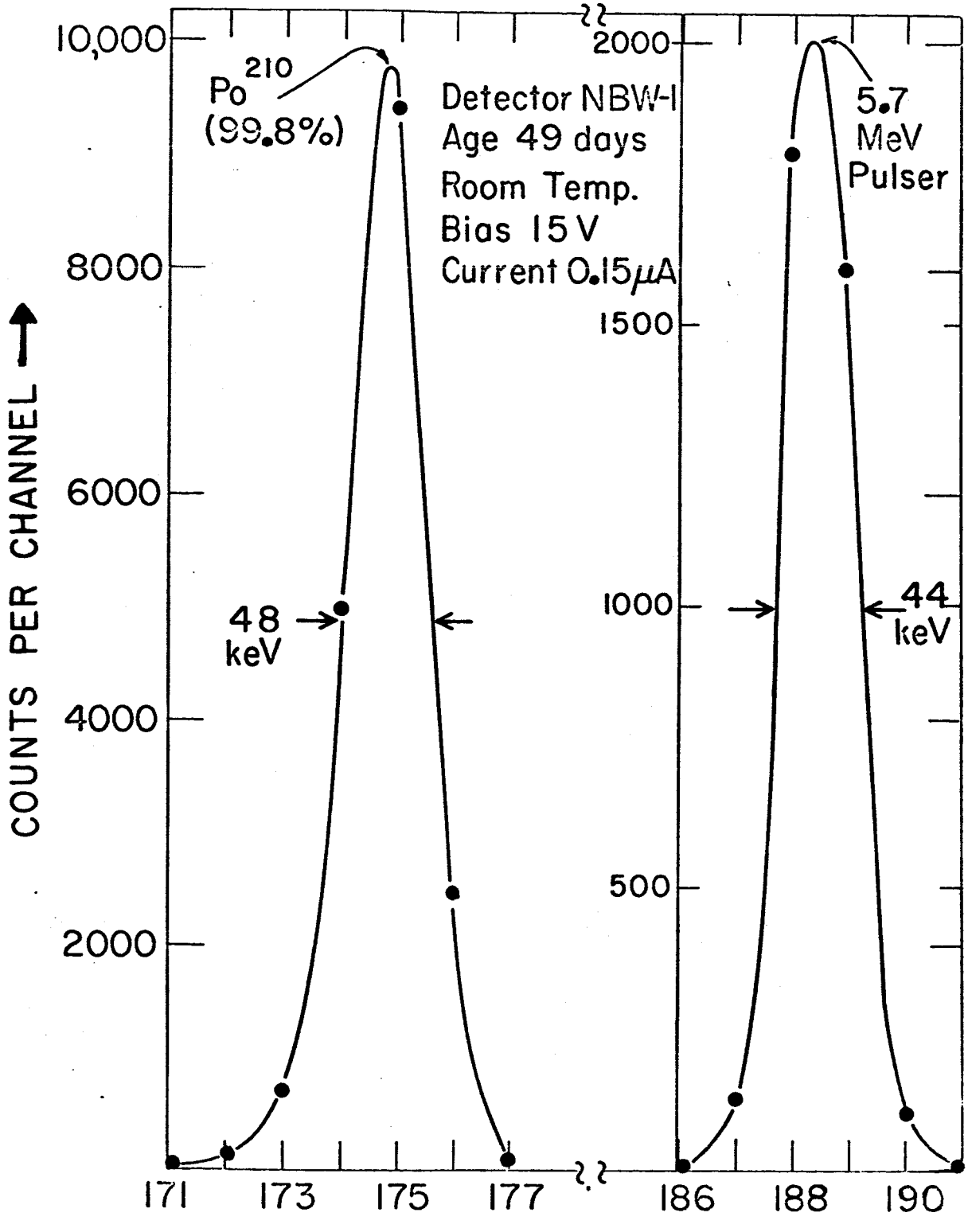
10,000
8000
6000
4000
2000
2000
1500
1000
500
Po 210
(99.8%)
Detector NBW-I
Age 49 days
Room Temp.
Bias 15 V
Current 0.15μA
5.7
MeV
Pulser
48
keV
44
keV
COUNTS PER CHANNEL
171
173
175
177
186
188
190
CHANNEL NUMBER

Fig. 1

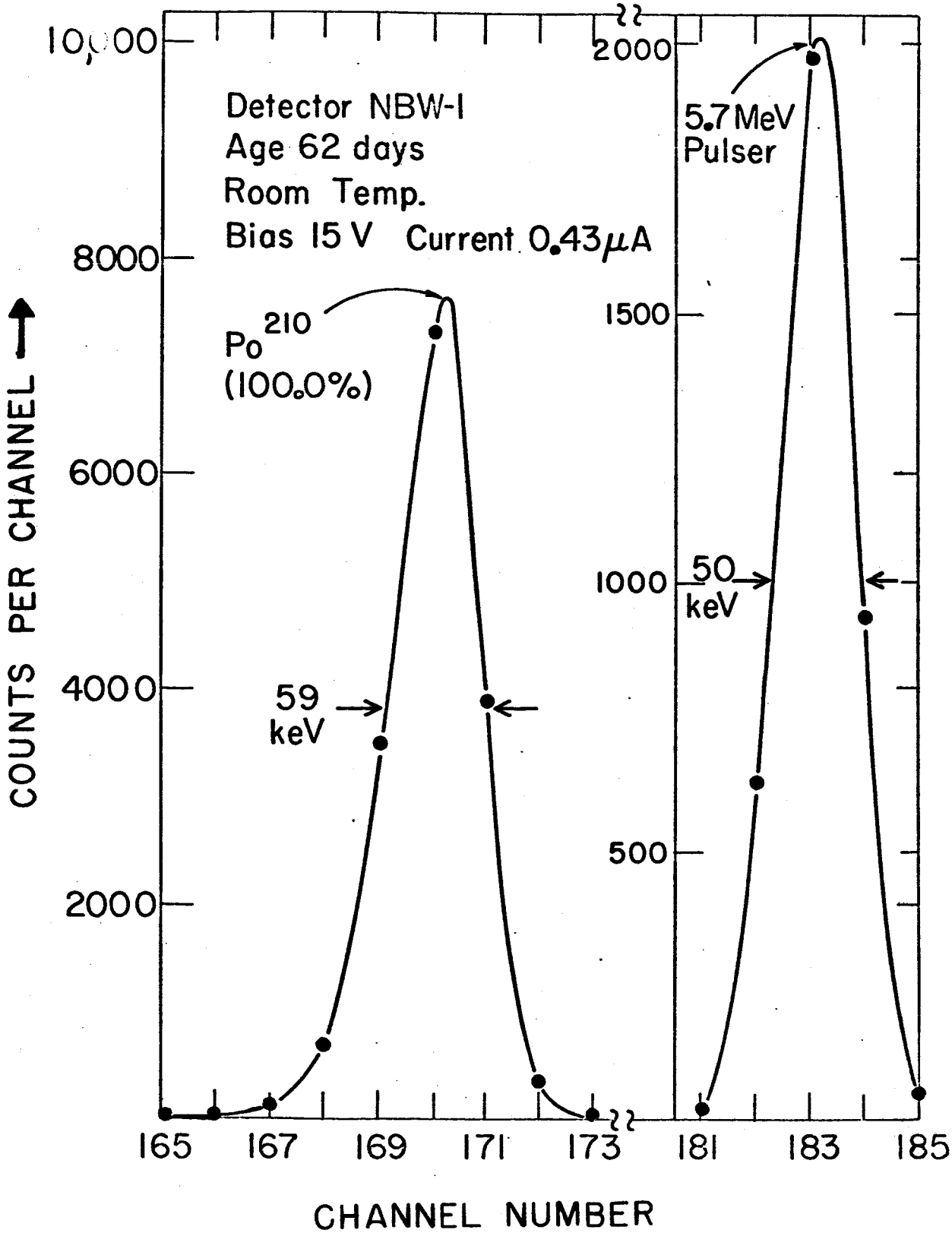
Detector NBW-1
Age 62 days
Room Temp.
Bias 15 V Current 0.43μA
Po 210
(100.0%)
59 keV
5.7 MeV Pulser
50 keV
COUNTS PER CHANNEL
CHANNEL NUMBER
10,000
8000
6000
4000
2000
2000
1500
1000
500
165
167
169
171
173
181
183
185

Fig. 2

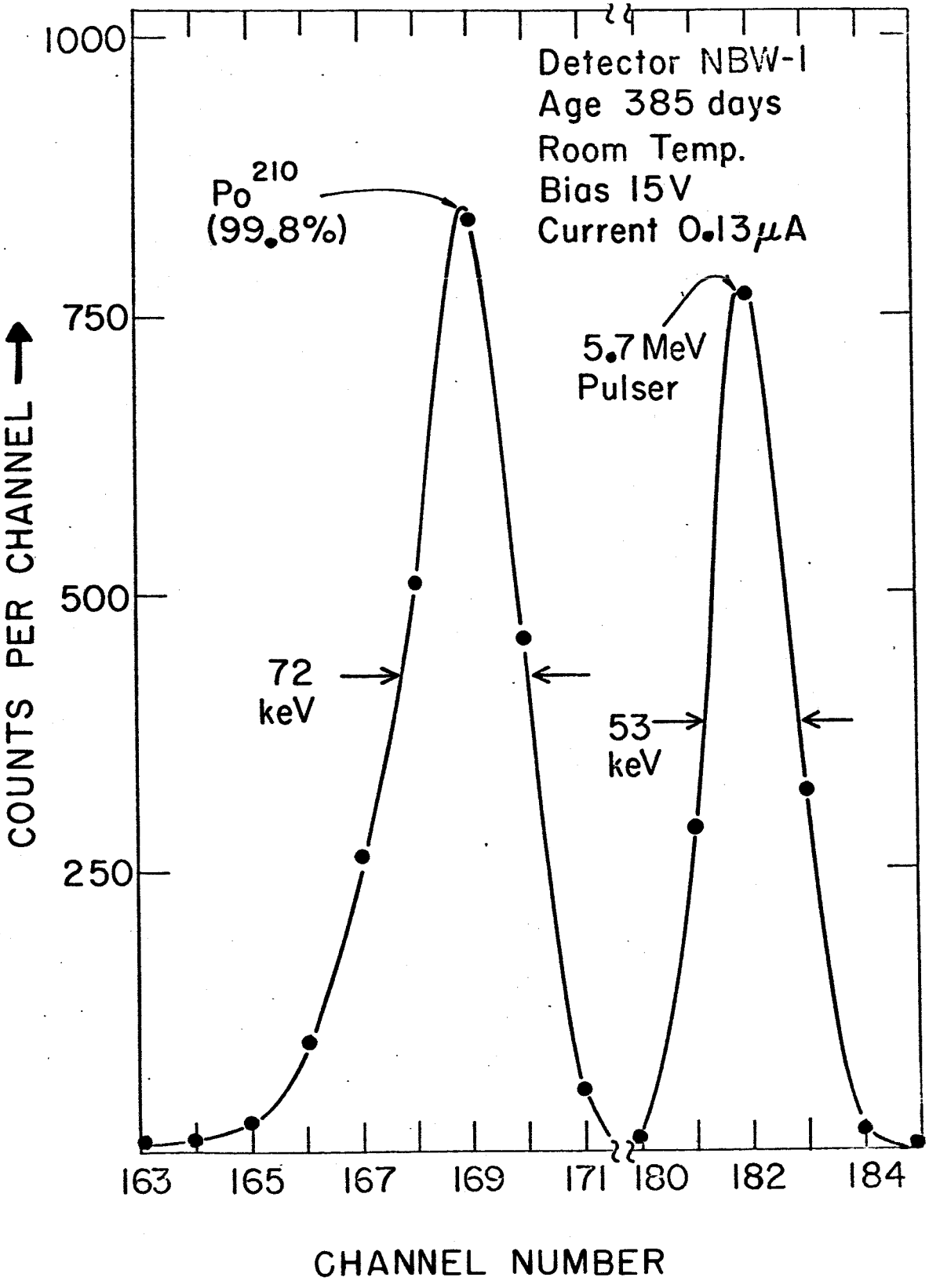
1000
750
500
250
COUNTS PER CHANNEL
Detector NBW-1
Age 385 days
Room Temp.
Bias 15V
Current 0.13μA
Po 210
(99.8%)
5.7 MeV
Pulser
72
keV
53
keV
163
165
167
169
171
180
182
184
CHANNEL NUMBER

Fig. 3

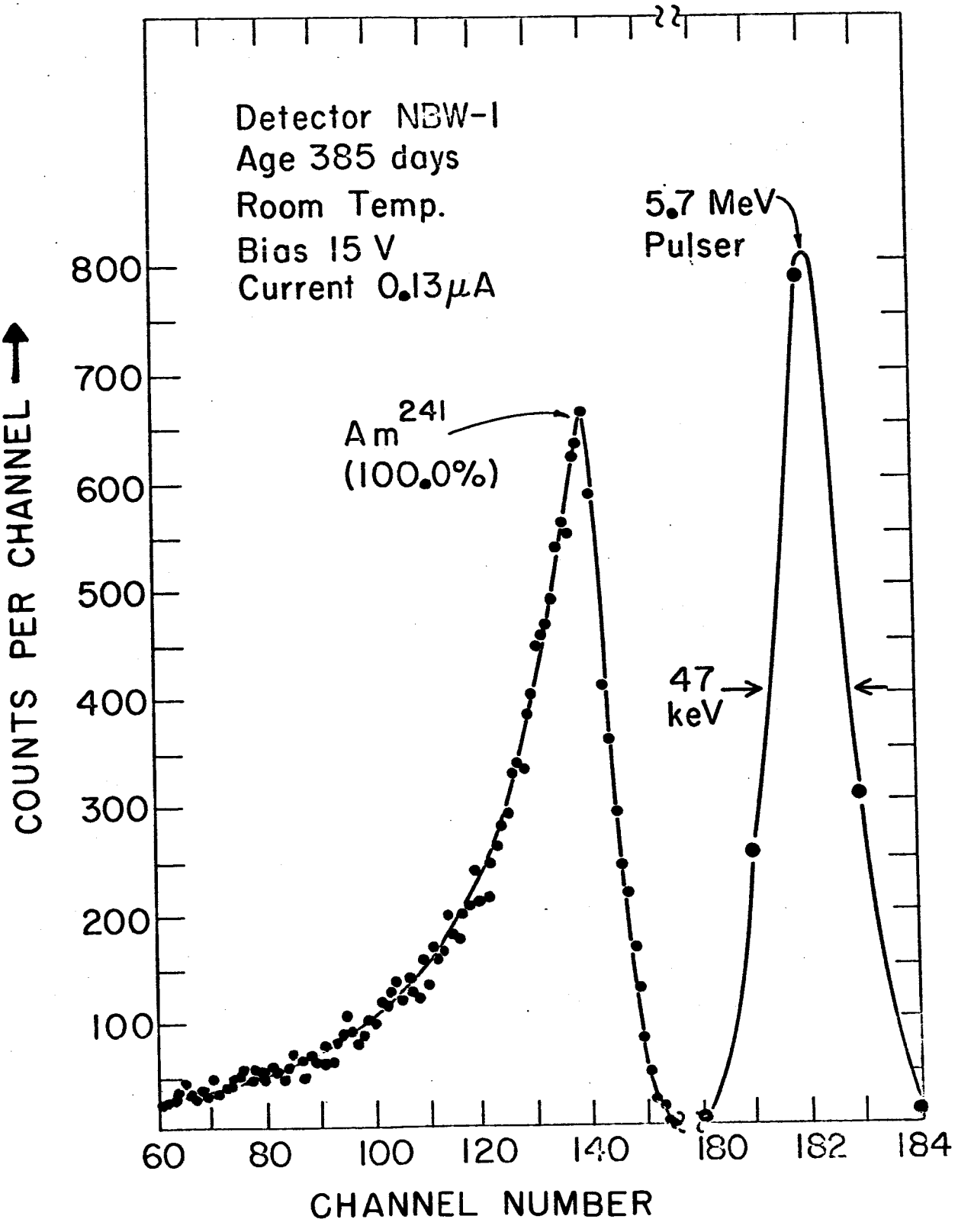
Detector NBW-1
Age 385 days
Room Temp.
Bias 15 V
Current 0.13μA
5.7 MeV
Pulser
Am 241
(100.0%)
47
keV
COUNTS PER CHANNEL
800
700
600
500
400
300
200
100
60
80
100
120
140
180
182
184
CHANNEL NUMBER

Fig.4

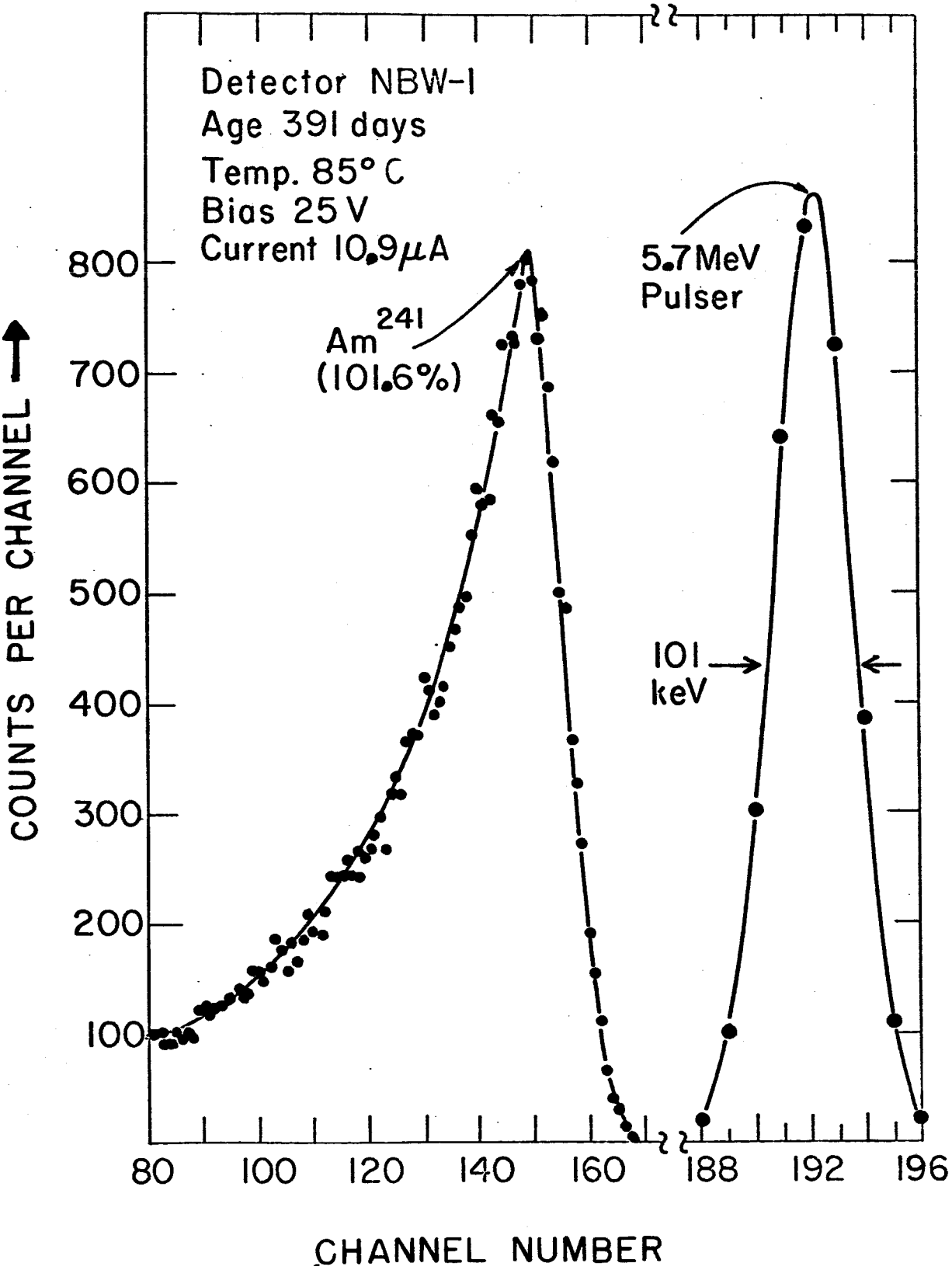
Detector NBW-I
Age 391 days
Temp. 85° C
Bias 25 V
Current 10.9μA
Am 241
(101.6%)
5.7 MeV
Pulser
101
keV
COUNTS PER CHANNEL
800
700
600
500
400
300
200
100
80
100
120
140
160
188
192
196
CHANNEL NUMBER

Fig.5

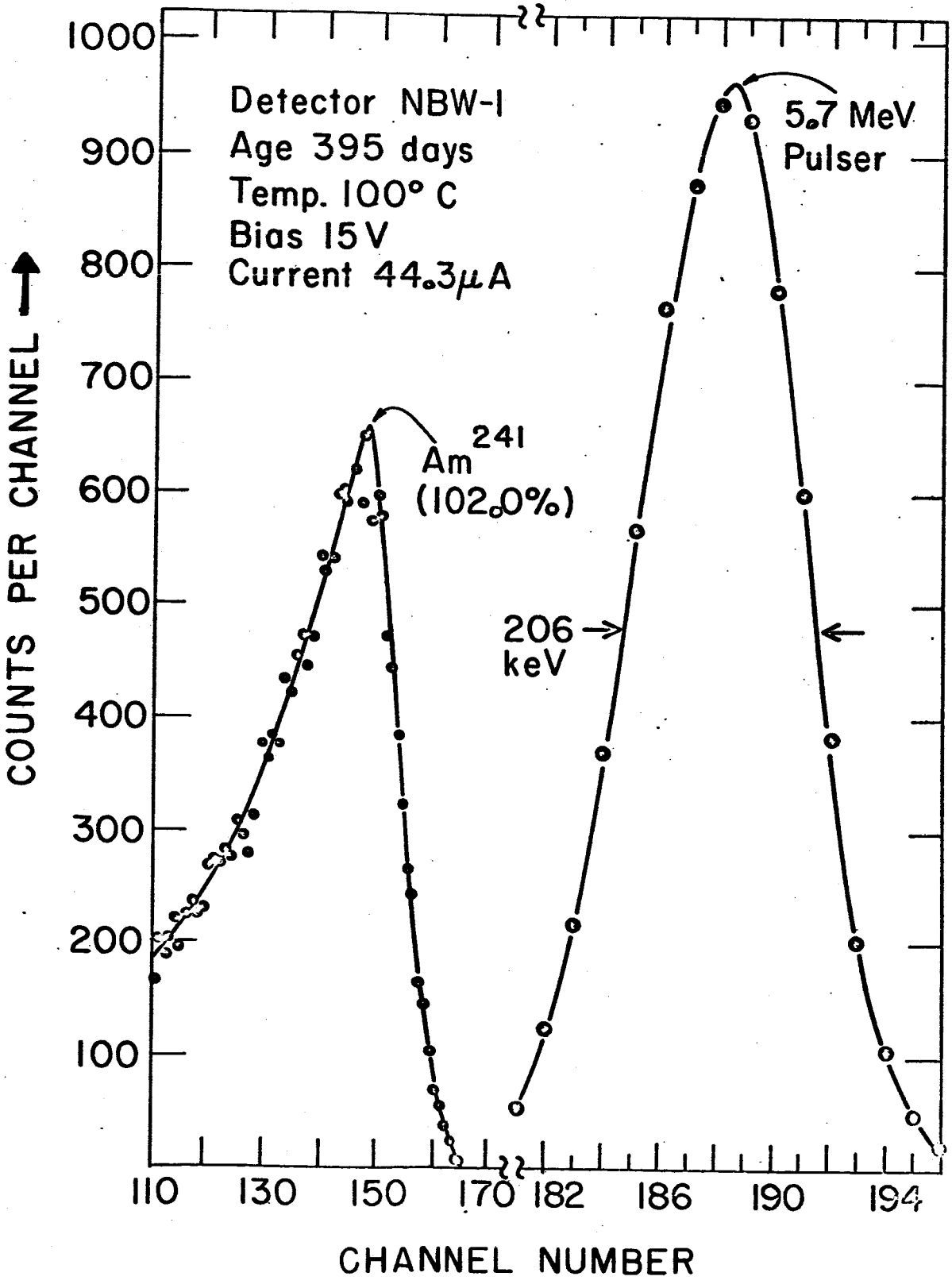
Detector NBW-I
Age 395 days
Temp. 100° C
Bias 15 V
Current 44.3μA
5.7 MeV
Pulser
Am 241
(102.0%)
206
keV
COUNTS PER CHANNEL
CHANNEL NUMBER
1000
900
800
700
600
500
400
300
200
100
110
130
150
170
182
186
190
194

Fig. 6

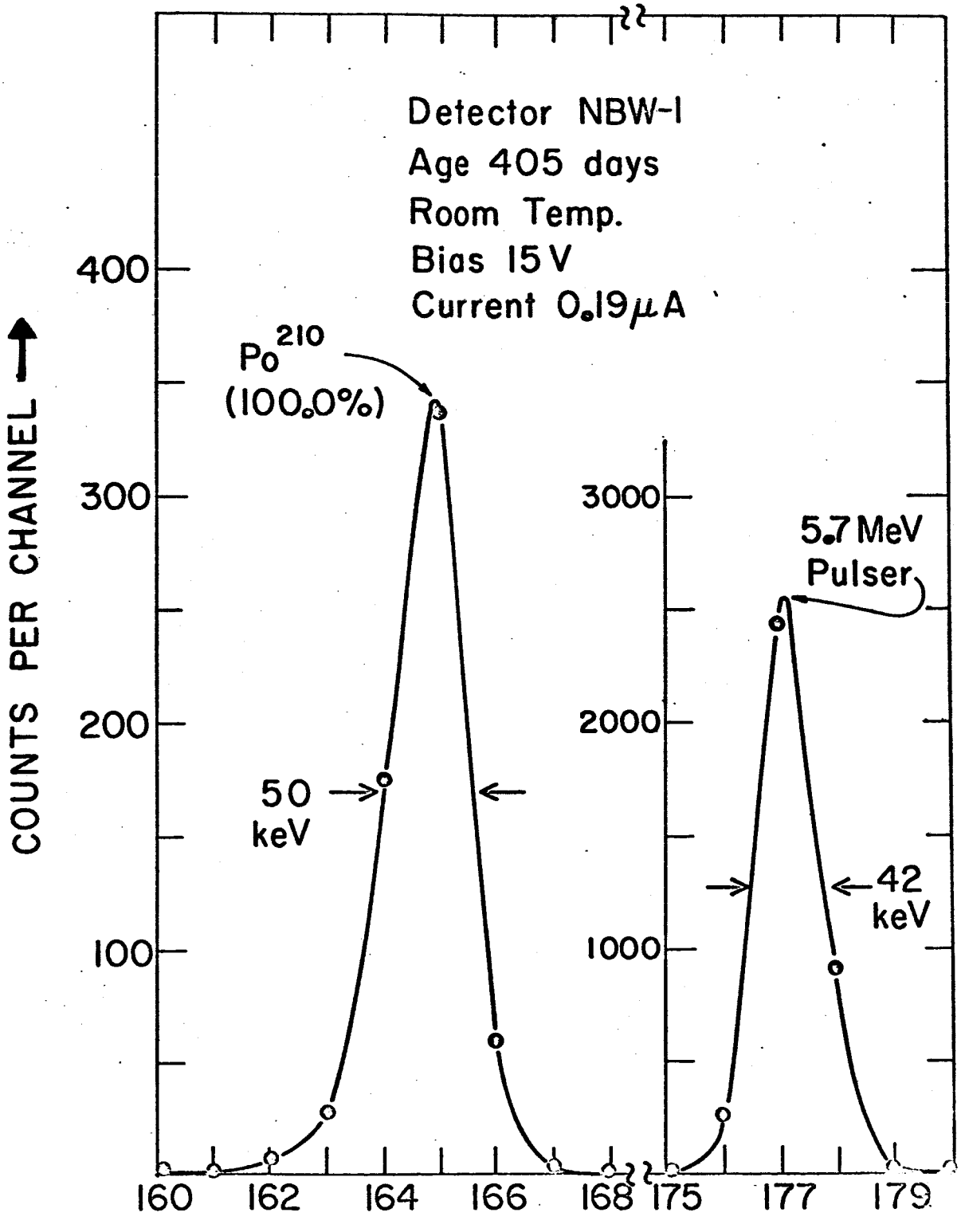
Detector NBW-I
Age 405 days
Room Temp.
Bias 15 V
Current 0.19μA
Po 210
(100.0%)
5.7 MeV
Pulser
50
keV
42
keV
COUNTS PER CHANNEL
CHANNEL NUMBER
400
300
200
100
3000
2000
1000
160
162
164
166
168
175
177
179

Fig. 7

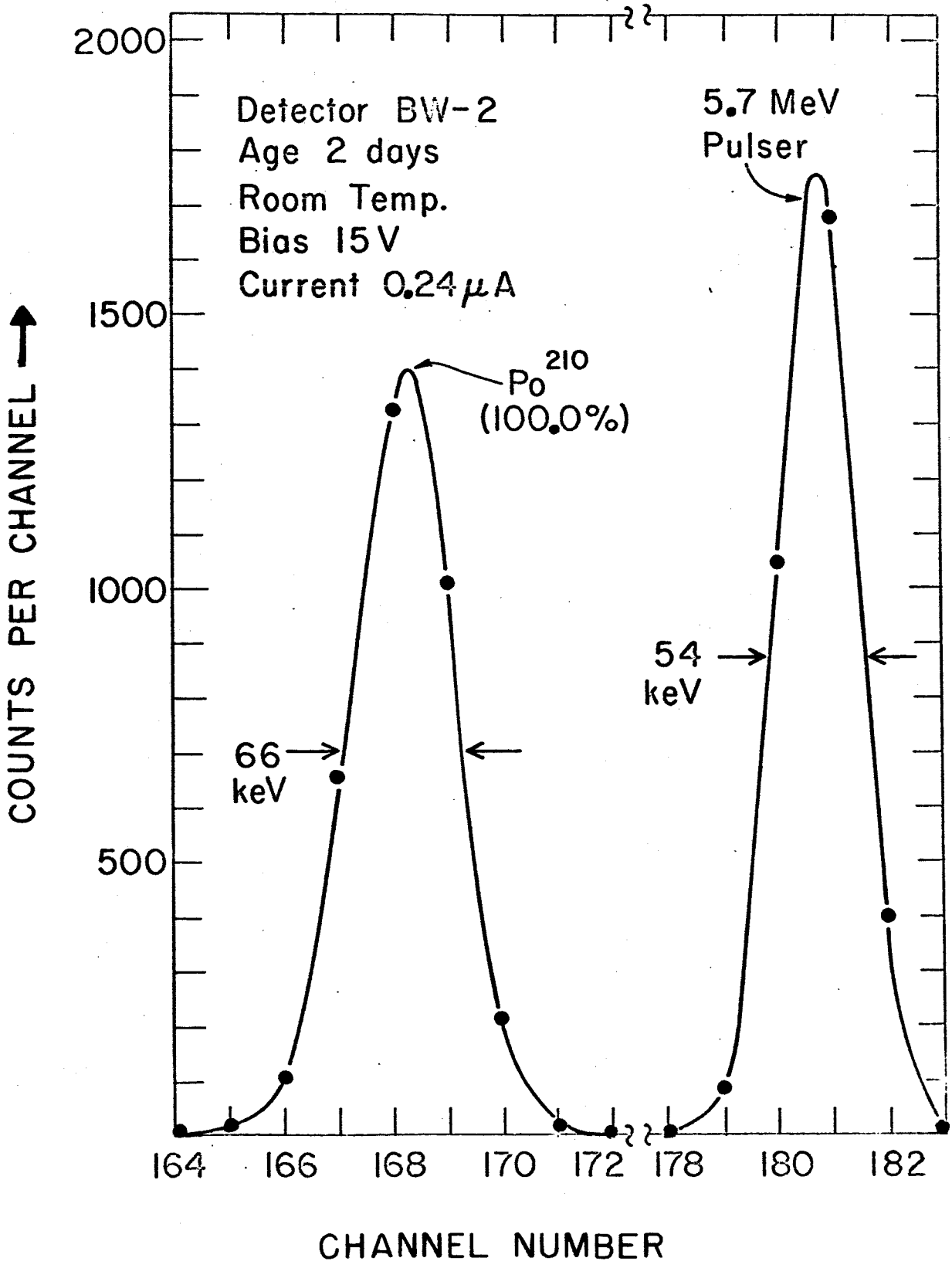
2000
1500
1000
500
COUNTS PER CHANNEL
Detector BW-2
Age 2 days
Room Temp.
Bias 15 V
Current 0.24 μA
5.7 MeV
Pulser
Po 210
(100.0%)
66
keV
54
keV
164
166
168
170
172
178
180
182
CHANNEL NUMBER

Fig. 8

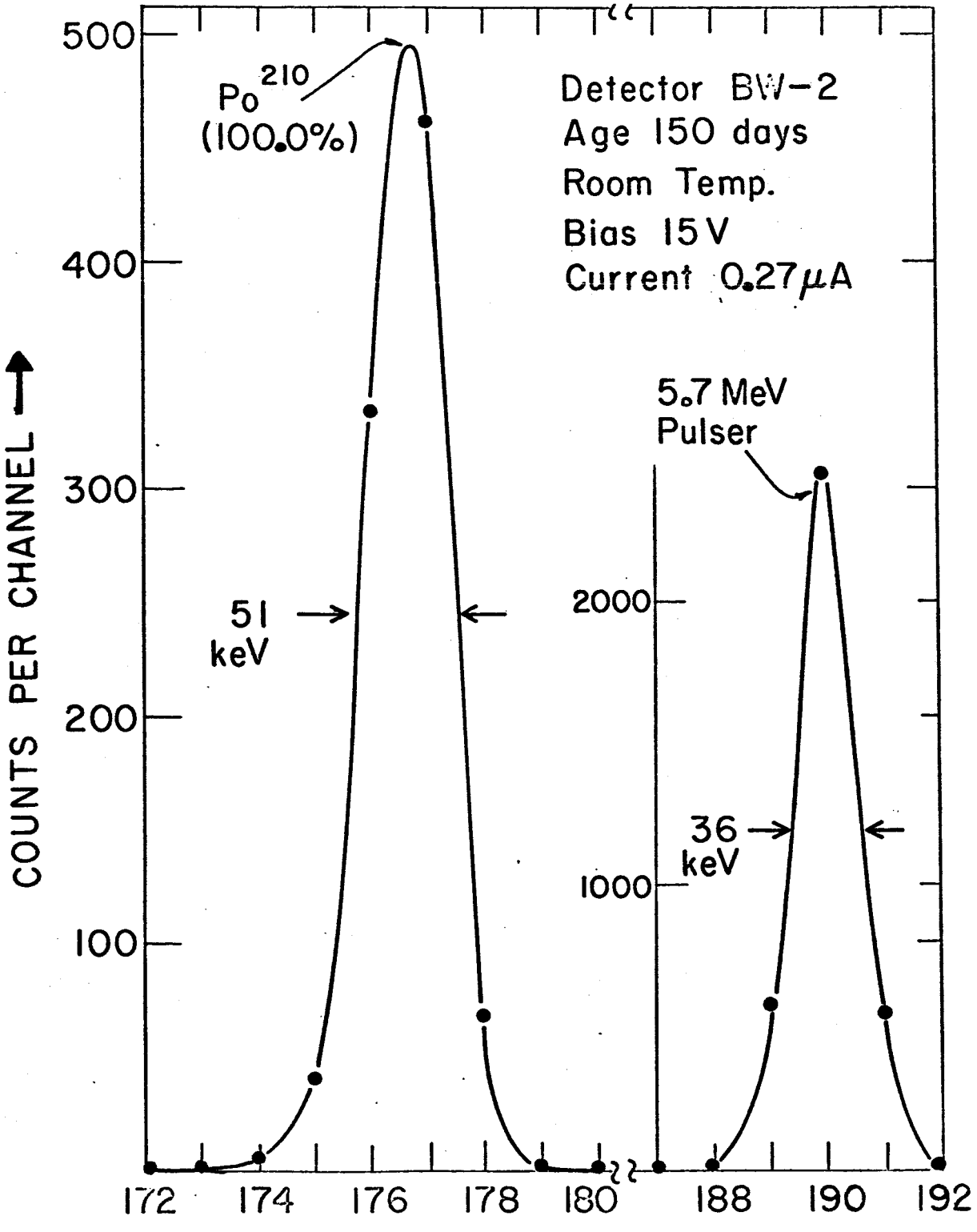
500
400
300
200
100
COUNTS PER CHANNEL
Po 210
(100.0%)
Detector BW-2
Age 150 days
Room Temp.
Bias 15 V
Current 0.27 μA
5.7 MeV
Pulser
51
keV
2000
1000
36
keV
172
174
176
178
180
188
190
192
CHANNEL NUMBER

Fig.9

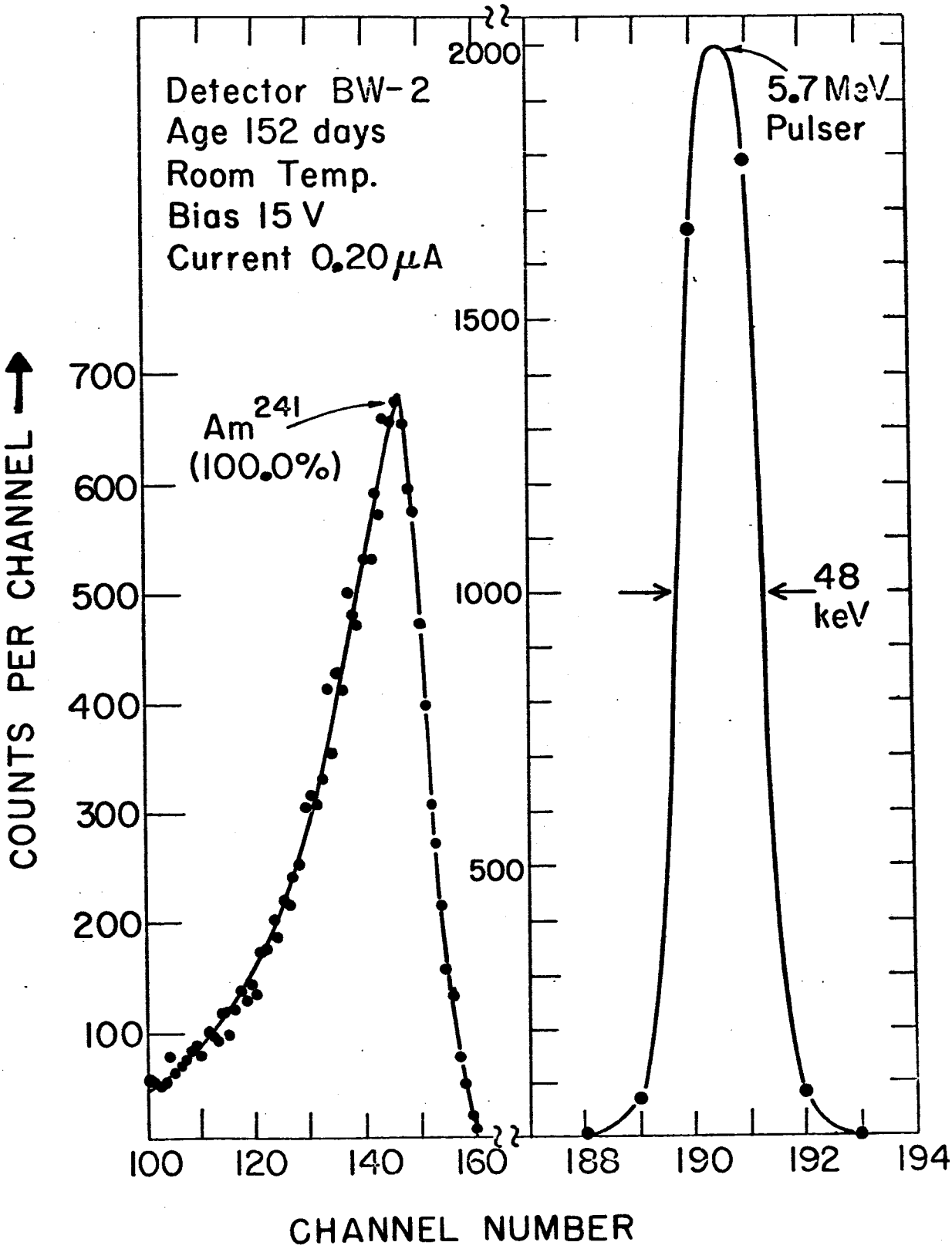
Detector BW-2
Age 152 days
Room Temp.
Bias 15 V
Current 0.20 μA
Am 241
(100.0%)
5.7 MeV
Pulser
48
keV
COUNTS PER CHANNEL
CHANNEL NUMBER
700
600
500
400
300
200
100
2000
1500
1000
500
100
120
140
160
188
190
192
194

Fig.10

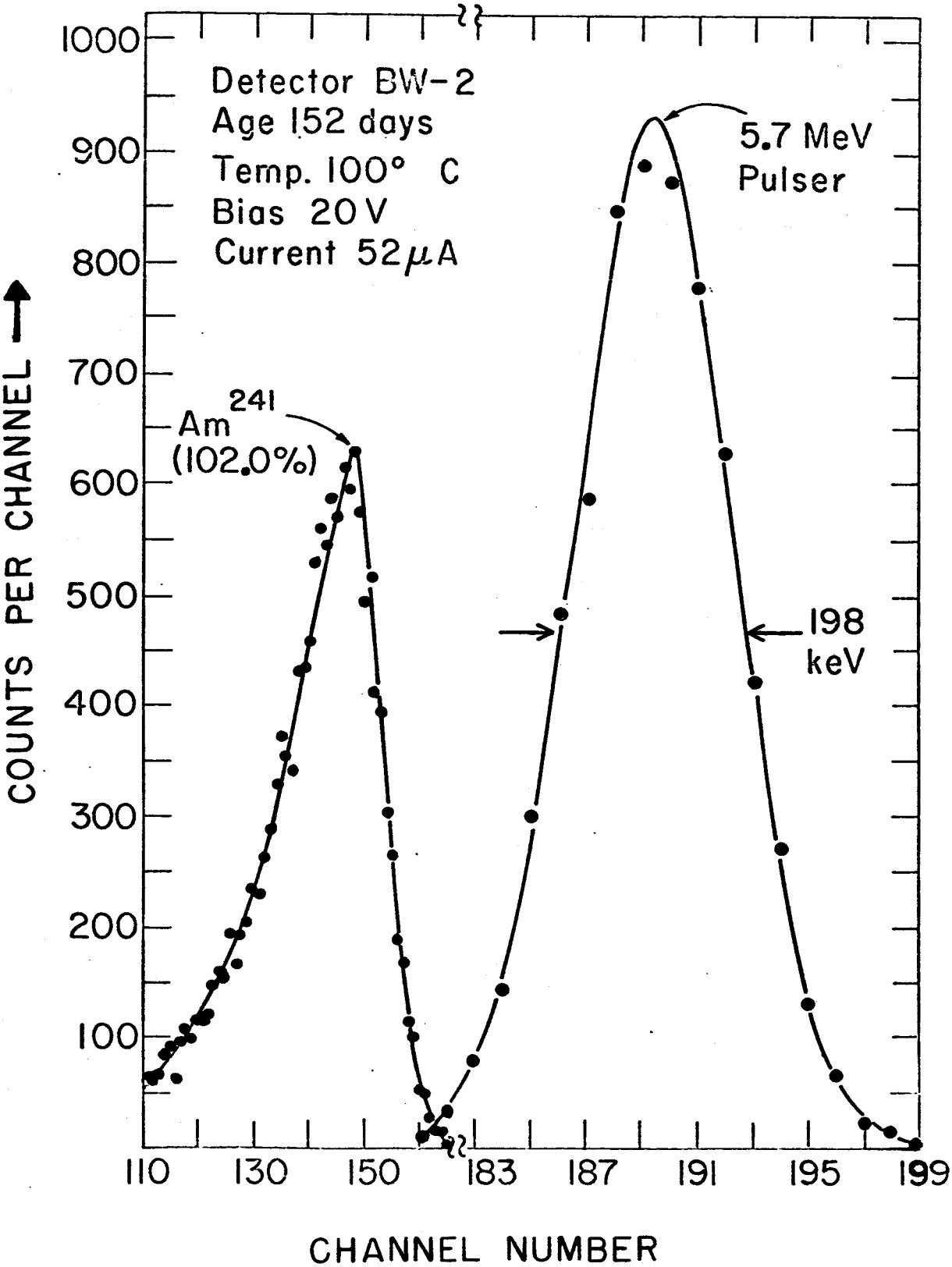
Detector BW-2
Age 152 days
Temp. 100° C
Bias 20 V
Current 52 μA
5.7 MeV
Pulser
Am 241
(102.0%)
198
keV
COUNTS PER CHANNEL
CHANNEL NUMBER
1000
900
800
700
600
500
400
300
200
100
110
130
150
183
187
191
195
199

Fig.11

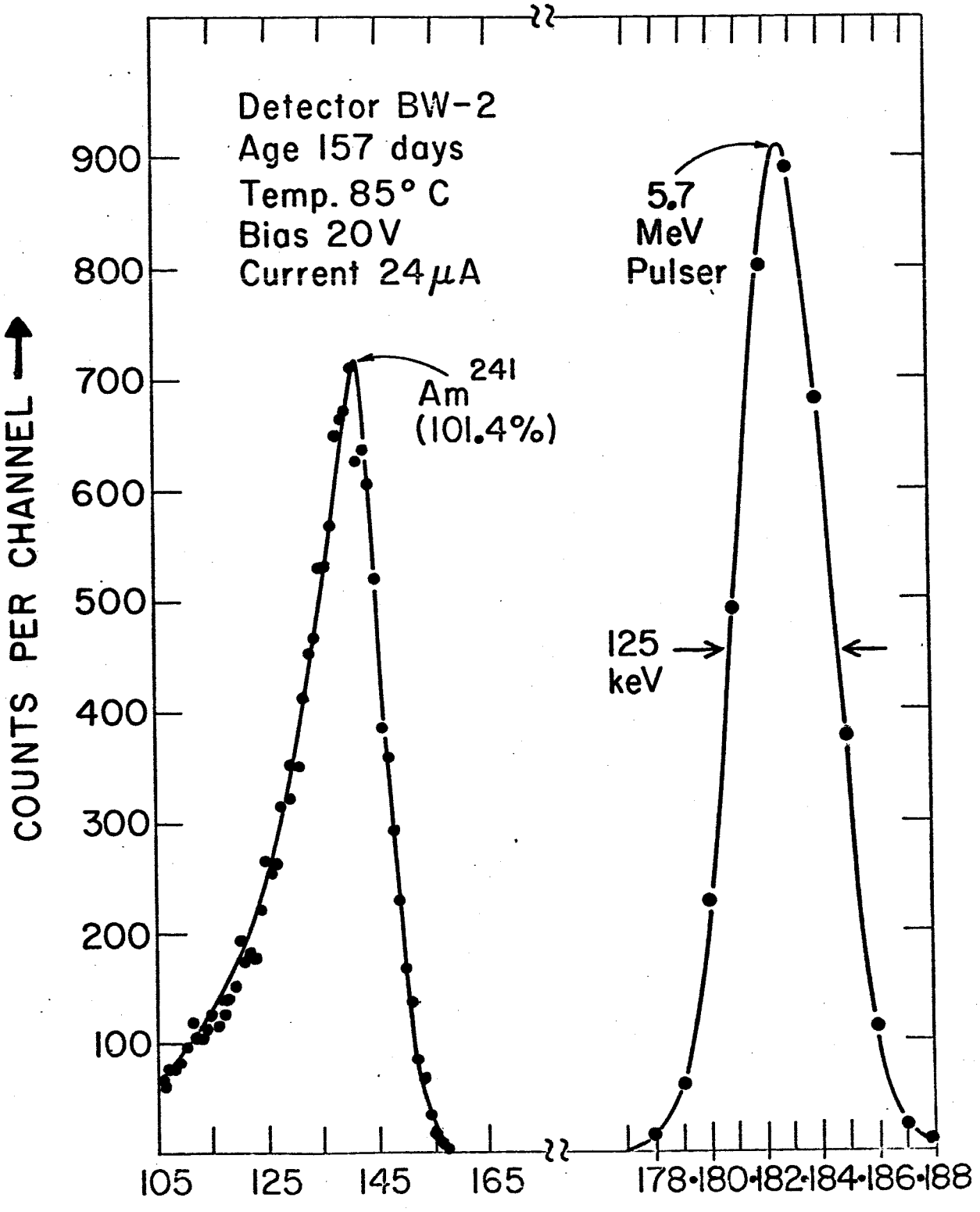
Detector BW-2
Age 157 days
Temp. 85° C
Bias 20V
Current 24μA
5.7
MeV
Pulser
Am 241
(101.4%)
125
keV
COUNTS PER CHANNEL
900
800
700
600
500
400
300
200
100
105
125
145
165
178
180
182
184
186
188
CHANNEL NUMBER

Fig. 12

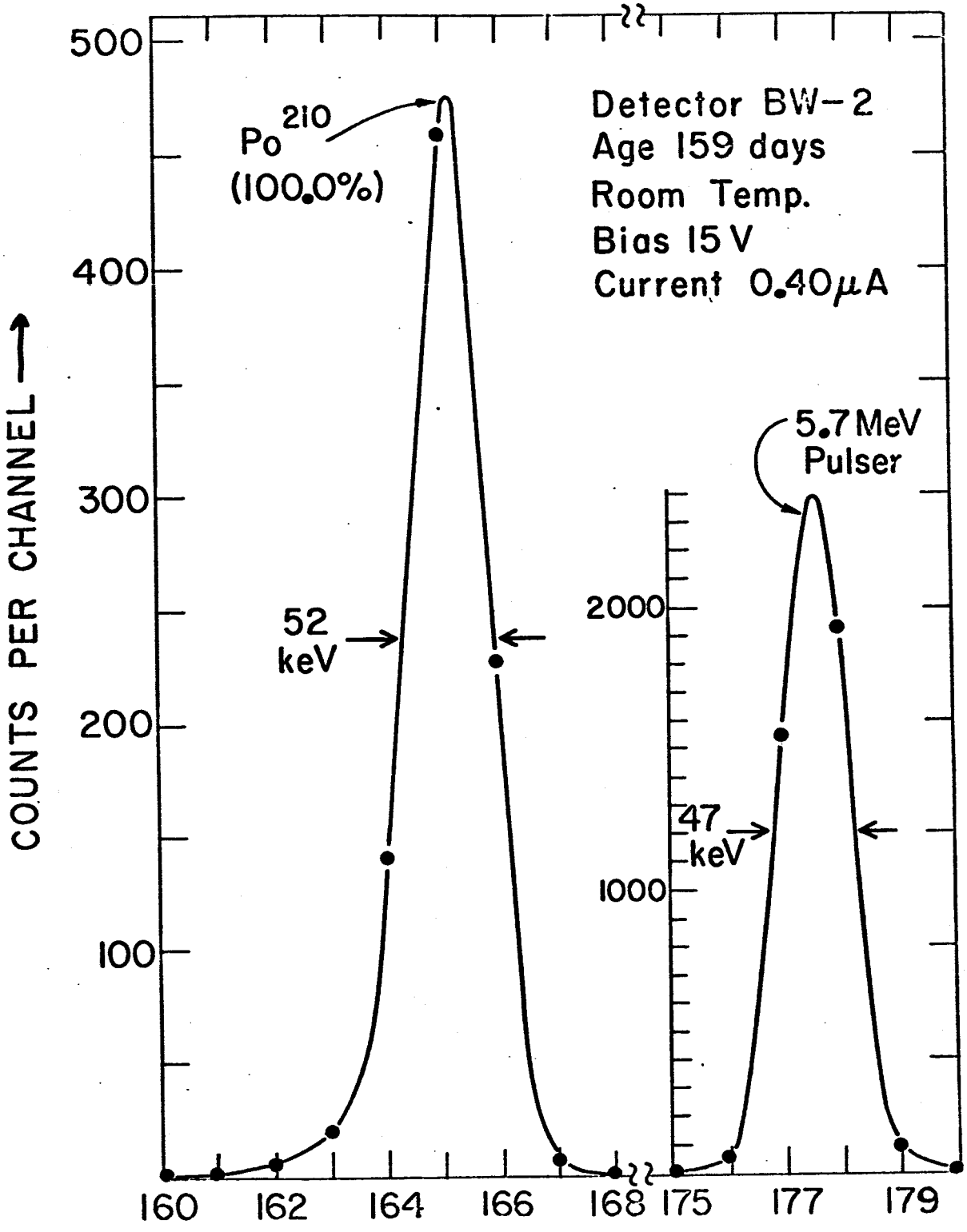
500
400
300
200
100
COUNTS PER CHANNEL
Po 210
(100.0%)
Detector BW-2
Age 159 days
Room Temp.
Bias 15 V
Current 0.40μA
5.7 MeV
Pulser
52
keV
47
keV
2000
1000
160
162
164
166
168
175
177
179
CHANNEL NUMBER

Fig.13