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ORNL-TM-3910
(ENDF-172)

COMPARISON OF (n_{th}, γ) YIELDS FROM THE CURRENT ENDF/B-III DATA WITH PUBLISHED DATA

W. E. Ford III

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OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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ABSTRACT

As a first check of the ENDF/B-III photon production data available as of June, 1972, the number of photons per thermal-neutron capture was calculated for 50 keV gamma-ray energy bins and compared with published data. This comparison was done for ^{1}H(MAT 1148), ^{9}Be(1154), ^{14}N(1133), ^{16}O(1134), ^{23}Na(1156), ^{27}Al(1135), Si(1151), Cl(1149), K(1150), Ca(1152), Fe(1180), and Pb(1136).

I. INTRODUCTION

Due to the infancy of the ENDF/B[a] photon production data[3] and of the processing codes to prepare secondary gamma-ray production cross sections (SGRPXS's), both the data and the codes are subject to valuation. As a first check of the ENDF/B-III photon production data available as of June, 1972, the number of photons per thermal-neutron capture (yields) were calculated from the 12 ENDF/B-III data sets which have photon production data - ^{1}H(MAT 1148), ^{9}Be(1154), ^{14}N(1133), ^{16}O(1134), ^{23}Na(1156), ^{27}Al(1135), Si(1151), Cl(1149), K(1150), Ca(1152), Fe(1180), and Pb(1136). The calculated yields were then compared with published data. The ENDF/B data used in this study were obtained on magnetic tape from the Radiation Shielding Information Center (RSIC).

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a. It is assumed that the reader is familiar with the ENDF/B system. Specifications for the data are given in References 1-3.

LAPHFOR[b], a modified version of LAPHANO[4,c] which is a P_0 multigroup photon-production matrix and source code for ENDF data, was used to calculate the thermal-neutron yields. The description of the nature of the problem solved and the method of solution given in Reference 4 are applicable to LAPHFOR.

II. COMPARISONS OF GAMMA-RAY YIELDS FROM THERMAL-NEUTRON INTERACTIONS

LAPHFOR was used to calculate the thermal (n, γ) yields within 0.5-MeV gamma-ray energy bins. In order to obtain results in terms of number of photons per (n_{th}, γ) reaction, the process of multiplying the yields by the appropriate File 3 neutron cross sections was suppressed in the code. One neutron fine group and one neutron broad group, $1.0 \times 10^{-5} \le E_n \le 0.41399$ eV, were assumed for the calculations. A constant weighting function was used to compute the photon yield in a group, i.e.,

$$Y_g^P(E) = \int_{E_g}^{E_{g+1}} dE_\gamma \; Y^P(E_\gamma \leftarrow E),$$

where E_g and E_{g+1} are the lower and upper energies for group g and $Y^P(E_g \leftarrow E)$ is the number of photons of energy E_g produced by the capture of a neutron of energy E. Calculated yields, expressed in terms of

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b. LAPHFOR will be documented in a subsequent ORNL-TM report.

c. The LAPHANO code is a revision of the LAPH code.[5]

photons/100 captures, are compared with results from the literature in Tables 1-12. The majority of the literature results were taken from a similar comparison in Reference 11.

For additional comparisons, the POPOP4[6] code was used to prepare yields from selected data sets from the POPOP4 library of neutron-induced secondary gamma-ray yield and cross-section data.[7] The results of these calculations are also shown in Tables 1-12.

Following are brief comments about the (n_{th}, γ) data based on the descriptive information in the ENDF/B data and observations from the results in Tables 1-12.

Table 1. Comparison of ^{1}H(MAT 1148) Thermal Capture Yields with Previous Results

	Photons/100 Captures		
Gamma-Ray Energy (MeV)	MAT 1148	Braid[a]	POPOP4 010101[b]
0.5 - 2.0	0.0		0.0
2.0 - 2.5	100.0	97.0	100.0
>2.5	0.0		0.0
%BE[c]	101	97	101

a. Reference 8, p. 385.

b. POPOP4 data set taken from Reference 9, p. 45.

c. ^{1}H binding energy = 2.25 MeV.

Table 2. Comparison of ^{9}BE(MAT 1154) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures				
	MAT 1154	Tarezyk[a]	Groshev[a]	Motz[a]	Rasmussen, Orphan, et al.[b]
0.5 - 0.98	25.5	16.0		"?"	25.4
0.98 - 2.5	0.0	0.0		0.0	0.0
2.5 - 3.0	24.1	17.0		28.0	24.0
3.0 - 3.5	46.3	43.0	54.0	48.0	46.0
3.5 - 5.5	0.0	0.0	0.0	0.0	0.0
5.5 - 6.0	2.0	2.0	0.0	14.0	2.0
6.0 - 6.5	0.0	0.0	0.0	0.0	0.0
6.5 - 7.0	62.9	70.0	73.0	62.0	62.5
>7.0	0.0	0.0	0.0	0.0	0.0
%BE[c]	99	101	100	98	99

a. Reference 8, p. 386.

b. Reference 12, p. 50.

c. ^{9}BE binding energy = 6.815 MeV.

Table 3. Comparison of ^{14}N(MAT 1133) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures					
	MAT 1133	Bartholomew et al.[a]	Groshev, et al.[b]	Motz, et al.[c]	POPOP4 070102[d]	Reactor Handbook[e]
0.5 - 0.98	0.4					
0.98 - 1.0	0.0					
1.0 - 1.5	0.2					
1.5 - 2.0	34.5			37.0	34.1	
2.0 - 2.5	0.1			0.0	0.0	
2.5 - 3.0	7.9			7.5	7.8	
3.0 - 3.5	0.9	6.0	10.0	0.0	0.0	
3.5 - 4.0	27.1	32.0	12.0	32.8	27.1	
4.0 - 4.5	0.0	0.0	20.0	0.0	0.0	54.0
4.5 - 5.0	16.5	16.0	0.0	16.0	16.3	
5.0 - 5.5	51.6	57.0	60.0	53.0	52.6	
5.5 - 6.0	29.0	32.0	30.0	32.0	30.6	
6.0 - 6.5	19.0	17.0	16.0	18.0	18.4	11.0
6.5 - 7.0	0.0	0.0	0.0	0.0	0.0	
7.0 - 7.5	9.9	9.8	6.0	9.0	9.5	
7.5 - 8.0	0.0	0.0	0.0	0.0	0.0	
8.0 - 8.5	4.5	4.0	2.0	4.0	4.2	15.0
8.5 - 9.0	0.1	0.2	0.0	0.0	0.2	
9.0 - 9.5	1.5	1.2	2.0	1.9	1.9	
9.5 - 10.0	0.1	0.0	0.0	0.0	0.0	
10.0 - 10.5	0.0	0.0	0.0	0.0	0.0	12.0
10.5 - 11.0	13.3	11.0	15.0	14.0	13.3	
%BE[f]	100	94	91	103	100	48

a. Reference 8, p. 391. No data for $E_\gamma < 3.267$ MeV.

b. Reference 8, p. 391. No data for $E_\gamma < 3.50$ MeV.

c. Reference 8, p. 391. No data for $E_\gamma < 1.677$ MeV.

d. POPOP4 data from Reference 11, p. 54. No data for $E_\gamma < 1.68$ MeV.

e. Reference 9, p. 45. No data for $E_\gamma < 3.0$ MeV.

f. ^{14}N binding energy = 10.898 MeV.

Table 4. ^{16}O(MAT 1134) Thermal Capture Yields

Gamma-Ray Energy (MeV)	Photons/100 Captures MAT 1134
0.5 - 0.98	100.0
0.98 - 1.0	0.0
1.0 - 1.5	85.4
1.5 - 2.0	0.0
2.0 - 2.5	85.4
2.5 - 3.0	0.0
3.0 - 3.5	14.6
>3.5	0.0
%BE[a]	100

a. ^{16}O binding energy = 4.20 MeV.

Table 5. Comparison of Na(MAT 1156) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures							
	MAT 1156	Maerker & Muckenthaler[a]	Greenwood[b]	Barfield, et al.[c]	Groshev[d]	Rasmussen, Orphan, et al.[e]	POPOP4 110101[f]	Reactor Handbook[g]
0.0 - 0.5	151.1		152.2		74.0			96
0.5 - 0.98	43.8		40.6	8.0	53.3			
0.98 - 1.0	0.0		0.0	0.0	0.0			
1.0 - 1.5	17.0	14.8	15.0	> 1.9	6.5	2.8	14.8	27
1.5 - 2.0	9.0	11.9	9.9	15.1	17.0	17.7	11.9	
2.0 - 2.5	24.8	26.9	21.4	18.7	29.5	34.7	26.9	87
2.5 - 3.0	43.5	47.6	43.6	26.1	36.5	38.0	47.6	
3.0 - 3.5	17.2	14.2	16.2	11.0	14.5	20.8	14.2	
3.5 - 4.0	37.2	34.0	36.4	32.3	42.4	44.5	34.0	70
4.0 - 4.5	2.8	6.4	5.3	4.2	4.7	2.7	6.4	
4.5 - 5.0	0.5	2.7	2.6	1.8	2.1	0.5	2.7	
5.0 - 5.5	1.1	2.2	1.1	1.2	0.8	1.2	2.2	
5.5 - 6.0	6.2	5.9	4.9	4.4	6.0	5.2	5.9	31
6.0 - 6.5	22.1	21.5	20.5	17.8	22.0	22.4	21.5	
>6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%BE[h]	97	89[i]	96	68	100	100	90[i]	110

a. Reference 11, p. 124. No data given for $E_\gamma \leq 1.0$ eV.

b. Reference 8, pp. 402-404.

c. Reference 8, pp. 402-404. No data given for $E_\gamma < 0.783$ MeV.

d. Reference 8, pp. 402-404.

e. Reference 12, p. 20. Spectrum normalized to binding energy including contribution from energies below 1 MeV. Observed %BE = 83.7.

f. POPOP4 data from Reference 11, p. 124. No data given for $E_\gamma \leq 1.0$ eV

g. Reference 9, p. 45.

h. Na binding energy = 6.96 MeV.

i. Does not include ~13% contribution from energies below 1 MeV.

Table 6. Comparison of Al(MAT 1135) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures										
	MAT 1135	Hardell, et al.[a]	Draper et al.[b]	Bartholomew, et al.[c]	Groshev, et al.[d]	Greenwood, et al.[e]	POPOP4 130102[f]	POPOP4 130103[g]	Rasmussen, Orphan, et al.[h]	Maerker & Muckenthaler[i]	Reactor Handbook[j]
0.5 - 0.98	0.3	2.4	2.7			0.0	0.0		6.3	18.6	95
0.98 - 1.0	10.0	1.9	0.0			9.2	0.0	0.0			
1.0 - 1.5	2.5	7.6	7.7			4.9	60.1[k]	12.9[k]			
1.5 - 2.0	7.9	7.0	5.4			4.3	88.8[k]	93.1[k]	7.8	10.4	
2.0 - 2.5	12.8	12.7	13.0		8.1	8.0	50.7	14.3	15.3	13.1	69
2.5 - 3.0	18.6	20.5	10.0	4.6	15.0		31.5	19.9	15.9	20.5	
3.0 - 3.5	13.9	17.3	17.0	13.5	10.9		27.2	16.3	12.8	15.9	62
3.5 - 4.0	16.5	13.6	7.0	6.9	11.8		22.9	14.5	13.2	14.3	
4.0 - 4.5	19.5	16.3	15.0	10.7	13.1		22.9	16.4	17.9	16.1	
4.5 - 5.0	20.3	18.8	16.0	7.6	15.4		22.9	17.8	19.2	17.6	
5.0 - 5.5	9.5	6.5	0.0	3.3	5.5		5.4	7.0	6.6	6.8	19
5.5 - 6.0	1.7	2.3	0.0	2.5	0.8		5.4	3.1	1.5	2.8	
6.0 - 6.5	7.9	6.4	0.0	3.4	5.3		5.4	6.3	5.4	6.0	
6.5 - 7.0	5.3	1.5	0.0	1.5	1.7		5.9	2.3	4.9	2.2	
7.0 - 7.5	3.0	0.1	0.0	0.5	0.0		7.2	1.1	.32	0.7	19
7.5 - 8.0	26.5	33.0	32.0	20.0	24.0	37.0	7.2	34.3	35.5	32.4	
8.0 - 8.5	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.0	0.0	0.0	
>8.5	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	
%BE[ℓ]	99	94	72	52	71	43	122[k]	95[k]	100	95	122

a. Reference 13, pp. 392-400.

b. Reference 8, p. 415.

c. Reference 8, p. 415. No data given for $E_\gamma < 2.84$ MeV.

d. Reference 8, p. 415. No data given for $E_\gamma < 2.12$ MeV.

e. Reference 8, p. 415.

f. POPOP4 data taken from Reference 10, p. 74.

g. POPOP4 data taken from Reference 11, p. 74.

h. Reference 12, p. 21. Spectrum normalized to binding energy includes contribution from $E_\gamma < 0.98$ MeV. Observed %BE = 83.7

i. Reference 11, p. 76.

j. Reference 9, p. 45. Top gamma group is 7-9 MeV.

k. Includes 1.78 MeV activation gamma-ray in ^{28}Si following β-decay of ^{28}Al. 1.78 MeV removed for BE calculation.

ℓ. Al binding energy = 7.724 MeV.

Table 7. Comparison of Si(MAT 1151) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures						
	MAT 1151	Maerker & Muckenthaler[a]	Rasmussen, Orphan, et al.[b]	Kennett[c]	POPOP4 140103[d]	POPOP4 140104[e]	Reactor Handbook[f]
0.5 - 0.98	1.5						100.0
0.98 - 1.0	0.0						
1.0 - 1.5	19.3	15.3	13.3	20.0	15.3	14.1	63.0
1.5 - 2.0	2.7	0.0	0.0	0.0	0.0	7.8	30.0
2.0 - 2.5	25.4	23.0	29.4	24.4	23.0	9.0	
2.5 - 3.0	1.5	4.6	2.5	3.0	4.6	7.6	
3.0 - 3.5	2.5	5.4	4.3	0.0	5.4	32.8	89.0
3.5 - 4.0	73.0	76.6	78.4	70.9	76.6	30.5	
4.0 - 4.5	0.0	0.8	0.2	0.0	0.8	7.2	
4.5 - 5.0	62.4	70.3	63.6	61.0	70.3	72.6	
5.0 - 5.5	4.9	6.4	4.5	4.5	6.4	9.8	11.0
5.5 - 6.0	0.0	0.2	0.0	0.0	0.2	3.0	
6.0 - 6.5	13.8	12.2	12.0	15.2	12.2	6.0	
6.5 - 7.0	1.2	0.8	1.6	1.5	0.8	7.6	
7.0 - 7.5	8.9	9.7	7.0	10.0	9.7	3.9	4.1
7.5 - 8.0	0.1	0.0	0.0	0.0	0.0	2.7	
8.0 - 8.5	2.7	2.2	2.0	2.7	2.2	0.6	0.1
8.5 - 10.5	0.0					1.2	
10.5 - 11.0	0.3					0.1	
%BE[g]	98	104[h]	100[h]	97[h]	104[h]	100[h]	76

a. Reference 11, p. 151. No data given for $E_\gamma \leq 1.0$ MeV.

b. Reference 12, p. 22. No data given for $E_\gamma \leq 1.0$ MeV.

c. Reference 8, p. 420. No data given for $E_\gamma \leq 1.273$ MeV.

d. POPOP4 data taken from Reference 11, p. 151. Bottom energy of POPOP4 calculation was 1.0 MeV.

e. POPOP4 data taken from Reference 10, p. 100. Bottom energy of POPOP4 calculation was 1.0 MeV.

f. Reference 9, p. 45.

g. Si binding energy = 8.92 MeV.

h. Does not include ~1% contribution from energies below 1 MeV.

Table 8. Comparison of Cl(MAT 1149) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures					
	MAT 1149	Maerker & Muckenthaler[a]	Rasmussen, Orphan, et al.[b]	Groshev, et al.[c]	Draper, et al.[d]	Reactor Handbook[e]
0.5 - 0.98	23.9			38.0	71.6	49
0.98 - 1.0	0			0	0	
1.0 - 1.5	13.1	45.2	16.3	28.8	26.0	85
1.5 - 2.0	29.1	45.4	57.2	32.8	35.0	
2.0 - 2.5	3.4	14.3	9.0	3.5	2.5	41
2.5 - 3.0	7.2	19.3	21.1	12.1	14.5	
3.0 - 3.5	1.3	12.3	12.5	9.0	7.3	
3.5 - 4.0	0.8	9.1	8.4	6.2	2.0	47
4.0 - 4.5	0.5	6.5	4.9	3.9	5.0	
4.5 - 5.0	4.7	9.0	8.8	7.5	9.4	
5.0 - 5.5	1.3	3.4	2.2	1.2	1.2	
5.5 - 6.0	7.9	11.7	11.2	10.0	9.8	
6.0 - 6.5	25.2	26.2	22.0	26.4	21.0	55
6.5 - 7.0	15.2	18.3	15.7	16.3	15.7	
7.0 - 7.5	18.6	12.4	11.6	12.7	9.9	
7.5 - 8.0	0	10.0	8.7	8.2	8.4	24
8.0 - 8.5	0	0	0	0	0	
8.5 - 9.0	2.5	3.2	3.0	3.1	2.3	
%BE[f]	70	108[g]	100	92	89	113

a. Reference 11, p. 132. No data given for $E_\gamma \leq 1.0$ MeV.

b. Reference 12, p. 24. No data given for $E_\gamma \leq 1.0$ MeV. Spectrum normalized to binding energy, including contribution from energies below 1 MeV. Observed %BE = 77.0.

c. Reference 8, pp. 434-436.

d. Reference 8, pp. 435-437.

e. Reference 9, p. 45.

f. Cl binding energy = 8.57 MeV.

g. Does not include ~3% contribution from energies below 1 MeV.

Table 9. Comparison of K(MAT 1150) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures						
	MAT 1150	Maerker & Muckenthaler[a]	Rasmussen, Orphan, et al.[b]	Groshev, et al.[c]	Kennett, et al.[d]	Rudolph et al.[e]	Reactor Handbook[f]
0.5 - 0.98	34.0			31.0			100.0
0.98 - 1.0	7.0			0.0			
1.0 - 1.5	4.0	35.0	20.4	11.0			81.0
1.5 - 2.0	33.0	25.6	26.2	28.0			
2.0 - 2.5	21.0	37.2	39.9	24.0			57.0
2.5 - 3.0	19.5	23.5	19.3	12.0			
3.0 - 3.5	17.2	16.7	15.8	8.5			
3.5 - 4.0	15.0	23.2	22.7	17.0			106.0
4.0 - 4.5	19.8	20.2	20.7	9.0	13.3	6.5	
4.5 - 5.0	3.4	7.7	5.5	3.5	5.2	1.9	
5.0 - 5.5	13.7	16.2	19.5	13.4	14.7	13.7	
5.5 - 6.0	16.3	17.3	17.9	16.0	17.0	16.3	37.0
6.0 - 6.5	0.0	0.95	0.4	0.0	0.0	0.0	
6.5 - 7.0	2.4	2.15	3.1	1.6	2.8	2.4	
7.0 - 7.5	0.3	0.45	0.0	0.2	0.0	0.0	
7.5 - 8.0	6.1	5.65	6.1	4.4	7.1	6.1	4.7
8.0 - 8.5	0.1						
8.5 - 9.0	0.0						
9.0 - 9.5	0.8						
%BE[g]	83	96[h]	100	67	42	34	128

a. Reference 11, p. 115. No data given for $E_\gamma \le 1.0$ MeV.

b. Reference 12, p. 25. No data given for $E_\gamma \le 1.0$ MeV. Spectrum normalized to binding energy which included contribution from energies below 1 MeV. Observed %BE = 74.4.

c. Reference 8, pp. 444-445.

d. Reference 8, p. 444. No data given for $E_\gamma < 3.913$ MeV.

e. Reference 8, p. 444. No data given for $E_\gamma < 4.137$ MeV.

f Reference 9, p. 45.

g. K binding energy = 7.80 MeV.

h. Binding energy does not include ~4% contribution from energies below 1 MeV.

Table 10. Comparison of Ca(MAT 1152) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures							
	MAT 1152	Maerker & Muckenthaler[a]	Rasmussen, Orphan, et al.[b]	Gruppelaar, et al.[c]	Bartholomew, et al.[d]	POPOP4 200101[e]	POPOP4 200102[f]	Reactor Handbook[g]
0.5 - 0.98	13.8			16.8		0.0	0.0	} 14.0
0.98 - 1.0	0.0			0.0		0.0	0.0	
1.0 - 1.5	5.6	20.9	4.9	7.5		84.0	20.9	} 191.0
1.5 - 2.0	96.7	79.6	88.6	83.0		135.8	79.6	
2.0 - 2.5	22.6	41.5	41.9	29.5		73.8	41.5	} 77.0
2.5 - 3.0	8.9	14.3	10.0	8.6		12.6	14.3	
3.0 - 3.5	1.2	7.9	3.2	1.7		3.4	7.9	} 85.0
3.5 - 4.0	10.9	13.5	14.0	9.6	10.0	15.2	13.5	
4.0 - 4.5	19.5	19.4	15.9	15.7	18.0	17.2	19.4	
4.5 - 5.0	6.2	6.6	7.1	6.0	9.0	7.8	6.6	
5.0 - 5.5	0.3	2.5	3.0	0.7	0.0	3.2	2.5	} 64.0
5.5 - 6.0	8.3	12.1	9.6	9.7	13.0	10.4	12.1	
6.0 - 6.5	51.7	40.0	42.0	40.2	40.0	45.6	40.0	
6.5 - 7.0	0.0				0.0	2.0	0.0	} 1.8
7.0 - 7.5	0.0				0.6	2.3	0.0	
>7.5	0.0				0.4	0.0	0.0	
%BE[h]	95	100	100	95	59	133	100	147

a. Reference 11, p. 107. Bottom energy of $1.0 < E_\gamma \leq 1.5$ MeV group is 1.06 MeV. % binding energy does not include ~2% contribution from energies below 1.06 MeV.

b. Reference 12, p. 26. Spectrum is normalized to binding energy which includes contribution from energies below 1.06 MeV. Observed %BE = 72.2.

c. Reference 8, p. 452.

d. Reference 8, p. 450. No data given for $E_\gamma < 3.62$ MeV.

e. POPOP4 data from Rasmussen, et al.'s data in Reference 8, p. 451.

f. POPOP4 data from Reference 11, p. 107.

g. Reference 9, p. 45.

h. Ca binding energy = 8.36 MeV.

Table 11. Comparison of Fe(MAT 1180) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures								
	MAT 1180	Maerker & Muckenthaler[a]	Rasmussen, Orphan, et al.[b]	Groshev, et al.[c]	POPOP4 260101[d]	POPOP4 260104[e]	POPOP4 260105[f]	POPOP4 260110[g]	Reactor Handbook[h]
0.5 - 0.98	3.8				0.0	0.0	0.0	0.0	75
0.98 - 1.0	0.5				0.0	0.0	0.0	0.0	
1.0 - 1.5	7.2	5.0	7.2	4.0	6.5	27.0	5.0	7.0	60.0
1.5 - 2.0	13.9	15.0	17.5	21.0	25.2	27.0	15.0	14.7	
2.0 - 2.5	6.4	3.9	4.2	2.0	2.0	15.7	3.9	6.1	27.0
2.5 - 3.0	7.1	6.0	5.3	5.7	5.7	12.9	6.0	4.3	
3.0 - 3.5	11.8	9.2	6.9	11.8	11.8	8.6	9.2	11.2	23.0
3.5 - 4.0	7.7	3.5	3.1	2.3	2.3	6.8	3.5	3.2	
4.0 - 4.5	10.5	7.2	7.9	6.0	6.0	6.8	7.2	9.1	
4.5 - 5.0	2.4	3.3	3.3	3.2	3.2	6.8	3.3	4.4	
5.0 - 5.5	1.4	1.0	1.2	0.6	0.6	6.6	1.0	1.2	25.0
5.5 - 6.0	5.8	9.9	10.7	8.7	3.7	6.4	9.9	9.3	
6.0 - 6.5	9.5	10.1	9.7	9.3	9.3	6.4	10.3	9.3	
6.5 - 7.0	0.3	0.5	0.4	0.2	0.2	8.3	0.3	0.2	
7.0 - 7.5	4.9	5.5	5.4	5.3	5.3	11.5	5.5	4.8	38.0
7.5 - 8.0	50.5	50.6	53.5	43.0	43.0	11.5	50.6	49.9	
8.0 - 9.0	0.9	0.8	0.8	0.8	0.8	11.3	0.8	0.8	
>9.0	5.2	3.3	4.3	3.3	3.3	1.3	3.3	4.3	2.1
%BE[i]	100	95	100	89	87	91	96	99	100

a. Reference 11, p. 68. No data given for $E_\gamma < 1.15$ MeV.

b. Reference 12, p. 28. Spectrum is normalized to binding energy which includes contribution from energies below 1 MeV. Observed %BE = 92.7. No data given for $E_\gamma < 1.15$ MeV.

c. Reference 8, pp. 502-503. No data given for $E_\gamma < 1.264$ MeV.

d. POPOP4 data from Groshev's and Greenwood's data in Reference 8, pp. 502-503.

e. Reference 10, p. 129.

f. POPOP4 data from Reference 11, p. 68.

g. Reference 14.

h. Reference 9, p. 45.

i. Fe binding energy = 7.79 MeV.

Table 12. Comparison of Pb(MAT 1136) Thermal Capture Yields with Previous Results

Gamma-Ray Energy (MeV)	Photons/100 Captures			
	MAT 1136	Rasmussen, Orphan, et al.[a]	POPOP4 820103[b]	Reactor Handbook[c]
1.0 - 1.5	0.0		1.1	
1.5 - 2.0	0.0		1.3	
2.0 - 2.5	0.0		0.9	
2.5 - 3.0	0.0		3.0	
3.0 - 3.5	0.0		2.1	
3.5 - 4.0	0.0		0.1	
4.0 - 4.5	0.0		2.2	
4.5 - 5.0	0.0		3.9	
5.0 - 5.5	0.0		0.8	
5.5 - 6.0	0.0		1.8	
6.0 - 6.5	0.0		0.5	7.0
6.5 - 7.0	5.1	5.0	4.6	
7.0 - 7.5	94.9	94.1	85.7	93.0
7.5 - 9.0	0.0		0.0	
%BE[d]	99	98	99	108

a. Reference 12, p. 663.

b. Reference 15.

c. Reactor Handbook, p. 46.

d. Pb binding energy = 7.27 MeV.

Hydrogen

MAT 1148 is an evaluation by L. Stewart, R. J. Labauve, and P. G. Young, dated October, 1970. The gamma-ray multiplicity is given as unity at all neutron energies. Sixteen energy bands are given for the (n, γ), MT = 102, data in the energy range 0.2 $E_n \leq 20$ MeV. The average gamma-ray energy, $\overline{E}_\gamma$, is determined from the average neutron energy, $\overline{E}_n$, in an energy band by

$$\overline{E}_\gamma = 2.225 \times 10^6 + \frac{\overline{E}_n}{2.0} .$$

Recoil energy is ignored.

For the thermal capture reaction, $E_\gamma = 2.225$ MeV. Thus, Table 1 shows that there are 100 photons/100 captures in the $2.0 < E_\gamma \leq 2.5$ MeV gamma-ray group as calculated by LAPHFOR. The per cent binding energy (%BE) shown in Table 1 for MAT 1148 was determined by

$$\%BE = \sum_i \frac{(\text{No. photons/capture})_i \times (\overline{E}_\gamma)_i}{\text{Given BE}} \times 100$$

where $\overline{E}_\gamma$ is the average energy of group i.

Beryllium-9

MAT 1154 is an evaluation by R. J. Howerton and S. T. Perkins of the Lawrence Livermore Laboratory, dated December, 1971. The evaluaters used the data of Reference 12 which gave the thermal (n, γ) cross sections for 0.8535, 2.59, 3.368, 3.444, 5.958, and 6.81 MeV. Therefore, the photon production data are given in File 13. Thermal (n, γ) yield data were obtained from the ENDF/B data by using LAPHFOR to calculate the multigroup SGRPXS's and then dividing the cross sections by the thermal capture cross section ($\sigma_{th}(n, \gamma) = 9.5$ mb*).

Table 2 shows very good agreement between the MAT 1154 yields and the yields taken directly from Reference 12.

^{14}N

MAT 1133, dated January, 1971, is an evaluation by P. G. Young and D. G. Foster, Jr. of LASL. The capture data are given in terms of multiplicities in File 12. For $0.0 \le E_n \le 0.25$ MeV, the thermal spectrum is based on measurements of References 17-20. For $0.25 < E_n \le 1.0$ MeV, the "thermal spectrum is phased into a single ground-state transition."

The comparisons in Table 3 show that except for minor exceptions MAT 1133 data are in very good agreement with the published data. The POPOP4 data set is based on Maerker and Muckenthaler's averaging of Motz's data with another set of nitrogen yields. Hence, three sets of data shown in Table 3 are based on Motz's work.

^{16}O

MAT 1134, dated August, 1971, is another evaluation by P. G. Young and D. G. Foster. The photon multiplicities given in File 12 are based on "private communication" from Reference 21.

No capture data were found in the literature suitable for comparison with MAT 1134 data.

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* Reference 16, p. 4-0-1.

Na

The neutron cross sections in MAT 1156 were evaluated by Paik and Pitterle of WARD and the photon production cross sections were evaluated by Perey of ORNL. Descriptive information given for the MAT 1156 MT = 102 data is as follows:

"The low energy neutron capture in sodium is dominated by the 2.85-keV resonance. There are no data which indicate that the gamma-ray spectrum observed at thermal should not apply to the 2.85-keV resonance. We have therefore used a single gamma-ray spectrum to describe capture over the complete energy range. The multiplicities were arrived at from a decay scheme based on the very consistent thermal capture data of References 8 and 22."

From Table 5 we see that except for $4.0 < E_\gamma \leq 5.0$ MeV the MAT 1156 (n_{th}, γ) yields are in good agreement with Maerker and Muckenthaler's and with Greenwood's yields. For the energy range of $4.0 < E_\gamma \leq 5.0$ MeV, MAT 1156 data are in agreement with the data of Rasmussen, Orphan, et al.

^{27}Al

MAT 1135, dated April, 1971, was evaluated by D. G. Foster, Jr. and P. G. Young. The (n, γ) energies are from Reference 12 and the intensities are from Bartholomew's data in Reference 8. Foster and Young note that Bartholomew's Al decay scheme does not account for the intensities of low-energy transitions and that lines in the Reference 12 data below 1 MeV are spurious and have been dropped from the MAT 1135 data.

The ground-state transition at 7.7 MeV appears to be ~30% too low when compared with the majority of other data in Table 6. Note also that the 1.78-MeV activation gamma ray from the β-decay of ^{28}Al ($t_{1/2}$ = 2.30 min.) is not represented in MAT 1135.

Si

MAT 1151 is based on neutron and gamma-ray production cross section data from Reference 23. The data from Reference 23 were subsequently revised by P. G. Young (LASL, 6/2/71), by R. Q. Wright (ORNL, 2/5/71), and by R. R. Kinsey (BNL, 1/15/72). The File 12, MT = 102 data for 1.0×10^{-5}eV ≤ E_n < 50 keV was taken from References 24, 25, and 26.

Cl

MAT 1149, dated February, 1967, is an evaluation by M. S. Allen and M. K. Drake as reported in Reference 27. The (n, γ) yields "were obtained by analyzing measurements of thermal neutron capture."

K

MAT 1150, dated 1967, is an evaluation by M. K. Drake which is based on work reported in Reference 27. The gamma rays from thermal-neutron capture were obtained from data summarized in References 28, 29, and 30.

Ca

MAT 1152 is the interim result of an incomplete series of reevaluations of the Ca cross sections of M. K. Drake, et al., reported in Reference 27. The Drake evaluation was originally translated into ENDF format by D. J. Dudziak of LASL (July, 1969). These data were then revised by P. G. Young of LASL and assigned MAT number 540. F. Perey then revised MAT 540 for $E_n \leq 9.0$ MeV and combined the revised data with the MAT 540 data for $E_n > 9.0$ MeV to give MAT 1152. Perey is continuing the revision of the MAT 540 data above 9.0 MeV. The source of the photon production data was not listed in the descriptive data.

Fe

MAT 1180, last modified in January, 1972, is an evaluation by Penny, Kenney, Wright, Perey, and Fu and reported in Reference 31. The descriptive information for the File 12, MT 102 data is as follows:

"These gamma rays are representative of neutron energy ranges. The last range strictly extends only to 1 McV but is assumed to extend to 15 MeV. The gamma rays are treated as a continuum distribution."

References 32 through 42 are cited as the source of the MT 102 data.

Pb

MAT 1136, latest revision dated January, 1972, is an evaluation by C. Y. Fu and F. G. Perey of ORNL. The multiplicities of gamma rays produced by neutron reactions are combined from contributions from radiative capture, inelastic scattering, (n, 2n'), and (n, 3n') reactions in the MT 3 section of ENDF data. References are not given for the literature source of the data.

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