UC-37. Instruments

A SYSTEMATIC PEAK REDUCTION METHOD FOR SEMICONDUCTOR DETECTOR SPECTRA

By

W. H. Zimmer

Separations Chemistry Laboratory
Research and Development
Chemical Processing Division

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ABSTRACT

A systematic method of data reduction for peaks obtained with semiconductor detectors has been developed. The method is designed for general analytical application and is easily programmed for utilization with small computers. The representative area of a spectral peak is established on the basis of the detector system resolution and the noise continuum level on each side of the peak, the latter being determined by a simple search routine. Specific comparisons of accuracy and precision are made to the "Total Photopeak" method of data reduction.

A SYSTEMATIC PEAK REDUCTION METHOD FOR SEMICONDUCTOR DETECTOR SPECTRA

INTRODUCTION

The spectra derived from semiconductor detectors are characterized as line spectra. Each spectral peak is representative of a defined amount of radioactivity for a specific isotope. The representative area of a peak is bounded by its envelope and a background continuum. The spectral evaluation problem lies in systematically determining the net peak area in order to obtain quantitative and reproducible results. By making the method systematic, the data reduction method becomes computer-compatible.

SUMMARY

The peak reduction method described is a very general, systematic method suitable for accurate, quantitative analysis of semiconductor detector spectra. Some very specific computer applications of this method are made to illustrate the versatility of the method and to suggest other modes of utilization.

Developed in June 1967 for data reduction of printed pulse height analyzer data using desk calculators, the described method has since been successfully applied to a large variety of analyses, to an extended range of detector systems and detector resolutions, and in several computer applications.

DISCUSSION

BASES

The data reduction method described is not a universal method. The assumption is made that the peak to be analyzed is at least resolved to one-tenth its height. With lithium drifted germanium [Ge(Li)] detectors and 100 to 2000 keV gamma spectra, this condition is almost always met. With any semiconductor detector system such as Ge(Li) and lithium drifted silicon [Si(Li)] detectors, surface barrier silicon detectors, and silicon diffused junction detectors, a considerable portion of the resulting spectra can be reduced by the subject method.

A peak area is bounded by its envelope on one hand and the background continuum on the other. The problem is to determine where one ends and the other begins--and to do it consistently so that data reduction will be quantitatively reproducible. If the problem is solved in a systematic manner, the method can be readily adapted to computer application.

A single peak contained in a spectrum will have a predictable resolution which is dependent on the capabilities of the detector, the energy of the peak, and the effect of count rate on the amplification system. The peak itself is composed of a favorable signal to noise region about its center and unfavorable signal to noise regions where the peak merges with the noise continuum. For this reason it is difficult to extract a full, net photopeak from a spectrum consistently and systematically. To illustrate, note the variation in the number of channels used to define repetitive, total photopeaks in Tables Ib and II by the Total Photopeak Method; or attempt to determine a uniform distance between peak limits using one of the spectrum segments in Tables III and IV.

Background continuum is also limited in relationship to

a peak. It can remain constant or decrease gently at increasing energy increments away from the peak, as illustrated by the 1332.4 keV peak of ^{60}Co in Figure 2. Background continuum can rise sharply due to an associated doublet or a Compton slope, as illustrated by the 375.0 keV ^{239}Pu peak in Figure 1; or background continuum can drop sharply with a peak near the Compton edge of a second higher energy peak. What happens to the noise continuum under the peak is immaterial as long as we adhere to the conditions of at least partial resolution of the peak and a symmetrical method of characterizing the peak area.

Routine reduction of doublets, triplets, and unresolved peaks is beyond the scope of this method. If there is need for routine determination of complex peak structure, the method of Ray Gunnick and J. B. Niday¹ is recommended, in which the noise continuum is characterized as a smoothed step function under each peak.

MECHANICS

To ensure a systematic approach to the data reduction of a peak, the following conditions are established:

1. The midpoint of the peak to be reduced, IP, is defined as the channel with the highest count content within the envelope of the peak.
2. The Full Width at Half Maximum (FWHM) resolution of a peak characteristic of the energy range being analyzed establishes the integration range to be used in determining gross photopeak area. Full Width at Half Maximum is a constant value named IX and it is

¹Ray Gunnick and J. B. Niday. *Computer Analysis of Gamma-Ray Spectra*, University of California, Lawrence Radiation Laboratory, Livermore, California, 1969.

applied as an integer number of whole channels on either side of the IP channel. For instance, in the gamma energy range of 100 to 2000 keV, the 1332.4 keV peak of ^{60}Co may be chosen as representative of system resolution. A resolution of 2.85 keV (FWHM) with the analyzer energy range set at 0.5 keV per channel results in a (FWHM) value of 5.7 channels for an integer IX value of 6. The number of channels integrated is $2IX + IP$ or 13.

The choice of isotopic peak to be used to establish IX is entirely arbitrary and that peak needs never appear in spectra being analyzed. However, the isotopic peak once chosen must remain the same as that used during detector response calibration of the system. For instance, it would not do to use the 1332.4 keV ^{60}Co peak to calibrate and then switch to the 661.59 keV ^{137}Cs peak to establish the IX value in sample spectra. On the other hand, it is legitimate to calibrate with an analyzer setting of 0.5 keV per channel and then to analyze samples using a different analyzer energy range--0.33 keV per channel, for instance. In this case, with a 1332.4 keV ^{60}Co resolution of 2.85 keV (FWHM), the integer IX value would be 9.

3. The limit of search for the noise continuum level on either side of IP is defined as I_l . It must be an integer number of channels equal to or greater than IX. As with IX, the choice is arbitrary; but once incorporated into a calibration, it should be applied consistently. For the author's own purposes, I_l is set equal to four times IX. To determine the noise continuum level, the search is made between the limit value, I_l , and IP for the lowest channel content. If the spectral data had previously been

smoothed using at least one pass of a five-point smoothing program, the single channel content will be sufficient to establish a minimum in the noise level continuum. If the data have not been smoothed, an average low channel content is established by averaging a number of adjacent channels consistent with the statistical quality of the data. Figures 1 and 2 illustrate the difference in statistical quality of the background continuum. A single point determination in Figure 1 reliably describes the continuum and does not do so in Figure 2. A Noise level Continuum Lower in energy (NCL) and Higher in energy (NCH) than each peak calculated is determined.

The units of photopeak area are counts. Counts per unit time are equivalent to activity. It should be understood that what has been defined as noise continuum is not background. Noise continuum is an unpeaked continuum due to degraded energy emission from the sample and associated emission sources. Background is net peak area per unit time of a photopeak present in a sample spectrum but not emitted by the sample. Background can be subtracted, if it exists at all, as either net count per unit time or as activity.

Calculation of Net Photopeak Area is as follows:

$$\text{Gross Photopeak Area} = \text{CG} = \sum \text{of channel contents of channels IP - IX through IP + IX}$$

$$\text{Noise Continuum} = \frac{\text{NCL} + \text{NCH}}{2} * ((2 * \text{IX}) + 1)$$

$$\text{Net Photopeak Area} = \text{CN} = \text{CG} - \left(\frac{\text{NCL} + \text{NCH}}{2} * ((2 * \text{IX}) + 1) \right)$$

A useful by-product of this calculation method is the percent precision of the activity at the 95 percent confidence level.

$$\pm \% @ 95\% CL = \frac{1.96 * 100 \sqrt{CG + \frac{NCL + NCH}{2} * (2IX + 1)}}{CN}$$

1.96 times standard deviation = 95% of the area of the distribution function.

The precision is a measure of counting statistics only.

VALIDATION

By defining the Gross Photopeak Area (CG) as IP plus twice the FWHM resolution and recognizing that modern semiconductor detectors have Full Width at Tenth Maximum (FW@TM) resolutions of less than twice FWHM, a consistent analysis of greater than 96% of the photopeak area is assured while the poorest signal to noise regions of that peak are discarded. If applications of this method are limited to photopeaks that are resolved to one-tenth their height or $2 * IX$ channels, the maximum interference will be less than 2% of the net area of the interfering peak. "Total Photopeak" calculation methods use all of the photopeak area regardless of signal to noise ratio of any particular portion of the whole; consequently the comparative interferences will be greater. An indication of this can be seen in the ratio of the 1291 keV ^{59}Fe peak to the 1332.4 keV ^{60}Co peak as obtained by the two different calculation methods in Table II. The ratio of activities of the test photopeaks should be 65:1. The same indication can also be seen in the comparative precisions of the Fe peak in Table II.

In order to illustrate the validity of this method of peak reduction in difficult circumstances, 12 duplicate analyses of a ^{239}Pu source were made. The 375.0, 392.9, and 413.6 keV peaks indicated in Figure 1 were reduced by the "Total Photopeak" method and by the method described here--labeled 50/50 Calculation Method. Tables Ia and Ib contain the results of the data reductions, respectively. The ^{239}Pu spectrum is

intended to illustrate the difficulty of determining the total photopeak area in a situation of highly packed and incompletely resolved peaks. In practice, only one of these photopeaks need be analyzed. Circled values represent deviations from the mean greater than predicted by the 95% confidence levels of the counting statistics. Note that even though the predicted precisions are about the same, there are 11 instances where the deviation from the mean exceeded the precision statement in the Total Photopeak method compared with 8 for the 50/50 Calculation method. The † values indicate the number of whole channels used to calculate the photopeak area by the total photopeak method. The eighth line of values in Tables Ia and Ib was calculated from the spectrum segment in Table III. If one has difficulty duplicating the net counts per second values in Table Ib, the error that can be introduced by the lack of a systematic approach to data reduction has been illustrated.

A second set of eight duplicate analyses using the spectrum in Figure 2 illustrates the difficulty of analyzing a small peak in the immediate influence of a larger peak. Table II contains the results of the evaluation. Note the generally poorer precision for the Total Photopeak method, especially with regard to the 1291 keV peak. The precision predicts the inclusion of less reliable, noisy data and the deviation from the mean bears it out. As stated before, the photopeak area ratio should have been 65:1. The ratios obtained by each method indicate that the Total Photopeak method is subject to greater errors in interpreting the proportionality of count to activity over the range illustrated.

The counting time for the data in Table II was purposely limited to simulate low activity and minimum counting statistics. The first line of values in Table II was calculated from the spectrum segment in Table IV.

All data were smoothed prior to data reduction.

LIMITATIONS

The method described is limited to fully resolved photo-peaks or photopeaks resolved at least to one-tenth their height. Unresolved peaks may be reduced by this method if the amount of interference contribution can be determined from a fully resolved peak of the same isotope and subtracted as a background contribution.

No attempt has been made to have the computerized version of this method perform qualitative identification of the peak being analyzed or to compare, internally, the yield of one peak of an isotope against any or all from that same isotope. The former could be programmed but every peak in a spectrum would have to be identified, analyzed, and reported; and that is not the intent of this method. The latter has been performed repeatedly in checking the performance of the described method, but to make it a requirement would cancel effectiveness.

Any biases that exist cause the resulting activities to be high because of the mode of noise continuum determination and subtraction. The noise continuum is a statistically poor region in any event, even after smoothing. The poorer the statistics are, the greater the probability that one or both of the noise continuum points chosen will be non-representatively low, resulting in a low correction for noise and a high net count. Because of this characteristic, the computer programs utilizing this method of data reduction are being changed from search for the lowest single channel content between IP and I1 to a search for the three consecutive channels with the lowest content within the IP-I1 limits. The search is to be conducted in increments of one channel.

COMPUTER APPLICATIONS

Nuclear Data² and Northern Scientific³ both have provided custom programs for their hybrid analyzer--computers incorporating the subject method of data reduction.

Figure 3 illustrates some of the variations possible for direct, interactive data reduction in a hybrid analyzer-computer. The ND40-9006 overlay of the *Single Parameter Analyzer Program*² is illustrated first. It represents the earliest effort at computerized implementation of this data reduction method. The program is called by teletype entry of the letters RP. The data entries are made in groups--if any entry in the group is changed, all must be entered. Groups are indicated by brackets on the left margin. The circled entries indicate the number and extent of manual entries which must be performed on the teletype for a routine peak reduction. The peak to be analyzed is isolated by an intensified zone on the oscilloscope and qualitatively identified prior to data reduction.

IX and Il are not normally re-entered for each analysis. They correspond to the IX and Il values in the description of the peak reduction method. The BD entry is a divider and BN is a multiplier. In practice, BN has been reserved for a combined efficiency-geometry factor and BD has been used for recovery, time base conversion, dilution factor, etc. Time zero is T0, time of count is TC, and half-life is Tl. All times are entered in units of days times 1000. The entry 2E5 for T0 equals 200,000 or 2 times exponent to the base 10 of 5. Five manual entries (circled values) were necessary

²ND40-9006: Special Peak Reduction for Atlantic Richfield Hanford Company. Overlays have been written for Series 50/50, Single Parameter Analyzer Program, Physics Analyzer Program, and Extended Physics Analyzer Program--all for PDP8L.

³NS-600 System: Atlantic Richfield Hanford Company, Richland, Washington, September 15, 1970, for the NOVA computer.

for each peak reduced. Peak center, PC (same as IP, the whole channel with the highest peak content), starts the output listing. The percent precision at the 95% confidence level is CL. The microcuries at time of count are UC and the microcuries at time zero are UO.

The second and third applications of "RP Reduce Peak" represent the latest version of the ND40-9006 overlay to the *Physics Analyzer*² program. Neither IX nor I1 values print out unless they have been changed. The output format has also been changed to one more suitable for customer reports. Time of count now represents the log number for the analysis, as well as the time. A running calendar is kept and all analytical times are recorded in decimal days from a converter NIM scaler.⁴ The punch control of the teletype is turned on immediately after "TC:" is printed for the first photopeak in a spectrum analysis. This causes the time-serial number to be entered on the punched paper tape just prior to the analysis of the first photopeak in a sample spectrum. The punch control is turned on AFTER completing the time of count entry for all subsequent photopeak analyses.

The second and third applications in Figure 3 illustrate two options for entry of the BN,T1 couplet in the latest version of the RP Peak Reduction overlay program. Manual entry is available as before, making a total of three entries per photopeak analysis. Using the second option, any of 63 couplets may be called from analyzer memory locations by typing the appropriate integer code followed by an "S". The latter mode consists of two manual entries. To implement the "S" (Set) mode of entry, the last 128 channels of each 4096

⁴L.H.W. Crowley and W. H. Zimmer. *A Digital Day Clock from an NIM Scaler*, ARH-1469, Atlantic Richfield Hanford Company, Richland, Washington, November 20, 1969.

channel of analyzer memory are reserved for pairs of constants which correspond to the BN and Tl values for most frequently analyzed photopeaks. The last couplet entered manually is stored in the first "Set" location and can be called by a "1S" entry.

Punched paper tapes are prepared in advance for each detector-geometry combination, and entry of the 63 data couplets to analyzer memory is made under routine I/O program control. All program routines which could alter the last 128 channels of memory (such as ERase, SMOOTH, TRansfer, etc.) have been rewritten to disregard these locations. Since hard-wired memory core is being used, the numbers stored must be positive integers. This does impose limitations but they are more than off-set by the time saved in looking up and manually entering BN and Tl values. Standard forms are posted with each 4096 memory section listing the integer Set code, the isotope, the photopeak energy, and the powers of ten by which BN and Tl are multiplied. For instance, BN may be multiplied by 10^7 and Tl by 10^3 , as in the case illustrated in Figure 3. To compensate, BD has been multiplied by 10^7 and TO and TC both have been multiplied by 10^3 .

The sample identification is punched under "local" Teletype control just prior to the spectral analysis. At the Separations Chemistry Laboratory of Atlantic Richfield Hanford Company a letter is entered to designate the detector-analyzer system. A set of paper punched tapes containing standard headings is also maintained.

To generate a customer report, as illustrated in the last section of Figure 3, the appropriate heading tape is read through any teletype terminal--not necessarily the terminal on which the report was generated. This is followed by the analytical tape; and the data section of the report is complete.

FIGURE 1
PLUTONIUM-239 SPECTRUM SEGMENT
LOG OF COUNT VERSUS keV

FIGURE 2

IRON-59-COBALT-60 SPECTRUM SEGMENT
LOG OF COUNT VERSUS keV

* RP REDUCE PEAK

```
{IX:6
{I1:24
{BD:1.723E5
{BN:1173
{T0:2E5
{TC:289407
{T1:271650
PC=      242
CL= +0.6553539E+00
UC= +0.1662418E+01
UO= +0.2088415E+01
```

* RP REDUCE PEAK

```
IX:
{BD:1.723E5
{T0:2E5
{BN:1173
{T1:271650
TC:289407
      242 +0.6553539E+00 +0.1662418E+01 +0.2088415E+01
```

* RP REDUCE PEAK

```
IX:
BD:      172300
T0:      200000
BN:59ET=      1173
T1=      271650
TC:289407
      242 +0.6553539E+00 +0.1662418E+01 +0.2088415E+01
```

EFF#2 STD.

A

ISOTOPE	PEAK CENTER	PLUS OR MINUS % @ 95% CL	MICROCURIES @ T OF COUNT	MICROCURIES @ T ZERO
---------	----------------	-----------------------------	-----------------------------	-------------------------

EFF#2 STD.

A289407

C057	242	+0.6553539E+00	+0.1662418E+01	+0.2088415E+01
C057	270	+0.2486279E+01	+0.1738568E+01	+0.2184079E+01
BA133	604	+0.2721064E+01	+0.1594749E+01	+0.1620338E+01
BA133	710	+0.1358947E+01	+0.1569059E+01	+0.1594236E+01
SB125	854	+0.2026436E+01	+0.1689296E+01	+0.1795652E+01
SR85	1027	+0.1271361E+01	+0.1491805E+01	+0.3859845E+01
SB125	1272	+0.3847386E+01	+0.1739335E+01	+0.1848842E+01

FIGURE 3

COMPUTER APPLICATION INPUTS AND OUTPUTS

TABLE I

COMPARISON OF CALCULATION METHODS USING PLUTONIUM-239 GAMMA SPECTRA

a. 50/50 Calculation Method

375.02 keV		392.92 keV		416.3 keV	
C/S Net Area	Deviation From Mean	C/S Net Area	Deviation From Mean	C/S Net Area	Deviation From Mean
49.366 ±0.71	+0.80	17.679 ±1.2	+1.2	49.392 ±0.68	+0.70
49.043 ±0.71	+0.14	17.646 ±1.2	+1.1	49.450 ±0.68	+0.82
48.806 ±0.71	-0.35	17.698 ±1.2	+1.4	48.900 ±0.68	-0.30
48.805 ±0.71	-0.35	17.346 ±1.3	-0.66	48.824 ±0.68	-0.46
48.777 ±0.71	-0.41	17.527 ±1.2	+0.37	49.064 ±0.68	+0.03
49.101 ±0.71	+0.25	17.354 ±1.3	-0.62	49.170 ±0.68	+0.25
48.936 ±0.71	-0.08	17.511 ±1.2	+0.28	49.202 ±0.68	+0.31
48.943 ±0.30	-0.07	17.455 ±0.53	+0.04	48.703 ±0.29	-0.70
49.060 ±0.30	-0.17	17.250 ±0.54	-1.1	48.840 ±0.29	-0.42
48.874 ±0.30	-0.21	17.268 ±0.54	-1.1	49.110 ±0.29	+0.13
48.897 ±0.30	-0.16	17.406 ±0.53	-0.32	48.980 ±0.29	-0.14
49.109 ±0.71	+0.27	17.381 ±1.3	-0.46	48.937 ±0.68	-0.23
48.9764		17.4618		49.048	Average
0.9985		0.3560		1.0	Ratio of Peaks

b. Total Photopeak Method

375.02				392.92 keV				413.6 keV			
C/S Net Area	No. of Channels	Deviation From Mean		C/S Net Area	No. of Channels	Deviation From Mean		C/S Net Area	No. of Channels	Deviation From Mean	
50.532	0.70	15	+0.28	17.687	1.3	21	-0.27	51.074	0.68	28	+0.07
50.706	0.70	15	+0.63	17.685	1.3	20	-0.28	51.424	0.69	32	+0.75
50.124	0.70	15	-0.53	18.096	1.3	21	+2.0	50.972	0.69	30	-0.13
50.452	0.71	16	+0.12	17.704	1.3	20	-0.17	50.402	0.16	27	-1.3
49.942	0.71	15	-0.89	17.899	1.3	16	+0.93	50.844	0.69	28	-0.38
50.229	0.71	15	-0.32	17.643	1.3	20	-0.51	51.101	0.68	28	+0.12
50.141	0.71	15	-0.49	17.809	1.3	20	+0.42	51.362	0.69	32	+0.63
50.676	0.30	16	+0.57	17.775	0.56	21	+0.23	51.065	0.29	30	-0.05
50.343	0.30	15	-0.09	17.596	0.56	19	-0.78	50.953	0.29	30	+0.17
50.584	0.30	16	+0.39	17.541	0.56	20	-1.1	51.189	0.29	30	+0.29
50.584	0.30	16	+0.39	17.694	0.56	20	-0.23	50.884	0.29	31	-0.31
50.362	0.70	15	-0.05	17.683	1.3	18	-0.29	51.216	0.69	31	+0.34
50.3896				17.7343				51.0405			Average
0.9872				0.3475				1.0			Ratio of Peaks

Twelve duplicate analyses of a ^{239}Pu source were made using the peaks corresponding to the posted energies. Values listed are net peak areas $\pm$ the 95% confidence levels in units of counts per second, calculated by the method in the heading. Averages and deviations from the mean illustrate the precision attained by each method. Circled values are deviations from the mean that exceed the 95% confidence levels.

TABLE II
COMPARISON OF CALCULATION METHODS
USING IRON-59 AND COBALT-60 GAMMA SPECTRA

50/50 Calculation Method			
C/S Net Area ±Counts 1291 keV	Deviation From Mean	C/S Net Area 1332/5 keV	Deviation From Mean
1.5342 ±15.	-7.8	108.84 ±1.1	+0.97
1.6400 ±14.	-1.4	108.35 ±1.1	+0.52
1.6400 ±14.	-1.4	107.52 ±1.1	-0.25
1.7101 ±13.	+2.8	107.27 ±1.1	-0.48
1.6124 ±16.	-3.1	108.53 ±1.1	+0.69
1.6792 ±14.	-0.94	106.93 ±1.1	-0.80
1.7296 ±13.	+4.0	107.38 ±1.1	-0.38
1.7622 ±13.	+5.9	107.50 ±1.1	-0.27
1.6635		107.99	<i>Average</i>
107.79/1.6635 = 64.797			<i>Ratio of Peaks</i>

Total Photopeak Method					
C/S Net Area ±Counts @ 1291 keV	No. of Channels	Deviation From Mean	C/S Net Area @ 1332.5 keV	No. of Channels	Deviation From Mean
1.4824 ±19.	20	-6.5	121.247 ±1.04	34	+0.65
1.7058 ±17.	21	-7.6	121.388 ±1.04	42	+0.77
1.6410 ±16.	16	+3.5	118.999 ±1.05	36	-1.21
1.4749 ±16.	14	-6.9	119.601 ±1.04	32	-0.71
1.4345 ±18.	16	-9.5	120.978 ±1.04	37	+0.43
1.6635 ±15.	17	+5.0	120.540 ±1.04	44	+0.07
1.7847 ±15.	19	+12.6	120.507 ±1.04	35	+0.04
1.4925 ±18.	18	-5.8	120.412 ±1.04	35	-0.04
1.5847			120.459		<i>Average</i>
120.459/1.5849 = 76.004					<i>Ratio of Peaks</i>

Eight duplicate analyses of a mixed ^{59}Fe - ^{60}Co source were made using the 1291 keV ^{59}Fe peak and the 1332.5 keV ^{60}Co peak. Values listed are net peak areas $\pm$ the 95% confidence levels in units of counts per second, calculated by the method in the heading. These peaks were chosen to illustrate the difficulty of analyzing a small peak in the immediate influence of a larger peak. Note the generally poorer precision for the Total Photopeak method, especially with regard to the 1291 keV peak. The precision indicates the inclusion of less reliable, noisy data and the deviation from the mean bears it out. The photopeak ratio should have been 65.1.

TABLE III
PLUTONIUM-239 SPECTRUM SEGMENT

700	3625	3625	3660	3732	3683
705	3708	3593	3596	3572	3699
710	3666	3723	3654	3727	3784
715	3951	4004	4177	4298	4423
720	4325	4242	4116	4210	4412
725	5059	5999	7371	8756	10432
730	11558	12145	11596	10658	9193
735	8074	7201	7220	7995	10427
740	15450	25687	40775	60109	76096
745	84170	77129	50975	38008	21728
750	11895	9019	10030	13702	17359
755	20083	20314	19611	18373	17932
760	17156	15742	12748	8964	5694
765	3739	2676	2326	2180	2229
770	2301	2461	2657	3139	3937
775	5537	8325	13304	19697	26176
780	29744	29603	25034	18154	11005
785	6101	3389	2329	1916	1836
790	1829	1909	1917	1976	1985
795	1995	1903	1844	1763	1753
800	1737	1786	1797	1823	1804
805	1860	1937	2026	2047	2188
810	2303	2532	2756	3392	4314
815	6374	10101	17643	29635	46914
820	64931	79639	81739	70691	49845
825	29875	14627	6240	2372	1178
830	913	983	1076	1268	1636
835	2426	3561	5053	6359	7260
840	7019	5832	4063	2701	1876
845	1689	1833	1976	1893	1720
850	1487	1214	997	941	905
855	864	817	763	665	631
860	609	598	572	586	575
865	587	604	630	607	594
870	587	597	574	582	585
875	608	602	607	605	639

Raw teletype readout of the pulse height analysis of the plutonium-239 spectrum segment in Figure 1 and the data for the calculations on line 8 of Tables Ia and Ib. Count time is 10000 seconds. The first column is channel address. The second through sixth columns are channel contents in units of counts starting at the address in Column 1.

TABLE IV
IRON-59-COBALT-60 SPECTRUM SEGMENT

260	36	41	39	37	27
265	30	33	35	36	37
270	40	42	43	44	45
275	43	42	42	52	54
280	62	76	91	93	92
285	94	84	67	53	45
290	40	36	35	38	40
295	40	40	39	37	36
300	40	37	38	42	38
305	32	37	41	38	35
310	37	35	35	34	31
315	34	39	38	30	31
320	40	50	53	46	37
325	35	44	46	42	39
330	37	40	38	39	38
335	49	51	54	60	68
340	61	54	58	69	76
345	75	76	85	91	95
350	115	152	166	179	218
355	267	340	436	603	855
360	1162	1574	2103	2872	3657
365	4395	4623	4363	3521	2583
370	1600	881	365	146	48
375	30	20	18	14	15
380	15	18	18	16	15
385	12	15	18	17	11
390	9	14	15	18	18

Raw teletype readout of the pulse height analysis of the ^{59}Fe - ^{60}Co spectrum segment in Figure 2 and the data for the calculations on line 1 of Table II. Count time is 307 seconds. The first column is channel address. The second through sixth columns are channel contents in units of counts starting at the address in Column 1.

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