PH425 ADVANCED LABORATORY III

EXPERIMENT 3K: STANDARDIZATION OF GAMMA RAY SOURCES

"Standardization" of a radiation source just means the determination of its activity. The activity is the amount of a radionuclide in the source expressed as a rate of decay. Thus the SI unit of activity is one (distintegration) per second, called one becquerel (Bq); a traditional special unit is the "curie" (Ci).

$$1Ci \equiv 3.70 \times 10^{10}\ Bq = 3.70 \times 10^{10}\ \text{sec}^{-1} \qquad [1]$$

Integration of a Spectrum Peak:

One of the things we will have to do is to turn some peak in a multichannel analyzer spectrum into a number of observed counts. Every pulse that comes into the MCA is stored in some channel or other, so in principle all we do is add up the counts in all the channels spanned by a peak. For instance, Figure 1 presents part of a spectrum (channels 90-125), with a photopeak in channel 110 or 111:

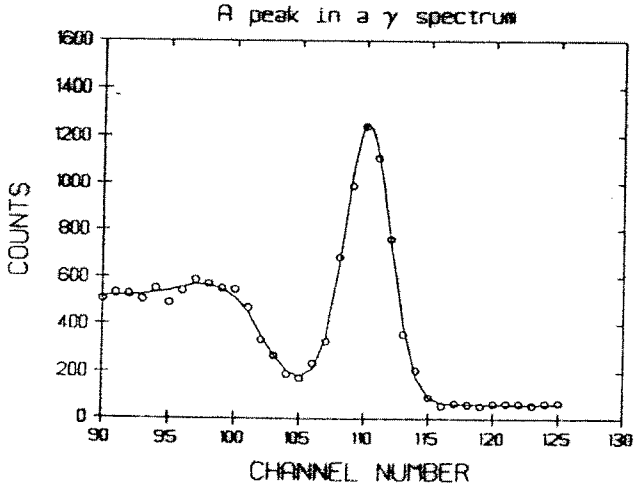

Figure 1 A Peak in a Spectrum

channel	cts	channel	cts
90	507	108	684
91	530	109	989
92	526	110	1242
93	505	111	1108
94	550	112	762
95	491	113	359
96	541	114	208
97	587	115	94
98	570	116	58
99	550	117	68
100	546	118	64
101	471	119	57
102	335	120	66
103	270	121	67
104	192	122	66
105	176	123	60
106	237	124	67
107	330	125	70

From the data, the peak is spread over about channels 104-117; if we just total the counts in those 12 channels, we get 6247 counts "in the peak".

But we have to be a little more sophisticated than that, because clearly there is more going on in this spectrum than the photopeak. Whatever the other things are, they produce 192 counts in channel 104, 64 counts in channel 117, etc.; it stands to reason that they are also producing counts in the channels we've counted as part of our peak. This background under the peak has to be accounted for. Do this by extending the "background" spectrum smoothly under the peak, and get an appropriate number of counts in each channel to subtract off, as is done in Figure

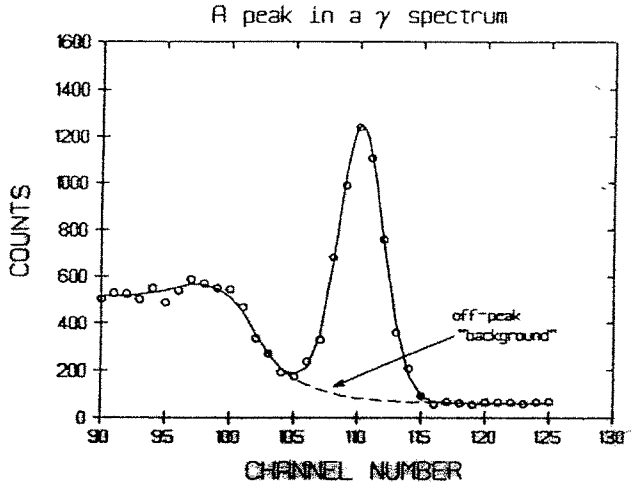

Figure 2 "Stripping" a Peak

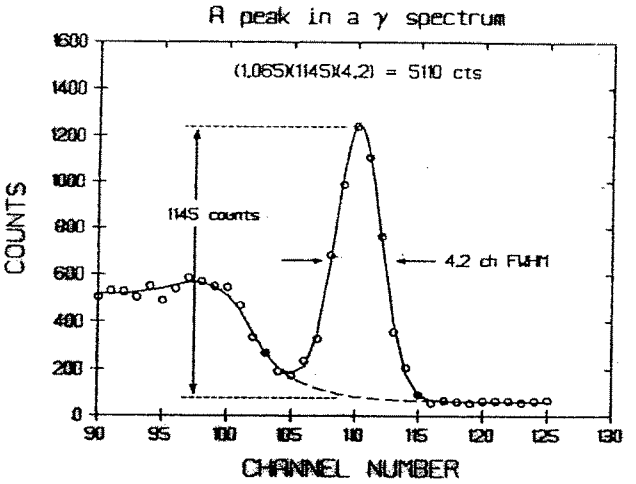

Figure 3 The Quick Way

channel	cts	bckgrnd	net
102	335		
103	270		
104	192	205	- 13
105	176	167	9
106	237	141	96
107	330	122	208
108	684	108	576
109	989	96	893
110	1242	86	1156
111	1108	80	1028
112	762	75	687
113	359	72	287
114	208	69	139
115	94	67	27
116	58	66	- 8
117	68	66	2
118	64		
total	6507	1420	5087

2 (above).

Even though this peak looks pretty clean, we will overestimate the count by more than 20% if we don't "strip" background!

There is a quicker way to do this, without reading out all the individual channel counts, which can be a genuine pain if the peak is 50 channels wide. Draw a smooth curve (actually, or in your mind's eye) through the data and read off the peak height above the smooth interpolated background. (In Figure 3, a smooth "background" curve extended under the peak has a value of about 85 counts in channel 110, and the total count there is 1230; so the net peak count is 1145 counts.) Read off the full width of the peak at half its maximum rise above the background the FWHM in Figure 3 is 4.2 channels). Then use

$$\begin{pmatrix} total \\ counts \end{pmatrix} = (1.065)\begin{pmatrix} peak \\ count \end{pmatrix}(FWHM) \qquad [2]$$

For the data in Figure 3, doing this carefully gives 5110 counts in the peak. This is within 1% of the result we got from stripping numerically, channel by channel. But 1% is considerably less than the error already present due to counting statistics, uncertainty in interpolating the "background" curve, etc., so we lose little no precision by integrating the peak the "quick way".

Source Activity

The purpose of this experiment is to examine some of the considerations involved in determining the activity of a source. The sources that will be used in these laboratories have activities of the order of one microcurie (μCi), and are weak enough, and securely enough sealed, so that you needn't take any special precautions in handling them.

The rate at which counts are observed in a detector involves several factors, of which the source decay rate is only one. Not all particles from the source strike the detector; not all particles striking the detector are counted by our electronics.

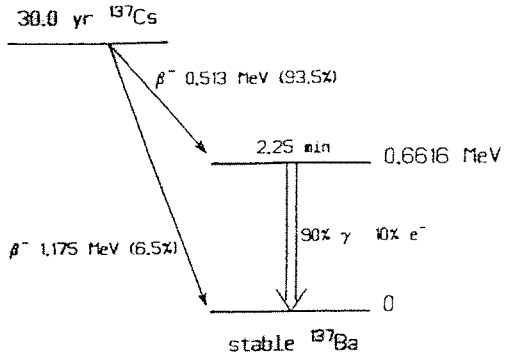

Figure 4 Cesium-137 Decay

We can write

$$\begin{bmatrix}\textit{count rate}\\ \textit{observed}\end{bmatrix} = \begin{bmatrix}\textit{source}\\ \textit{decay rate}\end{bmatrix}\cdot\begin{bmatrix}\textit{photons}\\ \textit{per decay}\end{bmatrix}\cdot\begin{bmatrix}\textit{fraction of}\\ \textit{photons}\\ \textit{intercepted}\\ \textit{by detector}\end{bmatrix}\cdot\begin{bmatrix}\textit{intrinsic}\\ \textit{detection}\\ \textit{efficiency}\end{bmatrix}$$

or $$R_0 = A_0 f_s G \epsilon_p \qquad [3]$$

in which R_0 = count rate observed in detector

A_0 = source activity in decays per second (1 μCi = 37000 d/s)

f_s = source fraction — how many photons, of the particular kind you are detecting, are emitted in each source decay. If there are multiple decay modes, this will ordinarily be less than 1. For example, from the decay scheme shown in Figure 4 above, the source fraction of the 0.662-MeV γ from ^{137}Cs is (0.90)(0.935) = 0.841.

G = geometry factor — the fraction of all the photons emitted which strike the detector. If the detector is not too close to the source, and the emission is isotropic, then

$$G \approx \frac{\textit{effective area of detector}}{4\pi r^2} \qquad [4]$$

where r is the source-to-detector distance.

ϵ_p = detection efficiency — the fraction of photons striking the detector which result in a count being recorded. A part of ϵ_p is the intrinsic efficiency of the detector. The energy dependence of the photopeak efficiency of an NaI detector is well represented by

$$\epsilon_p \propto E^{-a} \qquad [5]$$

The product $G\epsilon_p$ is the fraction of all photons emitted which result in an observed count; it could be called the absolute efficiency of the detector. Clearly it is a function of how far the detector is from the source. Some data on the absolute efficiency of 2" and 3" NaI(Tl) detectors are shown in Figure 5 on the last page

of this document.

A. Activity of a Gamma Emitter - Relative Method

If counts are taken from two (thin) sources of the same radionuclide, in precisely the same experimental arrangement, then all the factors on the right-hand side of Equation [3] are the same except for the source activity. In this case, the two observed counting rates are directly proportional to the count rates. The activity of an unknown source is thus readily determined if another source of the same radionuclide, of known activity, is available.

The most precisely known γ sources we have are the older ^{137}Cs source (activity 4.80 ± .15 μCi) and the yellow ^{60}Co source (0.43 ± .04 μCi). (Both standardizations are as of 7/1/82. How have they been affected by the passage of 10+ years?) Take these two as "known standards" for this part of the experiment.

1. Set up your scintillation counter and multichannel analyzer as you did in Experiment 2. Position the "standard" cesium source on the axis of the detector, at a convenient distance not less than several centimeters away. Accumulate a spectrum for one of the presettable live-time periods, long enough to produce a good clear well-defined spectrum.

2. As discussed earlier in this paper, determine the number of counts in the 662-keV full-energy peak.

3. Replace the standard source with an "unknown" ^{137}Cs source, as nearly as possible in the same position relative to the detector, and accumulate a spectrum for the same preset period you used in part 1. Determine the number of counts in the photopeak.

4. On the assumption that the observed count rates are directly proportional to the source activities, determine the activity of the unknown ^{137}Cs source. I would like to see a careful and complete consideration of the sources of error in your final result. Remember that the inherent standard deviation of a random counting process is the square root of the number of counts; and consider also the uncertainty in whatever method you use to integrate the counts in a spectrum peak.

5. Repeat this process to determine, by the relative method, the activity of an unknown ^{60}Co source.

B. Activity of a Gamma Emitter - Absolute Method

An alternative method, which does not depend on having a known standard of the same radionuclide, is to use all the factors in Equation (3). Enough must be known about the decay scheme to give you the source fractions.

1. Set up your scintillation counter and multichannel analyzer, as before. Position a ^{137}Cs source on the axis of the detector, at a convenient distance not less than several centimeters away.

2. Measure the distance from the source to the detector. In doing this, assume that the scintillation crystal begins 0.2 ± 0.1 cm behind the surface of the aluminum can, and that the actual radiation source is 0.1 ± 0.1 cm below the lettered surface of the plastic button. Use Figure 5 to determine the absolute peak efficiency $G\epsilon_p$. Estimate the error in your determination.

3. Accumulate a spectrum for one of the presettable live-time periods, long enough to produce a good clear well-defined spectrum. By the methods already employed, determine the number of counts in the peak, and the count rate.

4. Use Equation [3], your experimental results, and the known value of the source fraction for ^{137}Cs to determine the activity of your source. Estimate the error in your determination.

5. Repeat the procedure using a ^{54}Mn source. The source fraction for the 0.835-MeV photon emission from ^{54}Mn is 1.00.

C. Energy Dependence of the Efficiency of a NaI Detector

Indium-116m is a radionuclide produced by neutron activation of stable ^{115}In. (The "m" stands for "isomer", which simply means a long-lived excited state. In this case the half-life of the isomer is 54 min.) A γ spectrum from ^{116m}In will show six or seven clear lines; their energies and decay fractions can be found in the table at right. Since the source activity and the geometry factor in Equation [3] are the same for all these lines,

E_γ (MeV)	f_s
0.138	0.03
0.417	0.36
0.819	0.17
1.091	0.53
1.293	0.90
1.508	0.11
2.111	0.20

$$R_0 \propto \epsilon f_s \quad \text{or} \quad \epsilon \propto \frac{R_0}{f_s} \qquad [6]$$

Since you have several different γ energies, what you are seeing here is the dependence of the efficiency (ϵ) of the detector on photon energy.

1. You will probably need to change the amplifier gain and recalibrate your spectrometer. Set up the system so that the spectrum on the multichannel analyzer ranges from 0 - 2.5 MeV.

2. Your instructor will supply a freshly activated sample of ^{116m}In. Accumulate a spectrum for a period of 10-30 minutes, long enough so that all the peaks in the spectrum are well defined. Sketch the spectrum approximately to scale in your notebook, and identify as many as you can of the peaks expected from the table of energies.

3. Determine the (relative) efficiency from [6] for each of the peak energies, and estimate experimental errors in your values. Graph relative efficiency vs. energy in such a way as to determine whether Equation [6] is valid, and determine a value for the exponent a.

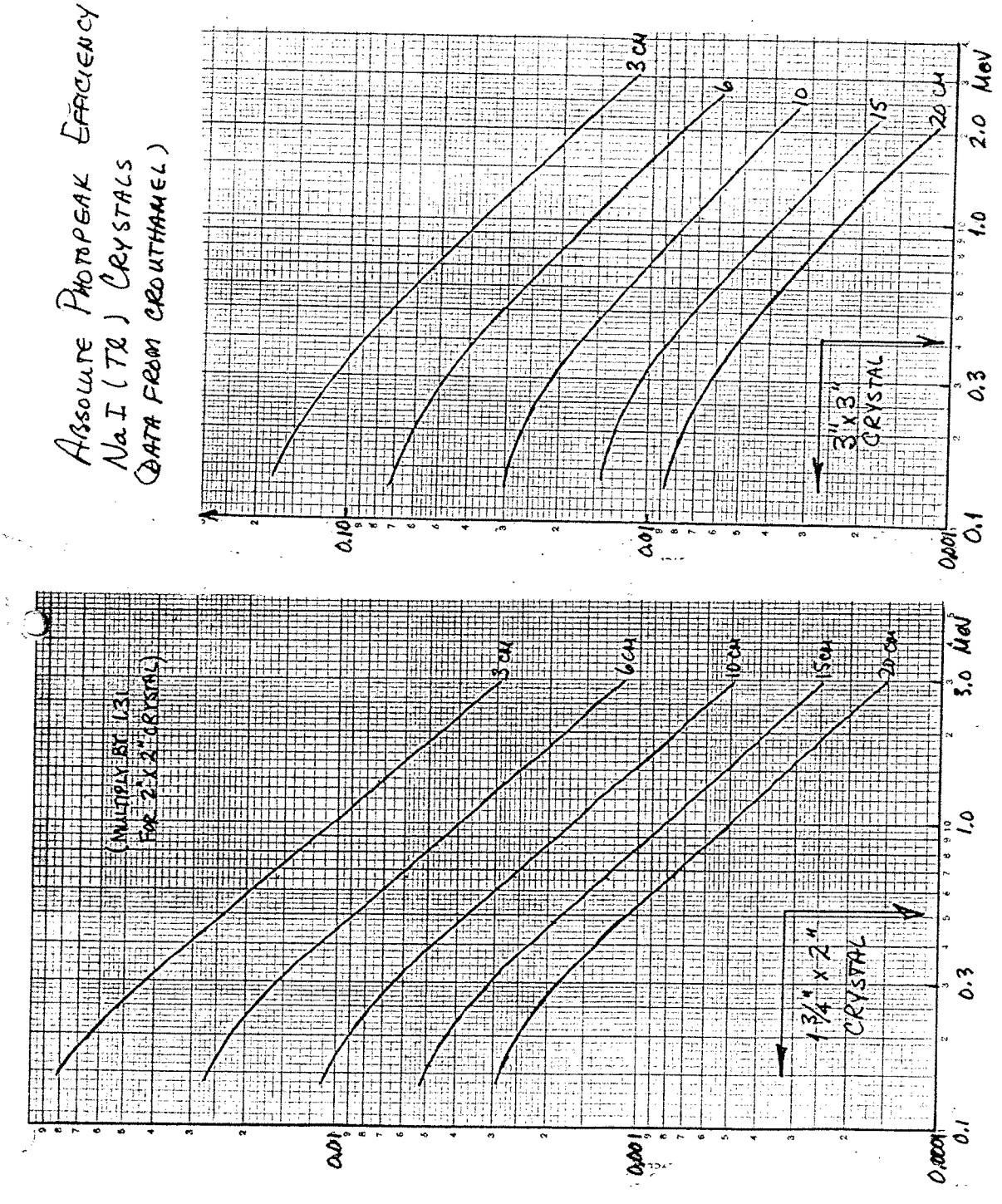

Figure 5 Scintillator efficiency curves