Response Function of a 1-inch Diameter by 6-inch Long ^{3}He Proportional Counter to Neutrons

AUTHOR(S):

NISHINO, Seiji; NAKAMURA, Takashi; HYODO, Tomonori

CITATION:

NISHINO, Seiji ...[et al]. Response Function of a 1-inch Diameter by 6-inch Long ^{3}He Proportional Counter to Neutrons. Memoirs of the Faculty of Engineering, Kyoto University 1973, 35(3): 309-329

ISSUE DATE:

1973-09-29

URL:

http://hdl.handle.net/2433/280923

Response Function of a 1-inch Diameter by 6-inch Long ^{3}He Proportional Counter to Neutrons

By

Seiji NISHINO*, Takashi NAKAMURA* and Tomonori HYODO*

(Received March 31, 1973)

Abstract

The response of a 1-inch diameter by 6-inch long ^{3}He proportional counter, of which the gas filling is 4 atm ^{3}He and 2 atm krypton, to axially incident neutrons has been studied and expressed as a 50 by 50 matrix for an energy range from zero to 5 MeV. Applications of the matrix were examined for the purpose of obtaining response-corrected spectra of neutrons transmitted through a matter.

1. Introduction

Recently a ^{3}He-filled proportional counter has been used as a neutron spectrometer, since it has some advantages for this purpose.[1)-4)] The ^{3}He(n, p)T reaction is suitable for neutron spectroscopy, because its reaction cross section is reasonably large and varies slowly with energy, and the Q-value of the reaction (Q=764 keV) is large enough to separate the pulses due to neutrons from gamma-ray pulses.

There is ambiguity in the pulse height distribution originating from monoenergetic neutrons, excluding the intrinsic Gaussian distribution of pulse-height. The ambiguity is caused by elastic scattering of neutrons by counter gas and wall- and end-effect.

The pulse-height distribution obtained by a ^{3}He counter for monoenergetic neutrons is mainly composed of three parts: ^{3}He(n, p)T reaction peak, the location of whose top is at the sum of energy Q and incident neutron energy E_n, ^{3}He-recoil distribution from 0 to 4 E_n, and wall- and end- effect distribution from 0 to E_n+Q. Contribution of the ^{3}He(n,d)D reaction is negligibly small, because of a high threshold energy (4.3 MeV) and a small cross section.

* Department of Nuclear Engineering

In the practical application, a ^{3}He counter usually indicates a large thermal neutron peak in the pulse height distribution. This is because there is a large amount of background neutrons in a room and the thermal neutron cross section of ^{3}He(n, p)T reaction is very large (5,460 barns).

Some efforts have been made to reduce the complex pulse-height distribution to the neutron spectrum. The risetime discrimination was applied to distinguish between pulses from the ^{3}He(n, p)T and ^{3}He$(n, n)^3$He reactions.[5] A wall-less counter was constructed to eliminate the wall effect.[6] The pulse-height distribution obtained by a ^{3}He counter was mathematically converted to a neutron energy spectrum by using the response function matrix.[3],[4]

In our study, the mathematical conversion method was chosen, because a wall-less counter could not be obtained and the rise-time discrimination decreased the counter efficiency. No response function matrix for a 1-inch diameter by 6-inch long ^{3}He proportional counter, of which the gas filling is 4 atm ^{3}He and 2 atm krypton, has been reported. The response function of a cylindrical ^{3}He-filled proportional counter must be obtained experimentally or by the Monte Carlo simulation, because it cannot be expressed by any exact analytic formula. The counter responses were measured to various monoenergetic neutrons, and the response function matrices for the neutron energy which range from zero to 5 MeV were calculated from interpolation of the measured responses with FACOM 230–60 computer of Kyoto University. In this paper, a table of the response function matrix composed of 50 rows by 50 columns is presented.

2. Experimental

A block diagram of the measuring system is shown in Fig. 1. The ^{3}He counter used is 1-inch in diameter and 6-inch in active length, filled with ^{3}He gas to 4 atm and

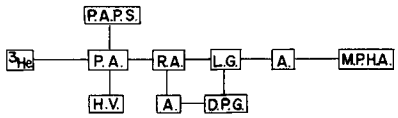

Fig. 1. Block diagram of the measuring system.

^{3}He	:	^{3}He Proportional counter
P.A.	:	Pre-amplifier (ORTEC Model 109 PC)
P.A.P.S.	:	Pre-amplifier power supply
H.V.	:	High voltage power supply
R.A.	:	Research amplifier (ORTEC Model 450)
A.	:	Amplifier (ORTEC Model 485)
L.G.	:	Linear gate and slow coincidence (ORTEC Model 409)
D.P.G.	:	Delayed pulse generator[7]
M.P.H.A.	:	Multichannel pulse height analyzer

krypton gas to 2 atm (Texas Nuclear Co. Model 9341), and is covered with 2.5 mm-thick cadmium in order to reduce the thermal neutron back-ground.

Since the rise-time of pulses from a gas-filled proportional counter is not unique and longer than the clipping time of an ordinary linear amplifier, a special sampling method was applied to eliminate the effect of the spread of rise-time and to improve the energy resolution. In the measuring system, the output pulses from the pre-amplifier are fed to the research amplifier, where pulse shaping (differentiation and integration) and amplifying are performed. The pulse height is sampled at about 10 μsec after the start of the output pulse from the amplifier, by means of the delayed pulse generator[7] and the linear gate and slow coincidence. These pulses are amplified and fed to a multi-channel pulse-height analyzer. The energy resolution of this system is about 7% in F.W.H.M. (=about 50 keV) for thermal neutrons, while it is

Table 1. List of neutron energy used in this experiment.

Reactions	Acceleration Voltage (MV)	Emergent Angle* (degree)	Neutron Energy (MeV)	Accelerators
$T(p, n)^3He$	1.5	90	0.147	Van de Graaf
	1.8	90	0.272	
	1.26	0	0.348	
	1.35	0	0.455	
	1.5	30	0.525	
	1.52	0	0.642	
	2.70	90	0.754	
	1.73	0	0.868	
	1.8	0	0.890	
	1.89	0	1.040	
	2.09	0	1.243	
	2.33	0	1.497	
	2.5	0	1.668	
	2.62	0	1.795	
	2.8	0	1.873	
	2.93	0	2.103	
	3.0	0	2.178	
$D(d. n)^3He$	0.2	120	2.276	Cockcroft-Walton
		90	2.485	
		60	2.718	
		30	2.923	
$T(p. n)^3He$	4.0	0	3.190	Tandem Van de Graaf
	4.5	30	3.332	
	4.5	0	3.694	
	5.0	0	4.197	
	5.3	0	4.499	
	5.5	0	4.700	
	6.0	0	5.202	

* This angle indicates the polar angle between axes of accelerated particle beam and detector.

about 15% or more with the conventional system.

For the purpose of counter response measurement, various monoenergetic neutrons were produced from the $T(p,n)^3He$ and $D(d,n)^3He$ reactions, using a Van de Graaf accelerator and a Cockcroft Walton accelerator at the Department of Nuclear Engineering, Kyoto University, and a Tandem Van de Graaf accelerator at the Department of Physics, Kyoto University. The D-target and T-target used in these experiments were solid targets that deuterium and tritium were adhered to zirconium which had been evaporated onto copper in vacuum. The energy of the produced neutrons was calculated by considering the energy losses of protons and deutrons. The responses were obtained experimentally for 28 mono-energetic neutrons from 0.15 MeV to 5.20 MeV, which are listed in Table 1. The measured responses to 0.89 MeV, 2.48 MeV and 3.69 MeV neutrons are shown in Fig. 2, as examples.

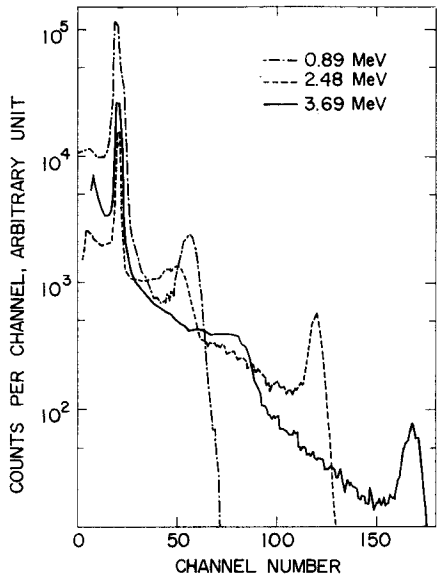

Fig. 2. Measured counter responses for monoenergeric neutrons.

3. The Response Function Matrix

In this paper, two response function matrices are presented. One is the response function matrix for the simple method,[8),9)] the other is that for the inverse matrix method, etc.[3),4),9)] Both of them were interpolated from the measured counter responses and normalized to the parallel beam of neutrons of an unit flux which was incident axially to the counter.

1) Modification of Measured Pulse-Height Distribution

The measured pulse-height distribution was modified to a response function suitable for calculation of the response function matrix by the following procedure.

a) The Fast Neutron Peak

The following two assumptions were made. For the response function of the inverse matrix method etc., the $^3He(n,p)T$ full energy peak for fast neutrons is of a Gaussian distribution, of which the width is proportional to the square root of the sum of E_n and Q, and the total counts are equal to those of the measured fast neutron peak when the mono-energetic neutrons of an unit flux are incident axially to the counter. The pulse-height at the maximum of the Gaussian distribution is proportional to E_n+Q.

For the response function of the simple method, the fast neutron peak is not Gaussian, but is rectangular, of which the width is equal to that of the energy group (ΔE=0.1 MeV), and the channel of the pulse-height corresponds to E_n+Q.

b) The ^{3}He-Recoil Distribution and the Wall- and End-Effect Distribution

We assumed that the pulse-height distributions due to the $^3He(n,n)^3He$ reaction and the wall- and end-effect for fast neutrons are of the same shape as those of the measured response.

c) Estimation and Reduction of Thermal Neutron Contribution

The full energy peak and the wall- and end-effect caused by thermal neutron backgrounds were removed from the measured pulse-height distribution by the procedure shown in Fig. 3.

The response function for the thermal neutrons which are incident parallel to the counter axis was calculated by the method described by Shalev et al.[10] Writing the distribution function for the pulse-height E' as $F(E')$, the following relationship is obtained for the wall- and end-effect and for the full energy peak due to thermal neutrons, respectively. For the full energy peak, it can be expressed as

$$F_p(E')=1-\frac{1}{D'}\{(S_p)_{\text{mixt.}}+(S_t)_{\text{mixt.}}\} \tag{1}$$

when D' is defined as

$$\frac{1}{D'}=\frac{1}{D}+\frac{1}{2L} \tag{2}$$

where D is the diameter of the counter, L the active length of the counter, and $(S_p)_{\text{mixt.}}$ and $(S_t)_{\text{mixt.}}$ the ranges of 573 keV protons and 191 keV tritons in the gas-filling of the counter (4 atm ^{3}He and 2 atm Kr), respectively. For the wall- and end-effect, it can be written as

$$F_W(E')=\frac{1}{D'}\left[\left\{\frac{(S_p)_{\text{mixt.}}}{(S_p)_{Kr}}\right\}\Big/\left(\frac{dE}{dx}\right)_p+\left\{\frac{(S_t)_{\text{mixt.}}}{(S_t)_{Kr}}\right\}\Big/\left(\frac{dE}{dx}\right)_t\right] \tag{3}$$

where $(S_p)_{Kr}$ and $(S_t)_{Kr}$ are the ranges of 573 keV protons and 191 keV tritons in krypton, respectively, and $(dE/dx)_p$ and $(dE/dx)_t$ are the specific ionization of protons and tritons in krypton, respectively. This distribution was smoothed by a Gaussian distribution, with a standard deviation equal to that obtained experimentally with the counter. The calculated response function for the thermal neutrons is shown in Fig. 3A.

Six points at both ends of the calculated thermal neutron peak were fitted to a cubic equation with the least square method, and the total counts of the calculated thermal neutron peak C_t (the hatched part in Fig. 3A) were easily obtained. The subtraction of this thermal neutron peak from the response function gave the counts in the i-th channel of the pulse-height analyzer W_i, which was due to the wall- and end-effect for thermal neutrons, as is shown in Fig. 3A.

At last, six points at both ends of the thermal neutron peak in the measured pulse-height distribution were also fitted to a cubic equation with the least square method, and the total counts of the measured thermal neutron peak C_t' (the hatched part in Fig. 3B) were obtained. The quantity W_iC_t'/C_t was subtracted from the pulse-height distribution, $C_i'(E_n)$, which had already got rid of the full energy peak due to thermal neutrons from the measured pulse-height distribution, as shown in Fig. 3B. Then

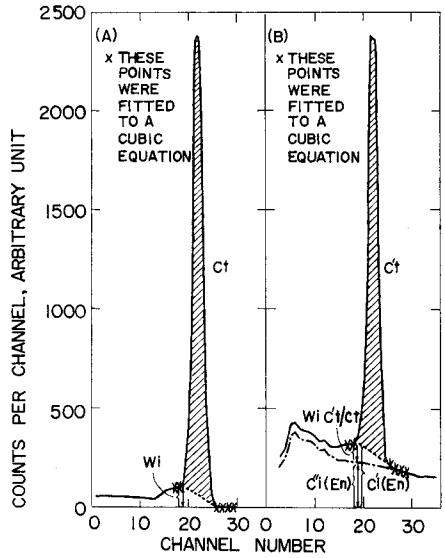

Fig. 3. A schematic illustration of the reduction of thermal neutron contribution.
(A) Calculated response for thermal neutrons.
(B) Thermal neutron peak part of measured counter response.

the resultant pulse-height distribution, $C_i''(E_n)$, after removal of thermal neutron peak is described as follows,

$$C_i''(E_n)=C_i'(E_n)-W_iC_t'/C_t \tag{4}$$

We used this distribution, $C_i''(E_n)$, as the input data for the determination of the response function matrix.

d) The Counter Efficiency

It was assumed that the pulse-height distribution caused by the wall- and end-effect for fast neutrons extends linearly from zero to E_n+Q. The pulse-height distribution of the wall- and end-effect was fitted to a linear equation by the least square method, from the channel which corresponds to $3/4E_n$ (point a in Fig. 4) to that of the lower end of the fast neutron peak (point b) ,and it was extrapolated to zero energy as shown in Fig. 4. The total $^3He(n,p)T$ reaction number for fast neutrons $C_{np}(E_n)$, which is the sum of the total counts of the fast neutron peak and those of the wall- and end-effect (the hatched part in Fig. 4), was obtained. The efficiency $\varepsilon(E_n)$ of a ^3He counter for the $^3He(n,p)T$ reaction, when the parallel beam of neutrons is incident axially to the counter and the effect of krypton is neglected, can be writted as

$$\varepsilon(E_n)=\frac{\pi D^2}{4}\cdot\frac{\Sigma np(E_n)}{\Sigma_t(E_n)}[1-e^{-\Sigma_t(E_n)L}] \tag{5}$$

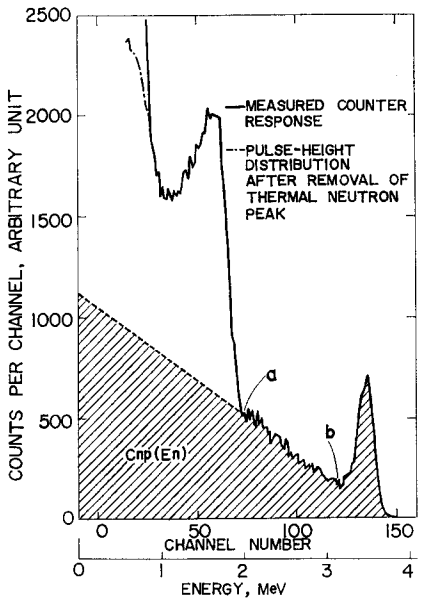

Fig. 4. A schematic illustration of the determination of the total $^3He(n,p)T$ reaction number for fast neutrons Cnp (E_n).

where $\sum_{np}(E_n)$ is the macroscopic $^3He(n,p)T$ reaction cross section and $\sum_t(E_n)$ is the total macroscopic cross section. From $C_{np}(E_n)$ and $\varepsilon(E_n)$, we can easily obtain the response function $R'_i(E_n)$ normalized to neutrons of an unit flux which are incident parallel to the counter axis. It is given by

$$R_i'(E_n)=C_i''(E_n)\varepsilon(E_n)/C_{np}(E_n) \tag{6}$$

2) Interpolation of the Response Function Matrix

The pulse-height higher than that corresponding to Q was adopted as the input data for the response function, since the information to obtain the fast neutron spectrum is sufficient and the effect of gamma-ray back-grounds is almost negligible in this energy range. The response functions calculated from Eq.(6) for 0.89 MeV, 2.48 MeV and 3.69 MeV neutrons are shown in Fig. 5.

From these response functions, two types of response function matrices, as described at the beginning of this chapter, were obtained approximately.[11] This is because the amount of input data was not enough to give an exact calculation, and the response of a ^3He counter varied slowly with the incident neutron energy. The response function matrix element R_{ij} was obtained by using an approximate formula,

$$R_{ij}=\frac{G\left(E_i', E_j-\frac{\Delta E}{2}\right)+4G(E_i', E_j)+G\left(E_i', E_j+\frac{\Delta E}{2}\right)}{6}\cdot\frac{\Delta E}{\Delta E'} \tag{7}$$

where $G(E'_i, E_j)$ is defined as

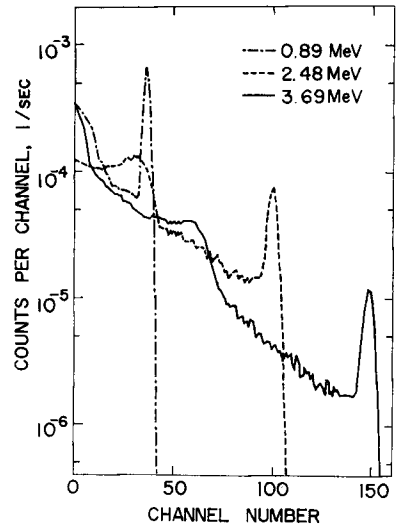

Fig. 5. The response functions calculated from Eq. (6).

Table 2. Response function matrix for the inverse matrix method, etc. E represents the center of the neutron energy interval (MeV), E' the energy corresponding to the center of the pulse-height interval (MeV). To yield the matrix elements, the numbers in the table should be multiplied by 10^{-6}.

E' \ E	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
0.05	17320	1298	337	498	436	388	384	281	346	321
0.15	278	7878	397	506	414	207	361	210	316	224
0.25	0	174	5306	578	353	165	306	164	286	141
0.35	0	0	154	4180	386	202	306	203	268	80
0.45	0	0	0	143	3254	290	313	170	269	54
0.55	0	0	0	0	138	2780	371	137	287	42
0.65	0	0	0	0	0	140	2498	241	261	37
0.75	0	0	0	0	0	0	141	2125	314	36
0.85	0	0	0	0	0	0	0	138	1910	170
0.95	0	0	0	0	0	0	0	0	137	1676
1.05	0	0	0	0	0	0	0	0	0	136
1.15	0	0	0	0	0	0	0	0	0	0
1.25	0	0	0	0	0	0	0	0	0	0
1.35	0	0	0	0	0	0	0	0	0	0
1.45	0	0	0	0	0	0	0	0	0	0
1.55	0	0	0	0	0	0	0	0	0	0
1.65	0	0	0	0	0	0	0	0	0	0
1.75	0	0	0	0	0	0	0	0	0	0
1.85	0	0	0	0	0	0	0	0	0	0
1.95	0	0	0	0	0	0	0	0	0	0
2.05	0	0	0	0	0	0	0	0	0	0
2.15	0	0	0	0	0	0	0	0	0	0
2.25	0	0	0	0	0	0	0	0	0	0
2.35	0	0	0	0	0	0	0	0	0	0
2.45	0	0	0	0	0	0	0	0	0	0
2.55	0	0	0	0	0	0	0	0	0	0
2.65	0	0	0	0	0	0	0	0	0	0
2.75	0	0	0	0	0	0	0	0	0	0
2.85	0	0	0	0	0	0	0	0	0	0
2.95	0	0	0	0	0	0	0	0	0	0
3.05	0	0	0	0	0	0	0	0	0	0
3.15	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	0	0
3.35	0	0	0	0	0	0	0	0	0	0
3.45	0	0	0	0	0	0	0	0	0	0
3.55	0	0	0	0	0	0	0	0	0	0
3.65	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0
3.85	0	0	0	0	0	0	0	0	0	0
3.95	0	0	0	0	0	0	0	0	0	0
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 2. (continued)

E' \ E	1.05	1.15	1.25	1.35	1.45	1.55	1.65	1.75	1.85	1.95
0.05	308	409	836	1294	1457	1621	1869	1244	1072	1076
0.15	325	321	410	707	1152	1440	1532	1232	1025	928
0.25	259	276	276	328	466	851	1211	1194	1171	1022
0.35	218	237	250	256	267	343	617	867	1159	1142
0.45	190	232	241	258	246	240	273	394	764	1013
0.55	182	219	235	248	264	247	232	228	328	520
0.65	182	204	213	235	232	243	241	220	215	234
0.75	179	213	190	212	223	224	236	221	202	194
0.85	182	214	204	203	210	212	213	208	211	197
0.95	275	221	204	210	192	198	199	187	201	200
1.05	1543	305	216	205	202	176	181	179	181	190
1.15	132	1394	303	217	193	183	166	163	168	169
1.25	0	127	1251	295	204	180	164	158	161	155
1.35	0	0	122	1118	276	196	171	153	150	144
1.45	0	0	0	116	996	266	190	153	137	135
1.55	0	0	0	0	110	897	260	157	140	121
1.65	0	0	0	0	0	104	812	229	155	128
1.75	0	0	0	0	0	0	97	720	218	142
1.85	0	0	0	0	0	0	0	90	627	194
1.95	0	0	0	0	0	0	0	0	82	542
2.05	0	0	0	0	0	0	0	0	0	76
2.15	0	0	0	0	0	0	0	0	0	0
2.25	0	0	0	0	0	0	0	0	0	0
2.35	0	0	0	0	0	0	0	0	0	0
2.45	0	0	0	0	0	0	0	0	0	0
2.55	0	0	0	0	0	0	0	0	0	0
2.65	0	0	0	0	0	0	0	0	0	0
2.75	0	0	0	0	0	0	0	0	0	0
2.85	0	0	0	0	0	0	0	0	0	0
2.95	0	0	0	0	0	0	0	0	0	0
3.05	0	0	0	0	0	0	0	0	0	0
3.15	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	0	0
3.35	0	0	0	0	0	0	0	0	0	0
3.45	0	0	0	0	0	0	0	0	0	0
3.55	0	0	0	0	0	0	0	0	0	0
3.65	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0
3.85	0	0	0	0	0	0	0	0	0	0
3.95	0	0	0	0	0	0	0	0	0	0
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 2. (continued)

E / E'	2.05	2.15	2.25	2.35	2.45	2.55	2.65	2.75	2.85	2.95
0.05	795	940	771	482	478	501	509	514	518	588
0.15	808	749	589	457	456	462	458	452	435	455
0.25	876	806	574	444	443	437	415	399	384	392
0.35	901	836	604	442	438	431	407	385	369	365
0.45	919	895	657	482	455	442	414	386	364	362
0.55	626	851	720	526	486	458	433	404	373	360
0.65	301	535	693	567	533	503	456	425	396	379
0.75	188	263	474	589	567	528	486	450	426	405
0.85	192	179	237	377	473	509	506	480	450	429
0.95	187	177	166	189	265	365	450	484	474	459
1.05	189	169	156	151	159	199	281	377	440	470
1.15	164	166	153	145	143	142	164	225	316	405
1.25	154	156	147	139	138	135	130	137	184	256
1.35	142	142	134	128	126	130	125	122	124	149
1.45	120	139	123	115	119	115	119	115	113	112
1.55	120	120	113	105	109	109	106	108	108	105
1.65	114	115	98	89	95	101	100	98	99	98
1.75	114	108	89	78	86	87	90	90	90	90
1.85	112	100	80	70	72	79	78	80	81	82
1.95	163	102	77	63	67	67	70	71	73	74
2.05	474	154	72	62	63	65	63	63	64	68
2.15	70	423	118	54	59	59	58	58	56	60
2.25	0	63	358	96	58	54	51	50	51	50
2.35	0	0	57	305	97	57	49	45	43	46
2.45	0	0	0	51	273	94	50	46	41	40
2.55	0	0	0	0	46	244	83	45	46	38
2.65	0	0	0	0	0	41	213	74	44	43
2.75	0	0	0	0	0	0	37	185	67	43
2.85	0	0	0	0	0	0	0	33	159	61
2.95	0	0	0	0	0	0	0	0	38	136
3.05	0	0	0	0	0	0	0	0	0	33
3.15	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	0	0
3.35	0	0	0	0	0	0	0	0	0	0
3.45	0	0	0	0	0	0	0	0	0	0
3.55	0	0	0	0	0	0	0	0	0	0
3.65	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0
3.85	0	0	0	0	0	0	0	0	0	0
3.95	0	0	0	0	0	0	0	0	0	0
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 2. (continued)

E' \ E	3.05	3.15	3.25	3.35	3.45	3.55	3.65	3.75	3.85	3.95
0.05	813	1285	2780	6684	8810	6744	3812	2589	2707	2995
0.15	585	853	1249	1910	2199	2181	1758	1446	1630	1851
0.25	453	568	764	1050	1202	1148	1044	988	1127	1321
0.35	395	475	631	839	923	903	851	823	931	1065
0.45	393	443	553	750	839	800	737	704	795	896
0.55	393	454	530	654	722	711	662	629	704	791
0.65	392	426	479	558	607	606	592	561	598	654
0.75	403	419	450	510	535	523	510	496	537	570
0.85	427	428	435	467	485	473	461	448	480	506
0.95	455	451	433	452	465	454	445	417	439	470
1.05	498	494	437	422	429	432	434	417	427	433
1.15	478	490	440	403	401	397	403	392	407	414
1.25	362	440	404	363	371	377	395	381	384	385
1.35	202	274	295	289	316	353	388	380	385	380
1.45	125	152	182	203	243	300	372	383	383	375
1.55	107	112	122	142	178	232	313	364	385	374
1.65	99	103	102	113	131	163	234	296	340	357
1.75	88	87	96	100	106	116	146	198	264	307
1.85	83	80	79	91	93	96	103	119	166	220
1.95	79	76	69	74	85	84	89	89	105	136
2.05	71	69	60	58	66	73	74	78	85	91
2.15	65	62	48	42	50	59	66	65	71	79
2.25	58	58	43	34	36	44	55	60	62	65
2.35	50	51	39	30	31	35	44	50	57	59
2.45	49	47	34	25	26	31	40	43	47	50
2.55	40	45	33	22	22	27	35	39	40	42
2.65	36	37	29	20	20	23	32	35	38	36
2.75	38	31	26	18	17	21	28	32	33	34
2.85	40	30	21	18	16	18	24	27	30	30
2.95	56	33	21	16	15	17	21	25	25	27
3.05	119	48	23	15	15	16	19	22	25	23
3.15	29	103	39	16	14	15	18	19	21	23
3.25	0	26	87	32	14	14	17	19	19	19
3.35	0	0	23	76	29	14	16	18	18	18
3.45	0	0	0	22	66	27	16	17	17	17
3.55	0	0	0	0	20	58	26	16	17	16
3.65	0	0	0	0	0	18	51	24	16	16
3.75	0	0	0	0	0	0	16	45	22	15
3.85	0	0	0	0	0	0	0	14	40	20
3.95	0	0	0	0	0	0	0	0	14	36
4.05	0	0	0	0	0	0	0	0	0	13
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 2. (continued)

E' \ E	4.05	4.15	4.25	4.35	4.45	4.55	4.65	4.75	4.85	4.95
0.05	3595	4562	7140	12497	19467	21024	14821	9231	5914	4663
0.15	2198	2747	3722	4921	6072	7382	7172	6252	5345	4830
0.25	1574	1900	2471	3186	3968	4603	4532	4303	4119	4315
0.35	1271	1541	2002	2511	2978	3394	3434	3411	3431	3650
0.45	1051	1248	1623	2093	2558	2919	2893	2830	2849	3071
0.55	916	1073	1361	1745	2165	2517	2534	2490	2513	2719
0.65	754	898	1136	1403	1683	2000	2135	2182	2203	2316
0.75	614	685	844	1077	1327	1550	1605	1654	1760	1936
0.85	550	607	715	861	1030	1219	1299	1347	1397	1510
0.95	507	537	619	716	827	968	1026	1082	1155	1282
1.05	456	501	577	642	699	786	828	883	944	1035
1.15	426	442	505	580	639	678	668	690	747	863
1.25	396	409	455	508	561	599	573	553	566	634
1.35	379	382	416	459	493	523	498	469	461	492
1.45	373	372	391	412	441	472	453	427	410	416
1.55	363	356	373	386	398	414	405	391	374	374
1.65	360	347	352	361	364	372	354	340	338	342
1.75	326	325	338	342	339	346	325	304	288	293
1.85	263	292	311	311	314	319	296	280	270	268
1.95	183	224	257	285	295	300	286	260	239	240
2.05	112	145	187	219	248	280	277	266	249	228
2.15	83	92	115	140	176	225	252	255	243	240
2.25	70	78	81	93	111	149	193	228	242	235
2.35	63	62	71	73	79	102	133	174	207	225
2.45	54	58	61	65	68	73	88	117	162	194
2.55	45	49	54	57	59	65	65	77	99	137
2.65	38	40	45	49	53	54	55	55	65	85
2.75	32	33	36	39	43	49	49	49	46	53
2.85	30	29	28	31	34	40	42	42	45	42
2.95	27	26	26	24	27	32	37	38	35	40
3.05	23	24	23	22	21	25	30	34	37	34
3.15	21	19	21	20	20	20	23	28	32	35
3.25	21	20	18	19	18	19	20	21	25	30
3.35	18	19	17	17	17	17	18	18	22	22
3.45	16	16	17	14	16	16	15	17	17	23
3.55	16	14	14	15	12	15	14	13	16	15
3.65	14	14	12	12	12	11	13	12	12	13
3.75	16	12	12	10	10	11	10	12	11	11
3.85	14	14	11	10	9	9	11	10	12	10
3.95	19	12	13	10	8	9	9	10	9	12
4.05	32	17	11	11	8	8	8	9	9	9
4.15	12	29	15	11	10	8	8	9	9	9
4.25	0	11	26	14	9	8	7	7	9	8
4.35	0	0	9	22	12	8	7	6	7	9
4.45	0	0	0	8	19	10	6	6	6	6
4.55	0	0	0	0	6	16	8	5	5	6
4.65	0	0	0	0	0	5	13	6	4	5
4.75	0	0	0	0	0	0	4	11	5	4
4.85	0	0	0	0	0	0	0	4	9	5
4.95	0	0	0	0	0	0	0	0	3	8

Table 3. Response function matrix for the simple method. E represents the center of the neutron energy interval (MeV), E' the energy corresponding to the center of the pulse-height interval (MeV). To yield the matrix elements, the numbers in the table should be multiplied by 10^{-6}.

E' \ E	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
0.05	17876	1124	337	498	436	388	384	281	346	321
0.15	0	8226	243	506	414	207	361	210	316	224
0.25	0	0	5614	435	353	165	306	164	286	141
0.35	0	0	0	4466	249	202	306	203	268	80
0.45	0	0	0	0	3529	150	313	170	269	54
0.55	0	0	0	0	0	3060	230	137	287	42
0.65	0	0	0	0	0	0	2780	103	261	37
0.75	0	0	0	0	0	0	0	2401	177	36
0.85	0	0	0	0	0	0	0	0	2184	34
0.95	0	0	0	0	0	0	0	0	0	1948
1.05	0	0	0	0	0	0	0	0	0	0
1.15	0	0	0	0	0	0	0	0	0	0
1.25	0	0	0	0	0	0	0	0	0	0
1.35	0	0	0	0	0	0	0	0	0	0
1.45	0	0	0	0	0	0	0	0	0	0
1.55	0	0	0	0	0	0	0	0	0	0
1.65	0	0	0	0	0	0	0	0	0	0
1.75	0	0	0	0	0	0	0	0	0	0
1.85	0	0	0	0	0	0	0	0	0	0
1.95	0	0	0	0	0	0	0	0	0	0
2.05	0	0	0	0	0	0	0	0	0	0
2.15	0	0	0	0	0	0	0	0	0	0
2.25	0	0	0	0	0	0	0	0	0	0
2.35	0	0	0	0	0	0	0	0	0	0
2.45	0	0	0	0	0	0	0	0	0	0
2.55	0	0	0	0	0	0	0	0	0	0
2.65	0	0	0	0	0	0	0	0	0	0
2.75	0	0	0	0	0	0	0	0	0	0
2.85	0	0	0	0	0	0	0	0	0	0
2.95	0	0	0	0	0	0	0	0	0	0
3.05	0	0	0	0	0	0	0	0	0	0
3.15	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	0	0
3.35	0	0	0	0	0	0	0	0	0	0
3.45	0	0	0	0	0	0	0	0	0	0
3.55	0	0	0	0	0	0	0	0	0	0
3.65	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0
3.85	0	0	0	0	0	0	0	0	0	0
3.95	0	0	0	0	0	0	0	0	0	0
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 3. (continued)

E / E′	1.05	1.15	1.25	1.35	1.45	1.55	1.65	1.75	1.85	1.95
0.05	308	409	836	1294	1457	1621	1869	1244	1072	1076
0.15	325	321	410	707	1152	1440	1532	1232	1025	928
0.25	259	276	276	328	466	851	1211	1194	1171	1022
0.35	218	237	250	256	267	343	617	867	1159	1142
0.45	190	232	241	258	246	240	273	394	764	1013
0.55	182	219	235	248	264	247	232	228	328	520
0.65	182	204	213	235	232	243	241	220	215	234
0.75	179	213	190	212	223	224	236	221	202	194
0.85	182	214	204	203	210	212	213	208	211	197
0.95	143	221	204	210	192	198	199	187	201	200
1.05	1807	178	216	205	202	176	181	179	181	190
1.15	0	1649	181	217	193	183	166	163	168	169
1.25	0	0	1494	179	204	180	164	158	161	155
1.35	0	0	0	1351	166	196	171	153	150	144
1.45	0	0	0	0	1216	162	190	153	137	135
1.55	0	0	0	0	0	1105	163	157	140	121
1.65	0	0	0	0	0	0	1006	139	154	128
1.75	0	0	0	0	0	0	0	900	136	141
1.85	0	0	0	0	0	0	0	0	792	119
1.95	0	0	0	0	0	0	0	0	0	693
2.05	0	0	0	0	0	0	0	0	0	0
2.15	0	0	0	0	0	0	0	0	0	0
2.25	0	0	0	0	0	0	0	0	0	0
2.35	0	0	0	0	0	0	0	0	0	0
2.45	0	0	0	0	0	0	0	0	0	0
2.55	0	0	0	0	0	0	0	0	0	0
2.65	0	0	0	0	0	0	0	0	0	0
2.75	0	0	0	0	0	0	0	0	0	0
2.85	0	0	0	0	0	0	0	0	0	0
2.95	0	0	0	0	0	0	0	0	0	0
3.05	0	0	0	0	0	0	0	0	0	0
3.15	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	0	0
3.35	0	0	0	0	0	0	0	0	0	0
3.45	0	0	0	0	0	0	0	0	0	0
3.55	0	0	0	0	0	0	0	0	0	0
3.65	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0
3.85	0	0	0	0	0	0	0	0	0	0
3.95	0	0	0	0	0	0	0	0	0	0
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 3. (continued)

E' \ E	2.05	2.15	2.25	2.35	2.45	2.55	2.65	2.75	2.85	2.95
0.05	795	940	771	482	478	501	509	514	518	588
0.15	808	749	589	457	456	462	458	452	435	455
0.25	876	806	574	444	443	437	415	399	384	392
0.35	901	836	604	442	438	431	407	385	369	365
0.45	919	895	657	482	455	442	414	386	364	362
0.55	626	851	720	526	486	458	433	404	373	360
0.65	301	535	693	567	533	503	456	425	396	379
0.75	188	263	474	589	567	528	486	450	426	405
0.85	192	179	237	377	473	509	506	480	450	429
0.95	187	177	166	189	265	365	450	484	474	459
1.05	189	169	156	151	159	199	281	377	440	470
1.15	164	166	153	145	143	142	164	225	316	405
1.25	154	156	147	139	138	135	130	137	184	256
1.35	142	142	134	128	126	130	125	122	124	149
1.45	120	139	123	115	119	115	119	115	113	112
1.55	120	120	113	105	109	109	106	108	108	105
1.65	114	115	98	89	95	101	100	98	99	98
1.75	114	108	89	78	86	87	90	90	90	90
1.85	112	100	80	70	72	79	78	80	81	82
1.95	93	102	77	63	67	67	70	71	73	74
2.05	615	91	72	62	63	65	63	63	64	68
2.15	0	551	61	54	59	59	58	58	56	60
2.25	0	0	472	45	58	54	51	50	51	50
2.35	0	0	0	408	51	57	49	45	43	46
2.45	0	0	0	0	366	52	49	46	41	40
2.55	0	0	0	0	0	327	46	45	46	38
2.65	0	0	0	0	0	0	288	41	44	43
2.75	0	0	0	0	0	0	0	252	38	43
2.85	0	0	0	0	0	0	0	0	227	35
2.95	0	0	0	0	0	0	0	0	0	195
3.05	0	0	0	0	0	0	0	0	0	0
3.15	0	0	0	0	0	0	0	0	0	0
3.25	0	0	0	0	0	0	0	0	0	0
3.35	0	0	0	0	0	0	0	0	0	0
3.45	0	0	0	0	0	0	0	0	0	0
3.55	0	0	0	0	0	0	0	0	0	0
3.65	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0
3.85	0	0	0	0	0	0	0	0	0	0
3.95	0	0	0	0	0	0	0	0	0	0
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 3. (continued)

E / E'	3.05	3.15	3.25	3.35	3.45	3.55	3.65	3.75	3.85	3.95
0.05	813	1285	2780	6684	8810	6744	3812	2589	2707	2995
0.15	585	853	1249	1910	2199	2181	1758	1446	1630	1851
0.25	453	568	764	1050	1202	1148	1044	988	1127	1321
0.35	395	475	631	839	923	903	851	823	931	1065
0.45	393	443	553	750	839	800	737	704	795	896
0.55	393	454	530	654	722	711	662	629	704	791
0.65	392	426	479	558	607	606	592	561	598	654
0.75	403	419	450	510	535	523	510	496	537	570
0.85	427	428	435	467	485	473	461	448	480	506
0.95	455	451	433	452	465	454	445	417	439	470
1.05	498	494	437	422	429	432	434	417	427	433
1.15	478	490	440	403	401	397	403	492	407	414
1.25	362	440	404	363	371	377	395	381	384	385
1.35	202	274	295	289	316	353	388	380	385	380
1.45	125	152	182	203	243	300	372	383	383	375
1.55	107	112	122	142	178	232	313	364	385	374
1.65	99	103	102	113	131	163	234	296	340	357
1.75	88	87	96	100	106	116	146	198	264	307
1.85	83	80	79	91	93	96	103	119	166	220
1.95	79	76	69	74	85	84	89	89	105	136
2.05	71	69	60	58	66	73	74	78	85	91
2.15	65	62	48	42	50	59	66	65	71	79
2.25	58	58	43	34	36	44	55	60	62	65
2.35	50	51	39	30	31	35	44	50	57	59
2.45	49	47	34	25	26	31	40	43	47	50
2.55	40	45	33	22	22	27	35	39	40	42
2.65	36	37	29	20	20	23	32	35	38	36
2.75	38	31	26	18	17	21	28	32	33	34
2.85	40	30	21	18	16	18	24	27	30	30
2.95	32	33	21	16	15	17	21	25	25	27
3.05	172	28	23	15	15	16	19	22	25	23
3.15	0	150	20	16	14	15	18	19	21	23
3.25	0	0	130	16	14	14	17	19	19	19
3.35	0	0	0	114	14	14	16	18	18	18
3.45	0	0	0	0	100	14	16	17	17	17
3.55	0	0	0	0	0	89	14	16	17	16
3.65	0	0	0	0	0	0	79	14	16	16
3.75	0	0	0	0	0	0	0	70	13	15
3.85	0	0	0	0	0	0	0	0	63	13
3.95	0	0	0	0	0	0	0	0	0	57
4.05	0	0	0	0	0	0	0	0	0	0
4.15	0	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0	0	0	0	0
4.35	0	0	0	0	0	0	0	0	0	0
4.45	0	0	0	0	0	0	0	0	0	0
4.55	0	0	0	0	0	0	0	0	0	0
4.65	0	0	0	0	0	0	0	0	0	0
4.75	0	0	0	0	0	0	0	0	0	0
4.85	0	0	0	0	0	0	0	0	0	0
4.95	0	0	0	0	0	0	0	0	0	0

Table 3. (continued)

E' \ E	4.05	4.15	4.25	4.35	4.45	4.55	4.65	4.75	4.85	4.95
0.05	3595	4562	7140	12497	19467	21024	14821	9231	5914	4663
0.15	2198	2747	3722	4921	6072	7382	7172	6252	5345	4830
0.25	1574	1900	2471	3186	3968	4603	4532	4303	4119	4315
0.35	1271	1541	2002	2511	2978	3394	3434	3411	3431	3650
0.45	1051	1248	1623	2093	2558	2912	2893	2830	2849	3071
0.55	916	1073	1361	1745	2165	2517	2534	2490	2513	2719
0.65	754	898	1136	1403	1683	2000	2135	2182	2203	2316
0.75	614	685	844	1077	1327	1550	1605	1654	1760	1936
0.85	550	607	715	861	1030	1219	1299	1347	1397	1510
0.95	507	537	619	716	827	968	1026	1082	1155	1282
1.05	456	501	577	642	699	786	828	883	944	1035
1.15	426	442	505	580	639	678	668	690	747	863
1.25	396	409	455	508	561	599	573	553	566	634
1.35	379	382	416	459	493	523	498	469	461	492
1.45	373	372	391	412	441	472	453	427	410	416
1.55	363	356	373	386	398	414	405	391	374	374
1.65	360	347	352	361	364	372	354	340	338	342
1.75	326	325	338	342	339	346	325	304	288	293
1.85	263	292	311	311	314	319	296	280	270	268
1.95	183	224	257	285	295	300	286	260	239	240
2.05	112	145	187	219	248	280	277	266	249	228
2.15	83	92	115	140	176	225	252	255	243	240
2.25	70	78	81	93	111	149	193	228	242	235
2.35	63	62	71	73	79	102	133	174	207	225
2.45	54	58	61	65	68	73	88	117	162	194
2.55	45	49	54	57	59	65	65	77	99	137
2.65	38	40	45	49	53	54	55	55	65	85
2.75	32	33	36	39	43	49	49	49	46	53
2.85	30	29	28	31	34	40	42	42	45	42
2.95	27	26	26	24	27	32	37	38	35	40
3.05	23	24	23	22	21	25	30	34	37	34
3.15	21	19	21	20	20	20	23	28	32	35
3.25	21	20	18	19	18	19	20	21	25	30
3.35	18	19	17	17	17	17	18	18	22	22
3.45	16	16	17	14	16	16	15	17	17	23
3.55	16	14	14	15	12	15	14	13	16	15
3.65	14	14	12	12	12	11	13	12	12	13
3.75	16	12	12	10	10	11	10	12	11	11
3.85	13	14	11	10	9	9	11	10	12	10
3.95	12	12	13	10	8	9	9	10	9	12
4.05	52	11	11	11	8	8	8	9	9	9
4.15	0	46	10	10	10	8	8	9	9	9
4.25	0	0	40	93	9	8	7	7	9	8
4.35	0	0	0	50	8	8	7	6	7	9
4.45	0	0	0	0	30	7	6	6	6	6
4.55	0	0	0	0	0	25	5	5	5	6
4.65	0	0	0	0	0	0	20	4	4	5
4.75	0	0	0	0	0	0	0	17	3	4
4.85	0	0	0	0	0	0	0	0	15	3
4.95	0	0	0	0	0	0	0	0	0	13

$$G(E_i', E_j)=\int_{E_i'-\frac{\Delta E'}{2}}^{E_i'+\frac{\Delta E'}{2}} R''(E_i', E_j)dE' \tag{8}$$

where $R''(E'_i, E_j)$ is the response function of the counter. This is obtained by means of the Lagrange interpolation method from the response function $R'_i(E_n)$ in Eq.(6). E'_i and E_j are the pulse-height of i-th interval and the neutron energy of j-th interval, respectively. $\Delta E'$ and ΔE are the intervals of the pulse-height and the energy, respectively.

As a result, the response function matrix, composed of 50 rows by 50 columns, of which the bin width is 0.1 MeV and the energy range from zero to 5 MeV, was obtained. The response function matrix for the simple method and that for the inverse matrix method, etc. are shown in Table 2 and Table 3, respectively.

4. Application of the Response Function Matrix

The response-corrected spectrum (ϕ) obtained by the inverse matrix method is given by

$$(\phi)=[R_I]^{-1}(P) \tag{9}$$

where (P) is the measured pulse-height distribution which has been divided into the pulse-height interval corresponding to the energy interval of 0.1 MeV. [R_I] is the response function matrix for the inverse matrix method etc.

The response-corrected spectrum (ϕ') calculated by the simple method[8),9)] can

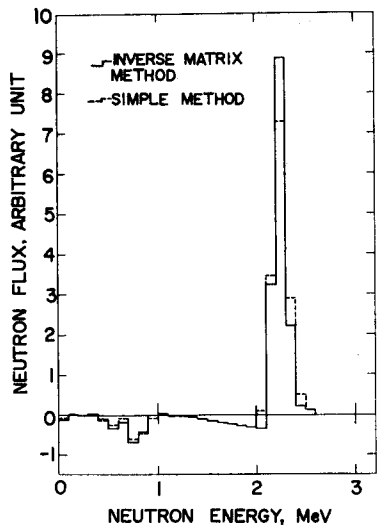

Fig. 6. A response-corrected spectrum for 2.28 MeV monoenergetic neutrons.

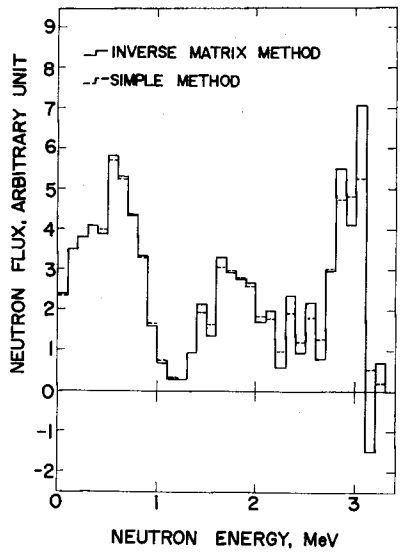

Fig. 7. A response-corrected spectrum of 3 MeV neutrons transmitted through 15 cm-thick iron.

be written as

$$(\phi)=[R_S]^{-1}(P) \qquad (10)$$

where $[R_S]$ is the response function matrix for the simple method.

Fig. 6 shows a typical response-corrected spectrum by means of the above two methods for 2.28 MeV monoenergetic neutrons. A response-corrected spectrum of 3 MeV neutrons transmitted through 15 cm-thick iron is shown in Fig. 7.

Acknowledgments

The authors wish to thank Messers. H. Hirayama, N. Sawano and Y. Urushidani for their co-operation in the experiment on this study. The authors are grateful to Dr. Y. Furuta and Mr. T. Miura for kindly sending their unpublished data. The authors express their gratitude to Dr. T. Hasegawa for his helpful contribution during the experiment with a Tandem Van de Graaf at the Department of Physics, Kyoto University. The authors are also grateful to Miss K. Todo for her helpful assistance with this paper.

References

1) R. Batchelor, R. Aves, and T. H. R. Skyrme: Rev. Sci. Instr. **26**, 1037 (1955).
2) R. Batchelor and G. C. Morrison: Fast Neutron Physics (ed. J. B. Marion and J. L. Fowler,

Intersci. Publ. Inc., New York, 1960) Pt. I, 413.
3) T. Fuse, T. Miura, A. Yamaji and T. Yoshimura: Nucl. Instr. and Methods, **74**, 322 (1969).
4) T. Iijima, T. Mukaiyama and K. Shirakata: J. Nucl. Sci. and Technol, **8**, 192 (1971).
5) A. Sayres and M. Coppola: Rev. Sci. Instr. **35**, 431 (1964).
6) W. K. Brown: Nucl. Instr. and Methods, **26**, 1 (1964).
7) Y. Furuta: private communication.
8) T. Hyodo: This memoirs, **30**, 187 (1968).
9) S. Nishino, Y. Urushidani, T. Nakamura and T. Hyodo: to be published.
10) S. Shalev, Z. Fishelson and J. M. Cuttler: Nucl. Instr. and Methods, **71**, 292 (1969).
11) T. Hyodo and F. Makino: This memoirs, **24**, 291 (1962).