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SUBJECT: IBM-704 Codes for Predicting the Response of Gamma-Ray Scintillation Counters

TO: Distribution

FROM: C. D. Zerby and H. S. Moran

Abstract

This paper is a manual for operating several codes for an IBM-704 automatic computor to calculate the pulse-height response functions for gamma-ray scintillation counters. Using the Monte Carlo method of computation the codes will calculate the pulse-height response function of xylene, CsI or NaI counters of various geometrical configurations with cylindrical symmetry. Various monoenergetic source configurations are possible with a maximum source energy of 10.22 Mev.

Table of Contents

Introduction

In the past few years there has been considerable interest generated by various groups at ORNL in the analysis of pulse-height response functions from gamma-ray scintillation counters. In particular, the effect of various source geometries and detector geometries and materials have been investigated experimentally to determine their effect on the response function. Realizing the large amount of time and money being expended in this effort, it was decided to code the general problem for an automatic computing machine incorporating in the code as much versatility as possible to meet the requirements of present-day interest.

The Monte Carlo method of computation was used to produce several codes for predicting the pulse-height response functions from gamma-ray scintillation counters. The results of calculations performed with these codes compared very favorably with experimental results and will be reported in another paper along with a complete report on the project.

Because it was impossible to survey and publish results for all possible parameters of interest, and because of the wide-spread interest in these codes it seemed advisable to release the code to those interested parties having a IBM-704 computing machine available to them. This paper describes the codes and general mechanics of operating them.

General Description

The problem of predicting the pulse-height response functions for gamma-ray scintillation counters has been idealized to a certain extent for ease of computation. In particular, the counter was assumed to have cylindrical symmetry and to be suspended in a vacuum with no surrounding materials to cause spurious pulses by scattering the source radiation into the detector or scattering radiation leaving the counter back into it. The source radiation is assumed to be purely monoenergetic and is restricted to three different configurations to be described below under "Source Geometry." The maximum source energy allowed is 10.22 Mev.

In general, it was attempted to take into consideration those physical processes that have the most significant effect on the response function. For this reason account is taken of bremsstrahlung and annihilation radiation losses as well as losses by radiation scattered out of the counter. This last statement is qualified to a certain extent in the case of the xylene counter as described below under "General Notes."

For completeness, several other pieces of information are computed besides the pulse-height function. Some of these are the intrinsic efficiency, peak-to-total ratio, analytic zero pulse-height response and others that are described under "Output."

Throughout this report pulse-height is assumed to be measured in units of Mev.

Three separate Monte Carlo codes have been written for the IBM-704 to predict the response functions of counters composed of sodium iodide (NaI), xylene (C_8H_{10}), and cesium iodide (CsI), for monoenergetic sources. Secondary radiations may (1) be entirely neglected, (2) include annihilation radiation effects only, or (3) include both annihilation radiation as well as secondary bremsstrahlung effects. Output histograms may, if desired, be "smeared-out" by a Gaussian broadening in order to match crystal resolutions. Each of these three programs comprises a separate binary deck. In operation, each deck is followed immediately by sets of cards (18 each) carrying the necessary input parameters for successive cases. These cards will be described below.

In addition to the three response function codes is a fourth for the purpose of broadening unbroadened spectra and is described under "Auxiliary Broadening Program."

To obtain the binary deck for any of these programs contact either one of the authors.

Minimum IBM-704 Requirements

The minimum IBM-704 required to run the programs described in this report must have at least an 8192 core memory and built-in Floating Trap. No tapes or drums are necessary.

Counter Geometry

Figure 1 shows the most complex counter geometry allowed by the codes. The letters shown on that figure refer to the respective dimensions in centimeter units and are input parameters to the code. By selecting certain values of each of these parameters a variety of geometrical configurations can be obtained. For instance, by selecting C, D, E, and F equal to zero one obtains the familiar cylindrical counter or by selecting F equal to A the hole will pass completely through the counter.

The various geometrical configurations of the counter can be inferred from Table 1 which displays the permitted ranges for the parameters C, D, E, and F for the four cases involving the presence or absence of the truncated conical end, each combined with the presence or absence of the hole. The parameters A and B are unrestricted.

Table 1. Restrictions on the Parameters C, D, E, and F

Cone	Hole	C	D	E	F
No	No	$C = 0$	$D = 0$	$E = 0$	$F = 0$
Yes	No	$0 < C < B$	$D \geq 0$	$E = 0$	$F = 0$
No	Yes	$C = 0$	$D = 0$	$E \geq 0$	$0 < F \leq A$
Yes	Yes	$0 < C < B$	$D \geq 0$	$E > 0$	$0 < F \leq A$

Source Geometry

Each of the three response-function programs permits the use of any one of three source geometries which are shown in Fig. 2. Each of these sources is described below along with the required restrictions on the parameters H, I, and J. If the source type does not require a particular parameter, set it equal to zero.

Source Type 1, Monodirectional

This source is a circularly collimated beam centered on the axis. The output normalization will be for one photon uniformly distributed over the area of the circle.

Parameter Restrictions: 1. With no cone $J \leq B$
2. With cone $J \leq C$

Source Type 2, Conical Exterior

This source is for purposes of approximating a collimated (or uncollimated) counter when an isotropic point source is placed on the axis near the counter. The radiation is assumed to be uniformly distributed in angle within the cone subtended by the circle with radius H. The output will be normalized to one photon uniformly distributed within the cone.

Parameter Restrictions: 1. With no cone $H \leq B$
2. With cone $H \leq C$

Source Type 3, Point Isotropic Interior Source

This source is self-explanatory with the exception that it must be on the axis. One unusual feature that may be achieved with this source is that of a source buried in the counter. This is accomplished by removing the hole.

Parameter Restrictions: 1. With hole $0 \leq I \leq A$
2. Without hole $0 < I < A$

Input

Number Format for Input

The input required three different types of number format. These are "decimal number" which is a decimally expressed number with a decimal point, a "decimal integer" which is a decimally expressed integer without a decimal point which is assumed to be at the right, and "octal number" which must be a 12-digit number of octal form without a decimal point.

General Description

All three response-function codes utilize the same input format described below and use the NYINP 1 input subroutine to read cards on-line (Sense Switch 1 on). Eighteen (18) input numbers are required for each case. These may be conveniently punched and printed on the yellow-edged cards labeled "UA SAP CARD 1," as displayed in Fig. 3. In the case of decimal numbers and decimal integers the symbol DEC is punched in columns 8, 9, and 10. For octal numbers the symbol OCT is punched in the corresponding columns. The number, in each case starts in column 12.

For those who are familiar with the options allowed by NYINPI, we remark here that the 18 input parameters are initially stored in absolute decimal addresses 1065-1082, inclusive. Thus, successive cases, for which one, or perhaps few, input parameters change, may require but one, or few, cards carrying absolute decimal addresses for the changed parameters, followed by a card reading TRA 3, 4. Also, input cards may be first transferred to tape, the tape mounted as tape 3, and the programs run without cards with Sense Switch 1 off.

Input Format

	Symbol	Definition	Number Format
1.	N	Number of source-photon histories	Decimal integer
2.	Q	Number of equal energy-intervals between 0 and ESUBM	Decimal integer
3.	E_0	Source energy (Mev)	Decimal number
4.	SOURCE	Source type: 1, 2, or 3	Decimal integer
5.	A	Length (cm)	Decimal number
6.	B	Radius (cm)	Decimal number
7.	C	Radius or truncation (cm)	Zero integer or decimal number
8.	D	Altitude of truncation (cm)	" "
9.	E	Radius of hole (cm)	" "
10.	F	Depth of hole (cm)	" "
11.	H	Radius of conical source (cm)	" "
12.	I	Altitude of conical source (cm), or depth of source type 3 (cm)	" "
13.	J	Radius of monodirectional source (cm)	" "
14.	A_b	First broadening coefficient	" "
15.	B_b	Second broadening coefficient	" "
16.	KEYWORD	A number indicating which secondary radiations are to be included:	
		0 All secondaries	Decimal integer
		1 Annihilation radiation only	Decimal integer
		2 No secondaries	Decimal integer
17.	E_M	The value, in Mev, of the maximum pulse height reported in all response histograms presented in the output	Decimal number
18.	R	A number indicating the initial random number to be used:	
		0 Initial random number is immaterial, i.e., use the next sequence	Octal zero
		Specified initial random number	12-Digit octal

463 003

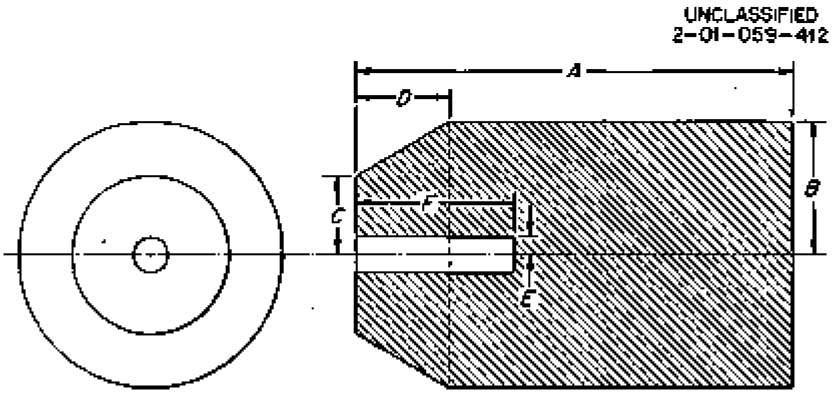

Fig. 1. Assumed Counter Geometry for Calculations of Scintillation Counter Gamma-Ray Response Functions.

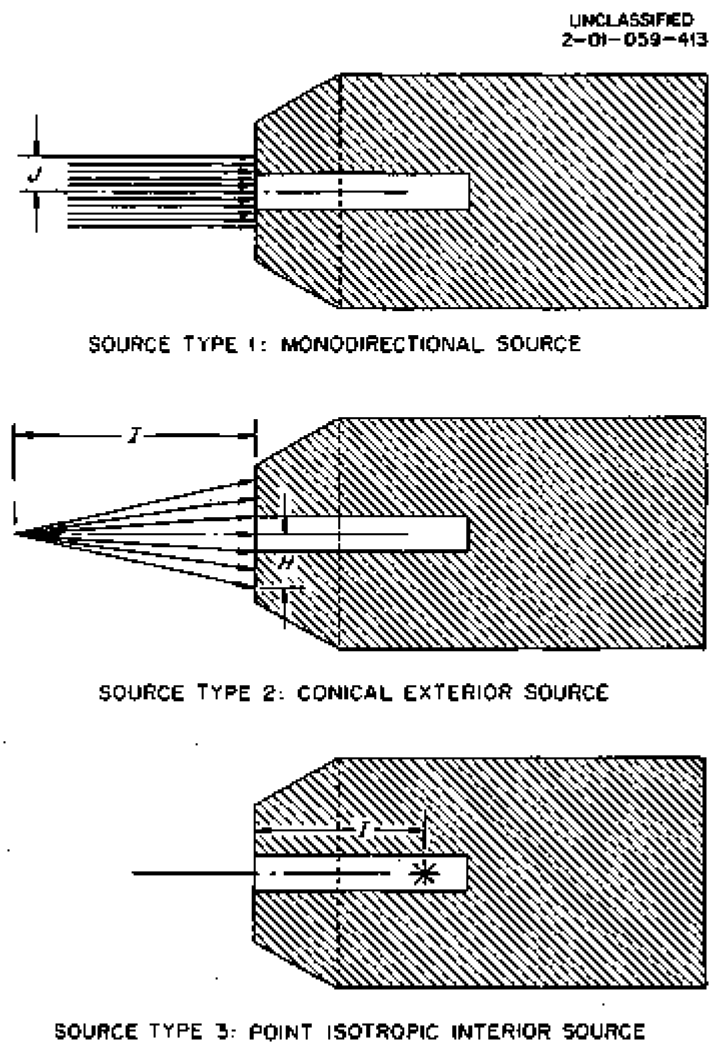

Fig. 2. Assumed Source-Counter Geometries for Calculations of Scintillation Counter Gamma-Ray Response Functions.

SHARE SYMBOLIC CODING FORM

PROBLEM: Sodium Iodide Crystal Input

CODER: R. S. Moran | DATE: March 21, 1960 | PAGE 1 OF 1

LOCATION	OP	ADDRESS, TAG, DECREMENT	COMMENTS	IDENTIFICATION
	DEC	500	N	
	DEC	25	Q	
	DEC	2.	E_o	
	DEC	2	SOURCE	
	DEC	7.62	A	
	DEC	3.81	B	
	DEC	0	C	
	DEC	0	D	
	DEC	0	E	
	DEC	0	F	
	DEC	2.	H	
	DEC	5.	I	
	DEC	0	J	
	DEC	.046	A_b	
	DEC	.0022	B_b	
	DEC	0	KEYWORD	
	DEC	2.5	E_M	
	OCT	343277244615	R	

WCX-2751 (10-57) NRC

Fig. 3

Description of Input Parameters

1. N, Number of Source Photon Histories

The value of this parameter depends to a large extent on the particular problem being calculated. For a particular production problem where the data is to be used for comparison with experiment, a minimum of 1,000 source photons should be used. For slightly better statistical accuracy N can be increased; however, no significant over-all improvement occurs for more than approximately 3,000 source photons. In most cases very good comparisons with experiments have been achieved with 2,000 source photons or less. For problems where it is desired to compare the different pulse-height outputs for various input parameters on a relative basis, fewer source photons can be used with a corresponding decrease in running time (see the section on "Timing").

By referring to the description of the output, one will see that there are several numbers which are calculated from analytical formulas. These numbers, in most cases, are derived from integrals which are solved numerically using a grid system which has the same number of intervals as N. As one would expect, if N is very small the analytical values become very inaccurate. This should be kept in mind when selecting the value of this parameter.

2. Q, Number of Equal Energy-Intervals Between Zero and E_M

This input parameter, the number of equal energy intervals between 0 and E_M, may assume any value from 1 to 600. It should be noted, however, that as the number of intervals increases, the statistics of the pulse-height spectra deteriorate rapidly, requiring disproportionately greater numbers of source-particle histories, concordant with longer running times. However, when Q is relatively large, in order to delineate in better detail any sharp peaks in the pulse-height spectra, it may be found expedient to average pairs, or even larger sets, of entries in the low-energy tail to achieve smoothness in this range.

3. E_0, Source Energy in Mev

This input parameter, the energy of the monoenergetic source photons in Mev, is restricted to the range $0.00511 < E_0 \leq 10.22$ Mev.

4-13.

The source parameter and parameters A-J are described in the sections "Counter Geometry" and "Source Geometry" along with certain restrictions pertaining to these numbers.

14-15. A_b and B_b, Broadening Coefficients

These broadening coefficients enter into the formula for Gaussian broadening of the zero-resolution pulse-height curve which is calculated in these programs. The first step in the computations is to compute the zero-resolution curve in the form of a histogram with interval widths equal to E_M/Q. This histogram is then used to generate the broadened histogram using the relation

$$F(E,E') = \frac{e^{-\frac{1}{2}\left(\frac{E - E'}{\sigma}\right)^2}}{\sigma\sqrt{\pi}} .$$

The function $F(E,E')$ expresses the probability that a pulse recorded at energy E (Mev) on a zero-resolution counter would have been recorded at energy E' (Mev) on a non-zero resolution counter. The factor σ is a function of E and is given by

$$\sigma = A_b \sqrt{E} + B_b E,$$

which demonstrates the dependence of the Gaussian broadening on the broadening coefficients.

The factor σ is related to the total width, W, at half maximum by the relation

$$W = 2\sigma \sqrt{2 \ln 2} = 2.3548\ \sigma;$$

and is related to the resolution, R, by

$$R = \frac{W}{E} = 2.3548 \left[\frac{A_b}{\sqrt{E}} + B_b \right] .$$

The value of each of the constants for a particular counter are best determined by plotting the resolution against $(1/\sqrt{E})$ where E is in Mev units.

The broadening is carried out by assuming the entry in the i^{th} box of the histogram of the unbroadened spectrum to be concentrated at the midpoint of the box at energy E_i. The final entry, F_j, in the j^{th} box of the broadened spectrum having energy limits E_j and E_{j+1} is then calculated using

$$F_j = \sum_i \int_{E_j}^{E_{j+1}} F(E_i, E')\, dE'.$$

16. Keyword

This parameter is self-explanatory, however, it might be pointed out that if secondary effects are expected to be small it is best to run the problem with KEYWORD set equal to 2 so that the secondaries are not calculated at all. This will reduce the running time to a considerable extent.

17. E_M

This input parameter, the value in Mev, of the maximum pulse height reported in all response histograms in the output, serves two purposes. First, when E_M is greater than the source energy, E_0, energy intervals above

E_O appear in the histograms. Although the unbroadened pulse-height spectra can never show contributions to these intervals, the broadened spectra will usually do so. The degree of this "spilling-over" into intervals above E_O is of course dependent upon the magnitudes of the two broadening coefficients. Second, when E_M is set less than E_O, the histograms display energy intervals between zero and E_M only. In this situation, annihilation radiation effects are not included, nor is bremsstrahlung from pair electrons; however, the bremsstrahlung from Compton ejected electrons is included if one specifies all secondaries. As E_M decreases from E_O downward, the smoothness of the low-energy end of the Compton tail may be improved by increasing the number of histories without a proportionate increase in computing time, since a decrease in E_M vitiates an increase in N. It should be noted that, when $E_M < E_O$, the printed value of the photofraction has no meaning, and that the histogram of the broadened photopeak is not printed.

For a crystal parameter study, from which only intrinsic efficiencies are being considered, E_M may be set very low (e.g., 0.00512 Mev), and KEYWORD set to 2 (no secondaries). Then a series of cases may be run comparatively rapidly, since there are no secondary events, while the number of primary collisions is reduced essentially to the number of particles incident on the counter.

18. R, Random Numbers

All three programs contain two major loops. The first is concerned with primary radiation effects, while the other works with the secondaries. Both of the loops use the same chain of random numbers, but separately and independently. When any of the codes is first loaded and the first case started with the parameter R set to zero, both major loops start with the first random number of their identical chains. If it is desired to run a case in which one or both major loops start with some random number other than their first, this may be accomplished under Sense Switch control, as described below.

When Sense Switch 3 is depressed (ON) during program loading or input reading, almost immediately after input has been read, the programs enter very short loops which pass through the chain of random numbers very rapidly (about 1 ms per pass). When Sense Switch 3 is then elevated (OFF) the current random number at that instant becomes the initial random number in the major secondary loop.

The same applies to Sense Switch 4 and the initial random number in the major primary loop. When both Switches 3 and 4 are used, Switch 3 must be raised first, since the loop it controls is entered first.

In general, when running either a single case or a series of cases, it is best to start with both Switches 3 and 4 down (ON). Almost immediately (1.1 ms) following the reading of input, the loop controlled by Switch 3 is entered. Switch 3 should then be lifted. At once the loop controlled by Switch 4 is entered. It should next be lifted, and computation will commence. This procedure insures randomization of initial random numbers in both major loops. Only a few seconds (or even a few tenths of a second) need separate the end of input, the raising of Switch 3, and the raising of Switch 4. For those cases following the first, one need only set R equal to zero and each random number generator will automatically continue in the chain of random numbers from where it stopped on the previous problem.

If, for some reason, it is desired to start with a particular random number which may be displayed on the output of some problem that had been run previously, this can be accomplished by setting (R) equal to this number and turning Sense Switches 3 and 4 off. If R is different from zero both random number generators start with the indicated random number.

If (R) is not equal to zero this parameter will become the first random number in each chain of random numbers regardless of the operation of Sense Switches 3 and 4 as described under "Machine Operating Procedure."

Timing

Computing time, exclusive of input and output, varies directly with N, the number of histories. Tabulated below are sample timings for a 3-1/2 in. by 5-in. CsI crystal, with N = 1000.

	Computing Time (minutes)	
E(Mev)	All Secondaries	No Secondaries
0.662	9.96	5.84
1.368	16.7	6.17
2.754	22.8	6.20

The increase in computing time with energy is due almost entirely to the increase in the number of secondary events. When no secondaries are called for, operation is much faster, with computing time increasing but very slightly with energy. Also, for constant N, larger crystals require longer times.

Crystals with holes and/or conical ends require somewhat longer times, due to more complicated geometrical calculations.

Machine Operating Procedure

1. Place set/sets of input cards behind program deck. Follow with three blank cards.
2. Sense Switch 1 On.
3. (Optional) Sense Switches 3 and 4 On (see description of random numbers).
4. Clear and Load Cards.
5. If Sense Switches 3 and 4 are on, turn off Switch 3 first approximately one to two seconds after computation starts and one to two seconds later turn off Switch 4.
6. Cases run continuously until output is exhausted.

Program Stops

Output Program

All three programs use the NYOUT3 output subroutine, and utilize the on-line printer. There are no programmed stops during the printing of output. Any stops during this time arise from an echo-check error from the on-line printer. Depressing START will cause the line in error to be reprinted, and the program to continue.

Error Stops

All experience to date with the three programs has indicated that any machine stops prior to output, or any "hanging-up" in loops can be attributed to machine error. To restart a case following such a stop, merely run any remaining cards out of the card reader, delete input cards for cases satisfactorily completed, and start over again, as listed under "Machine Operating Procedure."

Should a machine error occur which fails to generate a stop (e.g., a pick-up or drop-out in a stored constant), but which creates obviously anomalous results in the output, the only recourse is to reload the program and rerun the case.

Program Stop Option

Sometimes, while a case is running, it may be desired to know how near it is to completion. This information may be obtained by depressing Sense Switch 2. This causes the 704 to print on-line, as a decimal integer, the number of histories remaining to be computed, and then to stop. To proceed, turn Sense Switch 2 off, and depress START.

Output

Output Number Format

The only number format in the output which may not be familiar is the floating decimal format. These numbers are of the form

$$\pm\, yy \pm xxxx$$

representing the decimal number

$$\pm\, 0.xxxx\; 10^{\pm yy}$$

General Description

All three programs produce output via the on-line printer. Figure 4 displays the output derived from the input shown in Fig. 3. Circled numbers on Fig. 4 refer to numbers below.

1. Initial and final random numbers in octal.
2. The number (decimal integer) of primary-particle collisions before cutoff.
3. Added as a programming aid only.

4. Added as a programming aid only.

5. The fraction (decimal number) of source particles incident on counter; e.g., always unity for source types 1 and 2 if the hole does not extend completely through the crystal and also unity for source type 3 if hole is absent and $0 < I < A$; otherwise, some number less than unity. This number is calculated from an analytic formula and is not a statistical estimate.

6. Counter intrinsic efficiency; a decimal fraction equal to the probability that a source particle will make at least one collision in the crystal. This number is calculated from an analytic formula and is not a statistical estimate.

7. Photofraction + standard deviation. Two decimal fractions, the first of which, the photofraction, is equal to the probability that a particle will be completely absorbed, provided it makes at least one collision in the crystal. The second decimal fraction represents standard deviation of the photofraction. Both of these numbers are statistical estimates.

8. Interval width in Mev. A decimal number equal to E_M/Q.

9. Analytic Zero Energy Value (same units and normalization). The number printed here (in floating decimal) is the zero energy pulse height of the Compton tail as calculated from an analytic formula.

10. Number of intervals. Q as a decimal integer.

11. Response histogram of the Compton tail in units of counts per Mev in ascending order, normalized to a total response of one count. Numbers presented here are all in floating decimal notation. Numbers appear in pairs, five pairs per line, reading horizontally, top to bottom. The total number of pairs printed is equal to the number of intervals chosen (Q), and

thus the last row printed may consist of less than five pairs. The first number of each pair is a statistical estimate of the number of counts per Mev in the appropriate energy interval. The second number is a rough estimate of the standard deviation of the counts in the corresponding energy interval. Because of the roughness of the estimate (sometimes even negative!) the standard deviations should not be given too great a significance. Instead, the smoothness of the plot of the pulse-height spectrum is a better indication of the statistical error.

12. A_b and B_b as decimal numbers.
13. Response histogram of the Compton tail after broadening (same units and normalization). Here the format is the same as in the previous histogram with the standard deviations omitted, but with Gaussian broadening applied to the pulse-height spectrum of the first histogram.
14. A_b and B_b as before.
15. Response histogram of the photopeak after broadening (same units and normalization). The format here is again the same as in the previous histograms. The numbers displayed show the effect of the same Gaussian broadening when applied to the total absorption peak, which, because of the normalization, is here equivalent to the photofraction.
16. Response histogram of the Compton tail without secondaries of broadening (same units and normalization). Again the format is the same. This histogram is the same as the first, with standard deviations omitted, except that here the effects of any secondary radiations are not included.
17. Added as a programming aid only.

RESPONSE OF A SCINTILLATION COUNTER

COMPOSITION SODIUM IODIDE

DENSITY = 3.677 GRAMS PER CUBIC CENTIMETER

SOURCE TYPE CONICAL EXTERIOR

SOURCE ENERGY IN MEV = 2.0000

CRYSTAL DIMENSIONS CENTIMETERS	SOURCE DIMENSIONS CENTIMETERS	
A = 7.6200	H = 2.0000	INITIAL RANDOM NUMBER = 343277244615 (1)
B = 3.8100	I = 5.0000	FINAL RANDOM NUMBER = 307044266315 (1)
C = .0000	J = .0000	PRIMARY COLLISIONS = 3088 (2)
D = .0000		PRIMARY WEIGHT CUTOFFS = 500 (3)
E = .0000		PRIMARY ENERGY CUTOFFS = (4)
F = .0000		

NUMBER OF HISTORIES = 500

RESULTS INCLUDING EFFECTS OF ALL SECONDARY RADIATION

FRACTION OF SOURCE PARTICLES INCIDENT ON COUNTER 1.00000000 (5)
COUNTER INTRINSIC EFFICIENCY .6584 (6)
PHOTO-FRACTION + STANDARD DEVIATION .2877 .011576 (7)

RESPONSE HISTOGRAM OF THE COMPTON TAIL IN UNITS OF COUNTS PER MEV IN ASCENDING ORDER
NORMALIZED TO A TOTAL RESPONSE OF ONE COUNT
INTERVAL WIDTH IN MEV = .100000 (8)

ANALYTIC ZERO ENERGY VALUE (SAME UNITS AND NORMALIZATION) = 2192 (9)

NUMBER OF INTERVALS = 25 (10)

(11)

2132	-1 4452	2891	-1 5646	2071	-1 4533	1927	-1 4066	1632	-1 3825
2903	-1 5345	2272	-1 4608	2573	-1 4422	3014	-1 5213	2883	-1 4470
3398	-1 5396	3654	-1 5187	4357	-1 5478	3915	-1 4844	7567	-1 5190
5933	-1 5430	5806	-1 4640	5278	-1 4561	2725	-1 2886	4533	-1 3468
0000	0000	0000	0000	0000	0000	0000	0000	0000	0000

RESPONSE HISTOGRAM OF THE COMPTON TAIL AFTER BROADENING (SAME UNITS AND NORMALIZATION)

A = .04600000 B = .00220000 (12)

2140	2909	2080	1915 (13)	1742
2763	2353	2598	2942	2979
3368	3737	4173	4704	6548
6204	5693	4831	3637	3060
1024	-2 6472	-4 4690	0000	0000

RESPONSE HISTOGRAM OF THE PHOTO PEAK AFTER BROADENING (SAME UNITS AND NORMALIZATION)

A = .04600000 B = .00220000 (14)

0000	0000	0000	0000	0000
0000	0000	0000	0000	0000
0000	0000	0000	0000	0000 (15)
0000	0000	-2 5818	2099	1 1223
1 1223	2099	-2 5818	0000	0000

RESPONSE HISTOGRAM OF THE COMPTON TAIL WITHOUT SECONDARIES OR BROADENING (SAME UNITS AND NORMALIZATION)

2132	2891	2071	1927	1632
2903	2272	2573	2914	1907
2645	3458	4297	3519	4354 (16)
5338	5786	5503	-1 9489	-4 9779
0000	0000	0000	0000	0000

7 JBOXES HAVE BEEN FILLED

SECCC = 11654 SECEC = SECWC = 16 (17)

Fig. 4.

General Notes

Note on Cesium Iodide Program

The cesium iodide code, in its present state, calculates its secondary bremsstrahlung effects from the sodium iodide bremsstrahlung spectrum. It is planned to compute the necessary cesium iodide spectrum and to incorporate it in the program. Since bremsstrahlung effects become important only at the higher source energies, present errors should be small except perhaps at these higher energies.

Note on Xylene Program

The xylene code includes no secondary bremsstrahlung effects because of the low-Z materials. Errors should be negligible up to moderate energies. Should the xylene code be supplied with KEYWORD = 0 (all secondaries), it will compute the effects of annihilation radiation only, and so report in output.

Pulse-Height Response Functions for Complex Spectra

It is often the case in an experiment that the source may produce a complex spectrum of gamma rays consisting of photons at several different discrete energies. The pulse-height response function for this complex spectrum can be obtained by compounding the response functions for each separate energy of the photons appearing in the spectrum.

To carry out the compounding of the response functions we assume the broadened total absorption peak has been added to the broadened Compton tail. Both of these are separately displayed in the output. In addition, we assume the interval width used in the histograms for each source energy to be identical. If we let $G_i(E_j)$ be the entry in the i^{th} box of the histogram resulting from a monoenergetic source at E_j, then the entry K_i in the i^{th} box of the compounded histogram is given by

$$K_i = \frac{\sum_j F(E_j)Y(E_j)G_i(E_j)}{\sum_j F(E_j)Y(E_j)}$$

where $F(E_j)$ is the fraction of the complex spectra that has energy E_j and $Y(E_j)$ is the intrinsic efficiency recorded on the output for the monoenergetic source at energy E_j.

The resulting histogram after compounding as indicated above will be properly normalized to a total response of one count and will have the same units as the histograms for the monoenergetic sources.

The zero-energy pulse height for the complex spectrum can be obtained by using the same compounding formula given above but by replacing $G_i(E_j)$ by the corresponding analytic zero-energy value given on the output for the monoenergetic source at energy E_j.

The fraction of the source photons from the complex spectrum, z, making at least one collision in the counter is given by

$$z = \sum_j F(E_j)Y(E_j)$$

<u>Auxiliary Broadening Program</u>

It has been noticed, in the process of matching experimental pulse-height spectra with those predicted by the 704 codes, that frequently the matching is good in all respects except half-widths, and concurrently small differences in peak maxima and valley minima. Realizing that these differences might be attributed almost entirely to improper estimates of the broadening coefficients, an auxiliary program was written to demonstrate the effect of different broadening coefficients upon any unbroadened spectrum. This program is described on the following pages.

Input

As with the other 3 main programs, input cards may be conveniently punched and printed on the yellow-edged SAP cards. Displayed in Fig. 5 is a sample input derived from the output shown in Fig. 4, but with sets of different broadening coefficients. As one can observe from Fig. 5, it is only necessary to include the unbroadened spectrum and the constants other than A_b and B_b in the first set of input parameters. These remain unchanged in the machine until another set of parameters including all the constants and unbroadened spectrum data is read into the machine. After the first set of parameters are read in, subsequent sets of broadening constants are used to broaden the particular unbroadened spectrum that is at that time in the machine.

The program accepts unbroadened spectra for all Q up to and including Q = 300. For a given unbroadened spectrum, input consists of

1. The six parameters appearing on the first six lines of Fig. 5. The parameters E_0, Q, E_M/Q, and the photofraction can be obtained from the output shown in Fig. 4. All of these parameters except Q are represented as "decimal fractions" containing a decimal point. Q is a "decimal integer."

2. The unbroadened spectrum under consideration (lines 7 through 11 in Fig. 5) are taken directly from the "counts per Mev" displayed in the first histogram of the output from the main program shown in Fig. 4 followed by a card reading TRA 3,4. These numbers are represented as "decimal fractions" with a decimal point and are conveniently written five to a line with a comma separating the

SHARE SYMBOLIC CODING FORM

PROBLEM: Input for Auxiliary Broadening

CODER: H. S Moran | DATE: March 22, 1960 | PAGE 1 OF 1

LOCATION	OP	ADDRESS, TAG, DECREMENT	COMMENTS	IDENTIFICATION
	DEC	.048	A_b	
	DEC	.0024	B_b	
	DEC	2.	E_o	
	DEC	25	Q	
	DEC	.1	E_M/Q (INTERVAL WIDTH)	
	DEC	.2877	(PHOTO-FRACTION)	
	DEC	.2132, .2891, .2071, .1927, .1632		
	DEC	.2903, .2272, .2573, .3014, .2883		
	DEC	.3398, .3654, .4357, .3915, .7567		
	DEC	.5933, .5806, .5278, .2725, .4533		
	DEC	0,0,0,0,0		23
	TRA	3,4		
	DEC	.050	A_b	
	DEC	.0026	B_b	
	TRA	3,4		
	DEC	.052	A_b	
	DEC	.0028	B_b	
	TRA	3,4		

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Fig. 5

numbers. No spaces are to be included in the set of five numbers on each line. The card with symbol TRA is mandatory except when Q = 300, in which case it must not be included.

3. Additional sets of cards containing the parameters A_b and B_b followed by a card reading TRA 3,4.

4. Repetition of items 1, 2, and 3 above for different cases as desired.

Output

Output is via the on-line printer. Figure 6 displays the output derived from the input of Fig. 5. The broadened spectra presented here have the same format as in the output of the 3 main programs. However, the spectra here include the broadened photo-peak, instead of it being presented separately as in the main programs.

Operating Procedure

1. Place sets/set of input cards behind program deck. Follow with 3 blank cards.
2. Sense Switch 1 On.
3. Clear and Load Cards.
4. Cases run continuously until input is exhausted.

EZERO = 1 2000 WIDTH = 10000000 P(E) = 2877

A = .04800000 B = .00240000

2144	2911	2080	1911	1754
2745	2362	2599	2937	2986
3366	3741	4168	4747	6491
6213	5682	4903	6007	1 1496
1 1301	2426	-2 8695	0000	0000

EZERO = 1 2000 WIDTH = 10000000 P(E) = 2877

A = .05000000 B = .00260000

2148	2911	2079	1907	1767
2728	2370	2601	2932	2999
3365	3745	4167	4781	6440
6219	5672	4924	6264	1 1464
1 1278	2682	-1 1232	0000	0000

EZERO = 1 2000 WIDTH = 10000000 P(E) = 2877

A = .05200000 B = .00280000

2154	2911	2077	1904	1780
2711	2379	2603	2927	3001
3364	3750	4164	4816	6393
6220	5664	4955	6503	1 1432
1 1254	2926	-1 1661	-3 2877	0000

Fig. 6.

Distribution

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