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ENDF Formats and Procedures for Photon Production and Interaction Data

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ENDF FORMATS AND PROCEDURES FOR PHOTON PRODUCTION AND INTERACTION DATA

Compiled and edited by

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ABSTRACT

The ENDF formats for storage of photon production and photon interaction data are presented as are procedures for entering these data. Formats for photon production data are a revision of those given in Los Alamos Scientific Laboratory Report LA-3801 (ENDF-111) and supersede the earlier format. Sample sets of photon production data are given in the new format. Procedures are given to minimize ambiguities in entering data in the format and to facilitate writing processing codes to use the data. Classes of data for which formats and procedures are specified include photon production cross sections, multiplicities, transition probability arrays, angular distributions, energy spectra, and energy-angle distributions; also, photon interaction cross sections, secondary angular, energy, energy-angle distributions, and atomic form factors are included.

1. INTRODUCTION

Since the genesis of a Shielding Subcommittee of the Cross-Section Evaluation Working Group (CSEWG) in early 1967, the question of formats for storing photon production and photon interaction data has received considerable attention. A format emphasizing multiplicities (yields) and transition probabilities was adopted and documented in detail.[1] However, in early 1969, the Subcommittee decided to recommend a revised format, isomorphic to the existing one, but placing photon production cross sections, multiplicities, and energy distributions in separate files. This report, the second of two volumes, documents the latest accepted format and provides recommended procedures for placing data in the format and for writing codes to process the data. General features and descriptions of the data formats and record types are given in Chaps. 1 through 5 of the companion (BNL 50274, ENDF-102, Revised, Vol. I) to this report. A knowledge of those chapters is presumed for this volume.

The format for photon interaction data remains essentially unchanged, but it is included in this report for both completeness and clarification of the procedures.

The arrangement of this report is similar to that proposed to the CSEWG for the revision of the ENDF neutron data format specifications.[2] Sections 2 and 3 contain specifications for photon production and photon interaction files, respectively. Discussion of each ENDF photon data file is subdivided into two subsections, one for formats and one for procedures. A glossary of symbols and variable names is provided in Appendix A for convenient reference. The variable names are, in most cases, consistent with the corresponding FORTRAN variables in the photon production data processing codes.[3]

The same units as specified by Honeck[2] are used where appropriate, and the set is expanded as follows:

energy	- eV
angle	- dimensionless cosine
cross section	- barns
mass	- units of the neutron mass
yield	- photons

In any file, sections are always arranged in increasing order of MT number. Structures of sections are given below in the form of the binary records. Unused fields are now denoted by "b" (blank) in the format prescriptions, as opposed to the integer and floating-point zeros (0 or 0.0) used previously for ENDF/B. The

BCD card-image formats for each section are given in Appendix B, often with a sample set of data in the format (see Vol. I, Sec. 5.3 for a detailed description of the card-image formats).

2. PHOTON PRODUCTION

Photon production data are divided into five distinct files.

File	Description
12	Multiplicities and transition probability arrays
13	Photon production cross sections
14	Photon angular distributions
15	Continuous photon energy spectra
16	Photon energy-angle distributions

With the exception of File 12, all of the files are closely analogous to the corresponding neutron data files with the same number (modulo 10). The purpose of File 12 is to provide additional methods for representing the energy dependence of photon production cross sections. The parallel structure between neutron and photon data files facilitates the use of existing neutron data retrieval routines[4] for the photon data. Record types are identical to those used for neutron data (e.g., HEAD, CONT, LIST, TAB1, TAB2). The allowed reaction type (MT) numbers are the same as those assigned for Files 1 through 7, and they continue to maintain as closely as possible the parallelism with the United Kingdom Atomic Energy Authority data file.[5] However, they may have somewhat different meanings for photon production that require additional explanation in some cases, as follows

(1) MT = 3 should be used in Files 12 through 16 to represent composite $(n,x\gamma)$ cross sections, that is, photon production cross sections from more than one reaction type that have been lumped together.

(2) There is no apparent reason to have redundant or derived data for the photon production files as is the case for the neutron files, i.e., MT = 3, 4, etc. Therefore, to avoid confusion, the join of all sections of Files 12 and 13 should represent the photon production, with each section being disjoint with all others.

(3) Let us consider how one might represent the inelastic gamma-ray production data. The differential cross section for producing a gamma ray of energy E_γ resulting from the excitation of the m_oth level of the residual nucleus and the subsequent transition between two definite levels $(j \rightarrow i)$, including the effects of cascading from the $m_o - j$ levels higher than j, is

$$\frac{d\sigma}{dE_\gamma}(E_\gamma,E,m_o,i,j) = \delta(E_\gamma - \varepsilon_j + \varepsilon_i)A_{j,i}\ \sigma_{m_o}(E) \prod_{\ell=1}^{m_o-j} \sum_{m_\ell=j}^{m_{\ell-1}-1} TP_{m_{\ell-1},m_\ell} \ , \qquad (1)$$

where

$\sigma_{m_o}(E) \equiv$ neutron cross sections for exciting the m_oth level with neutron energy E,

$\delta(E_\gamma - \varepsilon_j + \varepsilon_i) \equiv$ delta function with ε_j, ε_i being energy levels of the residual nucleus,

$TP_{k,\ell} \equiv$ probability of the residual nucleus having a transition to the ℓth level given that it was initially in the excited state corresponding to the kth level, and

$A_{k,\ell} \equiv$ probability of a gamma ray of energy $E_\gamma = \varepsilon_k - \varepsilon_\ell$ being emitted as a result of the residual nucleus having a transition from the kth to the ℓth level.

We are at once beset with no clear choice of ENDF representation in terms of section number. The data may naturally be identified both with the m_oth level and the jth level. To avoid this problem, we can sum Eq. (1) over m_o

$$\frac{d\sigma_1}{dE_\gamma}(E_\gamma,E,i,j) = \sum_{m_o=j}^{N} \frac{d\sigma}{dE_\gamma}(E_\gamma,E,m_o,i,j) \quad , \tag{2}$$

where N is the highest level that can be excited by a neutron of incident energy E (i.e., $\varepsilon_N \leq \frac{AWR}{AWR + 1} E$). This gives us a <u>de-excitation</u> cross section that has the characteristic of singling out a definite gamma-ray transition and has the advantage when experimental data are to be represented. The de-excitation cross section is identified with the jth level. Alternatively, we can sum Eq. (1) over i and j

$$\frac{d\sigma_2}{dE_\gamma}(E_\gamma,E,m_o) = \sum_{j=1}^{m_o}\sum_{i=0}^{j-1} \frac{d\sigma}{dE_\gamma}(E_\gamma,E,m_o,i,j) \quad . \tag{3}$$

This gives us an <u>excitation</u> cross section that has the characteristic of singling out a definite excited state and has the advantage when calculated data are to be represented. The excitation cross section is identified with the m_oth level. If Eq. (2) is summed over i and j, or equivalently Eq. (3) is summed over m_o, then

$$\frac{d\sigma}{dE_\gamma}(E_\gamma,E) = \sum_{m_o=1}^{N} \frac{d\sigma_2}{dE_\gamma}(E_\gamma,E,m_o) \equiv \sum_{j=1}^{N}\sum_{i=0}^{j-1} \frac{d\sigma_1}{dE_\gamma}(E_\gamma,E,i,j) \quad . \tag{4}$$

This gives us a cross section for all possible excitations and transitions and thus corresponds to the total inelastic neutron cross section for discrete levels.

It is recommended that MT = 4 be used for the data represented by Eq. (4), as well as for the continuum. If, however, it is expedient or useful to use MT = 51 through 91, then one must use either the de-excitation cross sections of Eq. (2) or the excitation cross sections of Eq. (3) but not both. A restriction occurs if the transition probability array option is used and if the entire neutron energy range is not covered by the known transition probabilities. Then, for MT = 51 through 90 in File 12 to be used for the remaining neutron energy range, a representation by excitation multiplicities must be used.

The integrated cross sections of File 13 are obtained by integrating Eqs. (1) through (4) over E_γ.

(4) The same remarks as given in Item (3) apply for discrete gamma rays from $(n,p\gamma)$, $(n,d\gamma)$, $(n,t\gamma)$, $(n,{}^3He\gamma)$, and $(n,\alpha\gamma)$ reactions, and the use of MT = 103, 104, 105, 106, and 107 is recommended for these cases.

2.1. File 12: Multiplicities and Transition Probability Arrays

File 12 can be used to represent the neutron energy dependence of photon production cross sections by means of either multiplicities or transition probability arrays. Both methods rely upon the use by processing codes of neutron cross sections from File 2 and/or File 3 in order to generate absolute photon production cross sections.

Multiplicities can be used to represent the cross sections of discrete photons and/or the integrated cross sections of continuous photon spectra. The MT numbers that appear in File 12 designate the particular neutron cross sections (File 2 and/or File 3) to which the multiplicities are referred. The use of multiplicites is the recommended method of presenting (n,γ) capture gamma-ray cross sections provided, of course, that the (n,γ) cross section is adequately represented in File 2 and/or File 3.

For well-established level decay schemes, the use of transition probability arrays offers a concise method for presenting $(n,x\gamma)$ information. With this method, the actual decay scheme of the residual nucleus for a particular reaction (defined by MT number) is entered into File 12. This information can then be used by a processing code together with discrete level excitation cross sections from File 3 to calculate discrete gamma-ray production cross sections. This option cannot be used to represent the integrals of continuous photon spectra.

2.1.1. File 12 Format

File 12 is made up of sections with each section giving information for a particular reaction type (MT number). The information in each section is given either as multiplicities (LØ = 1) or as transition probability arrays (LØ = 2). Each section always starts with a HEAD record and ends with a SEND record.

2.1.1.1. Option 1 (LØ = 1): Multiplicities

The neutron energy dependence of photon production cross sections is represented by tabulating a set of neutron energy and multiplicity pairs $[E, y_k(E)]$ for each discrete photon and for the photon energy continuum.* The subscript k designates a particular discrete photon or a photon continuum, and the total number of such sets is represented by NK.

The multiplicity or yield $y_k(E)$ is defined by

$$y_k(E) = \frac{\sigma_k^\gamma(E)}{\sigma(E)} \qquad \text{(photons)} ,$$

where E designates neutron energy and $\sigma(E)$ is the neutron cross section in File 2 and/or File 3 to which the multiplicity is referred (by the MT number). In the case of discrete photons, $\sigma_k^\gamma(E)$ is the photon production cross section for the discrete photon designated by k. In the case of photon continua, $\sigma_k^\gamma(E)$ is the cross section for the photon continuum integrated over photon energy. In the continuum case,

$$y_k(E) = \frac{\sigma_k^\gamma(E)}{\sigma(E)} = \frac{\int \frac{d\sigma_k^\gamma}{dE_\gamma}(E_\gamma \leftarrow E)\,dE_\gamma}{\sigma(E)}$$

$$= \frac{\int \sigma(E)\; y_k(E_\gamma \leftarrow E)\,dE_\gamma}{\sigma(E)} = \int_0^{E_\gamma^{max}} y_k(E_\gamma \leftarrow E)\,dE_\gamma \quad ,$$

*There should be no more than one energy continuum for each MT number used. If the decomposition of a continuum into several parts is desired, this can be accomplished in File 15.

where E_γ designates photon energy (eV), $\frac{d\sigma_k^\gamma}{dE_\gamma}(E_\gamma \leftarrow E)$ is the absolute photon energy distribution in barns/eV, and $y_k(E_\gamma \leftarrow E)$ is the relative energy distribution in photons/eV. The quantity $y_k(E_\gamma \leftarrow E)$ can be broken down further as

$$y_k(E_\gamma \leftarrow E) = y_k(E)\ f_k(E_\gamma \leftarrow E) \ ,$$

which results in the requirement that

$$\int_0^{E_\gamma^{max}} f_k(E_\gamma \leftarrow E)dE_\gamma = 1 \ .$$

Any time a continuum representation is used for a given MT number in either File 12 or 13, then the normalized energy distribution $f_k(E_\gamma \leftarrow E)$ must be given in File 15 under the same MT number.

As a check quantity, the total yield

$$Y(E) = \sum_{k=1}^{NK} y_k(E) \qquad\qquad \text{(photons)}$$

is also tabulated for each MT number if NK > 1.

The structure of a section for LØ = 1 is

```
⎧[MAT, 12, MT/ZA, AWR; LØ=1, b; NK, b]HEAD
⎪[MAT, 12, MT/ b,    b;     b, b; NR, NP/E_int/Y(E)]TAB1*
⎪            < subsection for k = 1 >
⎪            < subsection for k = 2 >
⎨                        .
⎪                        .
⎪                        .
⎪            < subsection for k = NK >
⎩[MAT, 12,  0/ b,    b;     b, b;  b,  b]SEND  ,
```

and the structure of each subsection is

$$\text{[MAT, 12, MT/EG}_k\text{, ES}_k\text{; b, LF; NR, NP/E}_{int}\text{/y}_k\text{(E)]TAB1} \ ,$$

*If the total number of discrete photons and photon continua is one (NK = 1), then this TAB1 record is omitted.

where

ES_k ≡ the energy of the level from which the photon originates. If the level is unknown or if a continuous photon spectrum is produced, then $ES_k \equiv 0.0$ should be used.

EG_k ≡ the photon energy. For a continuous photon energy distribution, $EG_k \equiv 0.0$ should be used.

LF ≡ the photon energy distribution law number, which presently has only two values defined:

LF = 1, a normalized tabulated function (in File 15), and
= 2, a discrete photon energy.

2.1.1.2. Option 2 (LØ = 2): Transition Probability Arrays

With this option, the only data required are the level energies, de-excitation transition probabilities, and (where necessary) conditional photon emission probabilities. Given this information, the photon energies and their multiplicities can readily be calculated. Also, photon production cross sections can then be computed for any given level from the excitation cross section in File 3, along with the transition probability array. Similarly, multiplicities and photon production cross sections can be constructed for the total cascade. For any given level, the transition and photon emission probability data given in the section are for photons originating at that level only; any further cascading is determined from the data for the lower levels.

Now define the following variables.

LG = 1, simple case (all transitions are γ emission).
= 2, complex case (internal conversion or other competing processes occur).

NS ≡ number of levels below the present one, including the ground state. (The present level is also uniquely defined by the MT number and by its energy level.)

NT ≡ number of transitions for which data are given in a list to follow (i.e., number of nonzero transition probabilities), NT ≤ NS.

ES_i ≡ energy of the ith level, i = 0(1)NS. ($ES_0 \equiv 0.0$, the ground state.)

$TP_i \equiv TP_{NS,i}$, the probability of a direct transition from level NS to level i, i = 0(1)NS - 1.

$GP_i \equiv GP_{NS,i}$, the probability that, given a transition from level NS to level i, the transition is a photon transition (i.e., the conditional probability of photon emission).

$A_i \equiv (TP_i)(GP_i)$.

Note that each level can be identified by its NS number. Then the energy of a photon from a transition to level i is given by $E_\gamma = ES_{NS} - ES_i$, and its multiplicity is given by $y(E_\gamma \leftarrow E) = (TP_i)(GP_i)$. It is implicitly assumed that the transition probability array is independent of incident neutron energy.

The structure of a section for LØ = 2 is

```
[MAT, 12, MT/  ZA, AWR; LØ=2, LG;          NS,  b]HEAD .
[MAT, 12, MT/ES_NS,  b;    b,  b; (LG+1)*NT, NT/B_i]LIST .
[MAT, 12   0/   b,   b;    b,  b;           b,  b]SEND .
```

If LG = 1, the array B_i consists of NT doublets (ES_i, TP_i); if LG = 2, it consists of NT triplets (ES_i, TP_i, GP_i). Here the subscript i is a running index over the levels below the level for which the transition probability array is being given (i.e., below level NS). The doublets (ES_i, TP_i) or triplets (ES_i, TP_i, GP_i) are given in decreasing magnitude of energy ES_i.

2.1.2. File 12 Procedures

1. Under Option 1, the subsections are given in decreasing magnitude of EG_k.

2. Under Option 1, the convention is that the subsection for the continuum photons, if present, is last. In this case, the last value of EG_k (EG_{NK}) is set equal to 0.0, and logical consistency with Procedure 1 is maintained.

3. Under Option 1, the values of EG_k should be consistent to within four significant figures with the corresponding EG_k values for the File 14 photon angular distributions. This allows processing and "physics" checking codes to match photon yields with the corresponding angular distributions.

4. Under Option 1, ES_k is the energy of the level from which the photon originates. If ES_k is unknown or not meaningful (as for the continuous photon spectrum), the value 0.0 should be entered.

5. If capture and fission resonance parameters are given in File 2, photon production for these reactions should be given by use of Option 1 of File 12, instead of as photon production cross sections in File 13. This is due to the voluminous data required to represent the resonance structure in File 13 and the difficulty of calculating multigroup photon production matrices from such data.

6. Under Option 1, the total yield table, Y(E), should exactly span the same energy range as the combined energy range of all the $y_k(E)$. Within that range,

$$Y(E) = \sum_{k=1}^{NK} y_k(E)$$

should hold within four significant figures.

7. The excitation cross sections for all the levels appearing in the transition probability arrays must, of course, be given in File 3.

8. The join of all sections, regardless of the option used, should represent the photon production data with no redundancy. For example, MT = 4 cannot include any photons given elsewhere under MT = 51 through 91. Likewise, there can be no redundancy between Files 12 and 13.

9. If only one energy distribution is given under Option 1 (NK = 1), then the TAB1 record for the Y(E) table is simply deleted to avoid repetitive entries.

10. Data should not be given in File 12 for reaction types that do not appear in Files 2 and/or 3.

11. Under Option 2, the level energies, ES_i, in the transition probability arrays are given in decreasing magnitude.

12. The MT numbers for which transition probability data are given should be for consecutive levels, beginning at the first level, with no embedded levels omitted.

13. The energies of photons arising from level transitions should be consistent within four significant figures with the corresponding EG_k values in File 14. Therefore, care must be taken to specify level energies to the appropriate number of significant figures.

14. Under Option 2, the sum of the transition probabilities (TP_i) over i should equal 1.0000 (that is, should be unity to within five significant figures).

15. The limit on the number of energy points in any table of Y(E) or $y_k(E)$ is 1000. This is an upper limit that should rarely be approached in practice because yields are normally smoothly varying functions of incident neutron energy.

16. The limit on the number of interpolation regions is 10.

17. Tabulations of nonthreshold data should normally cover at least the energy range 10^{-5} eV $\leq E \leq 2 \times 10^{7}$ eV, where practical. Threshold data should be given from threshold energy up to 2×10^{7} eV, where practical.

2.2 File 13: Photon Production Cross Sections

The purpose of File 13 is the same as that for File 12; namely, it can be used to represent the neutron and photon energy dependence of photon production cross sections. In File 13, however, absolute cross sections in barns are tabulated, and there is no need to refer back to the neutron files.

2.2.1. File 13 Format

Similar to File 12, File 13 is made up of sections with each section giving information for a particular reaction type (MT number). Each section always starts with a HEAD record and ends with a SEND record.

The representation of the energy dependence of the cross sections is accomplished by tabulating a set of neutron energy-cross section pairs $[E,\sigma_k^\gamma(E)]$ for each discrete photon and for the photon energy continuum. The subscript k designates particular discrete photons or the photon continuum, and the total number of such sets is NK. In the case of discrete photons, $\sigma_k^\gamma(E)$ is the photon production cross section (b) for the photon designated by k. In the case of the photon continuum, $\sigma_k^\gamma(E)$ is the integrated (over photon energy) cross section for the photon continuum* designated by k. In the continuum case,

$$\sigma_k^\gamma(E) = \int_0^{E_\gamma^{max}} \frac{d\sigma_k^\gamma}{dE_\gamma}(E_\gamma \leftarrow E)\, dE_\gamma \qquad \text{(b)} \quad ,$$

where E_γ designates photon energy (eV), and $\frac{d\sigma_k^\gamma}{dE_\gamma}(E_\gamma \leftarrow E)$ is the absolute photon energy distribution in b/eV. The energy distribution can be further broken down as

$$\frac{d\sigma_k^\gamma}{dE_\gamma}(E_\gamma \leftarrow E) = \sigma_k^\gamma(E)\, f_k\, (E_\gamma \leftarrow E) \ ,$$

which obviously requires that

$$\int_0^{E_\gamma^{max}} f_k(E_\gamma \leftarrow E)\, dE_\gamma = 1.$$

Any time a continuum representation is used for a given MT number in File 13, then the normalized energy distribution, $f_k(E_\gamma \leftarrow E)$, must be given in File 15 under the same MT number.

---

*There should be no more than one energy continuum for each MT number used. If the decomposition of a continuum into several parts is desired, this can be accomplished in File 15.

As a check quantity, the total photon production cross section,

$$\sigma^{\gamma}_{TOT}(E) = \sum_{k=1}^{NK} \sigma^{\gamma}_{k}(E) \qquad \text{(b)},$$

is also tabulated for each MT number, unless only one subsection is present (i.e., NK = 1).

The structure of a section in File 13 is

$$\left\{\begin{array}{l}
[\text{MAT, 13, MT/ZA, AWR; b, b; NK, b]HEAD} \\
[\text{MAT, 13, MT/ b, b; b, b; NR, NP/}E_{int}/\sigma^{\gamma}_{TOT}(E)]\text{TAB1*} \\
\qquad \langle \text{subsection for } k = 1 \rangle \\
\qquad \langle \text{subsection for } k = 2 \rangle \\
\qquad\qquad \vdots \\
\qquad \langle \text{subsection for } k = NK \rangle \\
[\text{MAT, 13, 0/ b, b; b, b; b, b]SEND}
\end{array}\right.$$

and the structure of each subsection is

$$[\text{MAT, 13, MT/}EG_k, ES_k\text{; b, LF; NR, NP/}E_{int}/\sigma^{\gamma}_{k}(E)]\text{TAB1} \quad ,$$

where

ES_k ≡ the energy of the level from which the photon originates. If the level is unknown or if a continuous photon spectrum is produced, then ES_k = 0.0 should be used.

EG_k ≡ the photon energy. For a continuous photon energy distribution, EG_k = 0.0 should be used.

LF ≡ the photon energy distribution law number, which presently has only two values defined:

LF = 1, a normalized tabulated function (in File 15), and
= 2, a discrete photon energy.

*If the total number of discrete photons and photon continua is one (NK = 1), then this TAB1 record is omitted.

2.2.2. File 13 Procedures

1. The subsections are given in decreasing magnitude of EG_k.
2. The convention is that the subsection for the continuum photons, if present, is last. In this case, $EG_{NK} \equiv 0.0$.
3. The values of EG_k should be consistent to within four significant figures with the corresponding EG_k values in File 14.
4. ES_k is the energy of the level from which the photon originates, if known. Otherwise $ES_k \equiv 0.0$.
5. If capture and fission resonance parameters are given in File 2, the corresponding photon production should be given by use of Option 1 of File 12, instead of as photon production cross sections.
6. The total photon production cross section table, $\sigma^{\gamma}_{TOT}(E)$, should exactly span the same energy range as the combined energy range of all the $\sigma^{\gamma}_{k}(E)$. Within that range,

$$\sigma^{\gamma}_{TOT}(E) = \sum_{k=1}^{NK} \sigma^{\gamma}_{k}(E)$$

   should hold within four significant figures. If only one energy distribution is given, either discrete or continuous (NK = 1), then the TAB1 record for the $\sigma^{\gamma}_{TOT}(E)$ table is simply deleted.
7. The join of all sections in Files 12 and 13 combined should represent the photon production data with no redundancy. For example, MT = 4 cannot include any photons given elsewhere under MT = 51 through 91.
8. The limit on the number of energy points in a tabulation for any photon production subsection is 1000. This is an upper limit; in practice, the minimum number of points possible should be used. If there is extensive structure, the use of File 12 should be seriously considered, because yields are normally much smoother functions of incident neutron energy than cross sections.
9. The limit on the number of interpolation regions is 10.
10. Tabulations of nonthreshold data should normally cover at least the energy range 10^{-5} eV $\leq E \leq 2 \times 10^{7}$ eV, where practical. Threshold data should be given from threshold energy up to 2×10^{7} eV, where practical.

2.3. File 14: Photon Angular Distributions

The purpose of File 14 is to provide a means for representing the angular distributions of secondary photons produced in neutron interactions. Angular distributions should be given for each discrete photon and photon continuum that appears in Files 12 and 13, even if the distributions are isotropic.

The structure of File 14 is, with the exception of isotropic flags, closely analogous to that of File 4. Angular distributions for a specific reaction type (MT number) are given for a series of incident neutron energies in order of increasing neutron energy. The energy range covered should be the same as that for the data given under the corresponding reaction type in File 12 or File 13. The data are given in ascending order of MT number.

The angular distributions are expressed as normalized probability distributions, that is,

$$\int_{-1}^{1} p_k(\mu,E)\,d\mu = 1 \quad ,$$

where $p_k(\mu,E)$ is the probability that an incident neutron of energy E will result in a particular discrete photon or photon energy continuum (specified by k and MT number) being emitted into unit cosine about an angle whose cosine is μ. Because the photon angular distribution is assumed to have azimuthal symmetry, the distribution may be represented as a Legendre series expansion,

$$p_k(\mu,E) = \frac{2\pi}{\sigma_k^{\gamma}(E)} \frac{d\sigma_k^{\gamma}}{d\underline{\Omega}}(\underline{\Omega},E)$$

$$= \sum_{\ell=0}^{NL} \frac{2\ell+1}{2} a_\ell^k(E)\, P_\ell(\mu) \quad ,$$

where

$\mu \equiv$ cosine of the reaction angle.

$E \equiv$ energy of the incident neutron in the laboratory system.

$\sigma_k^{\gamma}(E) \equiv$ photon production cross section for the discrete photon or photon continuum specified by k, as given in either File 13 or the combination of Files 2, 3, and 12.

$\ell \equiv$ order of the Legendre polynomial.

$\frac{d\sigma_k^\gamma}{d\Omega} \equiv$ differential photon production cross section in barns/steradian.

$a_\ell^k(E) \equiv$ the ℓth Legendre coefficient associated with the discrete photon or photon continuum specified by k. (It is understood that $a_0^k(E) \equiv 1.0$.)

$$a_\ell^k(E) = \int_{-1}^{1} p_k(\mu,E)\ P_\ell(\mu)d\mu \quad .$$

Angular distributions may be given in File 14 by tabulating as a function of incident neutron energy either the normalized probability distribution function, $p_k(\mu,E)$, or the Legendre polynomial expansion coefficients, $a_\ell^k(E)$. Provision is made in the format for simple flags to denote isotropic angular distributions, either for a block of individual photons within a reaction type or for all photons within a reaction type taken as a group.

It is important to note that File 14 assumes separability of the photon energy and angular distributions for the continuous spectrum. If this is not the case, File 16 (analogous to File 6) must be used instead of Files 14 and 15. (Note that File 14 implicitly specifies an energy-angle distribution for discrete photons, and, therefore, File 16 is required only for the continuous spectrum.)

2.3.1. File 14 Format

As usual, sections are ordered by increasing reaction-type (MT) numbers. The following definitions are required.

LTT = 1, data are given as Legendre coefficients, where $a_0^k(E) \equiv 1.0$ is understood.

= 2, data are given as a tabulation.

LI = 0, distribution is not isotropic for all photons from this reaction type (but may be for some photons),

= 1, distribution is isotropic for all photons from this reaction type.

NE $\equiv$ number of neutron energy points given in a TAB2 record.

NI $\equiv$ number of isotropic photon angular distributions given in a section (MT number) for which LI = 0, i.e., a section with at least one anisotropic distribution.

NL_i $\equiv$ highest value of ℓ required at each neutron energy E_i.

a. LI = 1: Isotropic Distribution

If LI = 1, then all photons for the reaction type (MT) in question are assumed to be isotropic. This is a flag that the processing code can sense, thus avoiding the necessity to enter needless isotropic distribution data in the file. In this case, the section is composed of a HEAD card and a SEND card, as follows:

```
{ [MAT, 14, MT/ZA, AWR; LI=1, b; NK, b]HEAD
{ [MAT, 14,  0/ b,   b;    b, b;  b, b]SEND  .
```

b. LI = 0: Anisotropic Distribution

If LI = 0, there are two possible structures for a section, depending upon the value of LTT, but the section always starts with a HEAD record of the form:

```
[MAT, 14, MT/ZA, AWR; LI=0, LTT; NK, NI]HEAD  .
```

i. LTT = 1: Legendre Coefficient Representation

```
{ [MAT, 14, MT/ZA, AWR; LI=0, LTT=1; NK, NI]HEAD
{     <subsection for k = 1 >
{     <subsection for k = 2 >
{                 .
{                 .
{                 .
{     <subsection for k = NK>
{ [MAT, 14,  0/ b,   b;    b,     b;  b,  b]SEND  .
```

The structure of each record in the first block of NI subsections, which is for the NI isotropic photons, is

$$[\text{MAT, 14, MT}/\text{EG}_k,\ \text{ES}_k;\ \text{b, b; b, b}]\text{CONT} \quad .$$

That is, there is just one CONT record for each isotropic photon. (The set of CONT records is empty if NI = 0.) The subsections are ordered in decreasing magnitude of EG_k, and the continuum, if present and isotropic, appears last with $EG_k \equiv 0.0$.

This block of NI subsections is then followed by a block of NK-NI subsections for the anisotropic photons in decreasing magnitude of EG_k (photon energy). The continuum, if present and anisotropic, appears last with $EG_k \equiv 0.0$. The structure for the last NK-NI subsections is

$$\left\{\begin{array}{l}
[\text{MAT, 14, MT}/\text{EG}_k,\ \text{ES}_k;\ \text{b, b; NR, NE}/\text{E}_{int}]\text{TAB2} \\
[\text{MAT, 14, MT}/\ \text{b},\ \ \text{E}_1;\ \text{b, b; NL}_1,\ \text{b}/a_\ell^k(\text{E}_1)]\text{LIST} \\
[\text{MAT, 14, MT}/\ \text{b},\ \ \text{E}_2;\ \text{b, b; NL}_2,\ \text{b}/a_\ell^k(\text{E}_2)]\text{LIST} \\
\qquad\qquad\qquad\vdots \\
[\text{MAT, 14, MT}/\ \text{b},\ \text{E}_{NE};\ \text{b, b; NL}_{NE},\text{b}/a_\ell^k(\text{E}_{NE})]\text{LIST} \quad .
\end{array}\right.$$

Note that lists of the $a_\ell^k(E)$ start at $\ell = 1$ because $a_o^k(E) \equiv 1.0$ is always understood.

ii. LTT = 2: Tabulated Angular Distributions

The structure of a section for LI = 0 and LTT = 2 is

$$\left\{\begin{array}{l}
[\text{MAT, 14, MT/ZA, AWR; LI=0, LTT=2; NK, NI}]\text{HEAD} \\
\qquad \langle\text{subsection for k = 1}\rangle \\
\qquad \langle\text{subsection for k = 2}\rangle \\
\qquad\qquad \vdots \\
\qquad \langle\text{subsection for k = NK}\rangle \\
[\text{MAT, 14, 0/ b, b; b, b; b, b}]\text{SEND} \quad .
\end{array}\right.$$

The structure of the first block of NI subsections (where NI may be zero) is the same as for the case of a Legendre representation, i.e., it consists of one CONT record for each of the NI isotropic photons in decreasing magnitude of EG_k (photon energy). The continuum, if present and isotropic, appears last with $EG_k \equiv 0.0$.

The structure of the first NI subsections is

$$[\text{MAT, 14, MT}/EG_k, ES_k; \text{b, b; b, b]CONT} \quad .$$

This block of NI subsections is then followed by a block of NK-NI subsections for the anisotropic photons, again in decreasing magnitude of EG_k with the continuum, if present and anisotropic, appearing last with $EG_k \equiv 0.0$. The structure of the last NK-NI subsections is

$$[\text{MAT, 14, MT}/EG_k, ES_k; \text{b, b; NR, NE}/E_{int}]\text{TAB2}$$

$$\left\{\begin{array}{l} [\text{MAT, 14, MT/ b, } E_1; \text{ b, b; NR, NP}/\mu_{int}/p_k(\mu,E_1)]\text{TAB1} \\ [\text{MAT, 14, MT/ b, } E_2; \text{ b, b; NR, NP}/\mu_{int}/p_k(\mu,E_2)]\text{TAB1} \\ \quad\vdots \\ [\text{MAT, 14, MT/ b, } E_{NE}; \text{ b, b; NR, NP}/\mu_{int}/p_k(\mu,E_{NE})]\text{TAB1} \quad . \end{array}\right.$$

2.3.2. File 14 Procedures

1. The subsections are given in decreasing magnitude of EG_k within each of the isotropic and anisotropic blocks.

2. The convention is that the subsection for the continuous photon spectrum, if present, appears last in its block. In this case, $EG_{NK} \equiv 0.0$.

3. The values of EG_k should be consistent within four significant figures with the corresponding EG_k values in File 12 or 13. In the case of File 12, Option 2 (transition probability arrays), the values of EG_k are implicitly determined by the level energies.

4. ES_k is the energy of the level from which the photon originates, if known. Otherwise, $ES_k \equiv 0.0$ (as is always the case for the continuum).

5. Data should not appear in File 14 for photons that do not have production data given in File 12 or 13. Conversely, every photon appearing in File 12 or 13 must have an angular distribution given in File 14. The neutron energy range over which the angular distributions are given should be the same as that for which the photon production data are given in File 12 or 13.

6. For LTT = 1 (Legendre coefficients), the value of NL should be the minimum number of coefficients that will reproduce the angular distribution with sufficient accuracy and be positive everywhere. In all cases, NL should be an even number less than or equal to 20.

7. The TAB1 records for the $p_k(\mu,E_i)$ within a subsection are given in increasing order of neutron energy, E_i.

8. The tabulated probability functions, $p_k(\mu,E_i)$, should be normalized within four significant figures (to unity).

9. The interpolation scheme for $p_k(\mu,E)$ with respect to E must be linear-linear or log-linear (INT = 2 or 3) to preserve normality of the interpolated distributions. It is recommended that the interpolation in μ be linear-linear (INT = 2).

10. For LI = 1 (isotropic distribution), the parameter NK is a count of the number of photons in that section and should be given consistent with the NK values in Files 12 and 13. This parameter could also be determined independently from Files 12 and 13, but it is useful in File 14 for the "physics" checking code.[6]

11. The minimum amount of data should be used that will accurately represent the angular distribution as a function of both μ and E.

12. If all photons for a reaction type (MT number) are isotropic, the LI = 1 flag should be used. The use of LI = 0 and NI = NK is strongly discouraged. Likewise, isotropic distributions should not be entered explicitly as a tabulation or as a Legendre expansion with $a_\ell^k(E) \equiv 0$, $\ell \geq 1$.

2.4. File 15: Continuous Photon Energy Spectra

File 15 provides a means for representing continuous energy distributions of secondary photons. The energy distributions are expressed as normalized probability distributions. The energy distribution of each photon continuum that occurs in Files 12 and 13 should be specified in File 15 over the same neutron energy range as used in Files 12 and 13. File 15 is divided into sections with each section giving the data for a particular reaction type (MT number), and the sections are ordered by increasing MT number.

The energy distributions, $f(E_\gamma \leftarrow E)$, have the units of eV^{-1} and are normalized such that

$$\int_{o}^{E_\gamma^{max}} f(E_\gamma \leftarrow E)\, dE_\gamma = 1 \ ,$$

where E_γ^{max} is the maximum possible secondary photon energy and its value depends on the incoming neutron energy as well as the particular nuclei involved.* The energy distributions $f(E_\gamma \leftarrow E)$ can be broken down into the weighted sum of several different normalized distributions in the following manner

$$f(E_\gamma \leftarrow E) = \sum_{j=1}^{NC} p_j(E)\ q_j(E_\gamma \leftarrow E) \qquad (eV)^{-1},$$

where

$NC \equiv$ the number of partial distributions used to represent $f(E_\gamma \leftarrow E)$.

$q_j(E_\gamma \leftarrow E) \equiv$ the jth normalized partial distribution in the units eV^{-1}.

$p_j(E) \equiv$ the probability or weight given to the jth partial distribution, $q_j(E_\gamma \leftarrow E)$.

*Note that the subscript k that occurs in the sections describing Files 12 and 13 has been dropped from $f(E_\gamma \leftarrow E)$. This is done because only one energy continuum is allowed for each MT number, and the subscript k has no meaning in File 15. It is, in fact, the NKth subsection in File 12 or 13 that contains the production data for the continuum.

The following normalization condition is imposed.

$$\int_0^{E_\gamma^{max}} q_j(E_\gamma \leftarrow E)\ dE_\gamma = 1 \quad .$$

Thus,

$$\sum_{j=1}^{NC} p_j(E) = 1 \quad .$$

The absolute energy distribution cross section, $\sigma^\gamma(E_\gamma \leftarrow E)$, can then be constructed from the expression

$$\sigma^\gamma(E_\gamma \leftarrow E) = \sigma^\gamma(E)\ f(E_\gamma \leftarrow E) \qquad \text{(b/eV)},$$

where $\sigma^\gamma(E)$ is the integrated cross section for the continuum given either directly in File 13 or through the combination of Files 2, 3, and 12.

The system used to represent continuous photon energy distributions in File 15 is similar to that used in File 5. At present, however, there is only one continuous distribution law activated for File 15, i.e.,

$$q_j(E_\gamma \leftarrow E) = g(E_\gamma \leftarrow E) \ ,$$

where $g(E_\gamma \leftarrow E)$ represents an arbitrary tabulated function. In the future, new laws (for example, the fission gamma-ray spectrum) may be added.

2.4.1. File 15 Format

The structure of a section is

$$
\begin{cases}
[\mathrm{MAT},\ 15,\ \mathrm{MT/ZA},\ \mathrm{AWR};\ b,\ b;\ \mathrm{NC},\ b]\mathrm{HEAD} \\
\qquad \langle \text{subsection for } j = 1 \rangle \\
\qquad \langle \text{subsection for } j = 2 \rangle \\
\qquad \vdots \\
\qquad \langle \text{subsection for } j = \mathrm{NC} \rangle \\
[\mathrm{MAT},\ 15,\ 0/\ b,\ b;\ b,\ b;\ b,\ b]\mathrm{SEND}\ .
\end{cases}
$$

For LF = 1, the structure of a subsection is

$$
\begin{cases}
[\mathrm{MAT},\ 15,\ \mathrm{MT}/b,\ b;\ b,\ \mathrm{LF{=}1};\ \mathrm{NR},\ \mathrm{NP}/E_{int}/p_j(E)]\mathrm{TAB1} \\
[\mathrm{MAT},\ 15,\ \mathrm{MT}/b,\ b;\ b,\ b;\ \mathrm{NR},\ \mathrm{NE}/E_{int}]\mathrm{TAB2} \\
[\mathrm{MAT},\ 15,\ \mathrm{MT}/b,\ E_1;\ b,\ b;\ \mathrm{NR},\ \mathrm{NP}/E_{\gamma\ int}/g(E_\gamma \leftarrow E_1)]\mathrm{TAB1} \\
[\mathrm{MAT},\ 15,\ \mathrm{MT}/b,\ E_2;\ b,\ b;\ \mathrm{NR},\ \mathrm{NP}/E_{\gamma\ int}/g(E_\gamma \leftarrow E_2)]\mathrm{TAB1} \\
\qquad \vdots \\
[\mathrm{MAT},\ 15,\ \mathrm{MT}/b,\ E_{NE};\ b,\ b;\ \mathrm{NR},\ \mathrm{NP}/E_{\gamma\ int}/g(E_\gamma \leftarrow E_{NE})]\mathrm{TAB1}\ .
\end{cases}
$$

At present, there is no other continuous energy distribution law defined. Therefore, formats for other laws remain to be defined in the future, but their structures will probably closely parallel those in File 5 for LF = 5, 7, 9, and 10.

2.4.2. File 15 Procedures

1. Photon energies, E_γ, within a subsection are given in increasing magnitude.

2. The TAB1 records for the $g(E_\gamma \leftarrow E_i)$ within a subsection are given in increasing order of nuetron energy, E_i.

3. The tabluated functions, $g(E_\gamma \leftarrow E_i)$, should be normalized to unity within four significant figures.

4. The interpolation scheme for $p_j(E)$ must be either linear-linear or log-linear (INT = 1, 2, or 3) to preserve probabilities upon interpolation. Likewise, the interpolation scheme for $g(E_\gamma \leftarrow E)$ must be linear-linear or log-linear with respect to E.

5. The neutron energy mesh should be a subset of that used for the $y_{NK}(E)$ tabulation in File 12 or for the $\sigma^\gamma_{NK}(E)$ tabulation in File 13, and the energy ranges must be identical. However, the neutron energy mesh for the $p_j(E)$ need not be the same as for the $g(E_\gamma \leftarrow E)$, as long as they span the same range.

6. For an MT number which appears in both File 12 and File 13, a continuous photon energy distribution (LF = 1) can appear in only one of those files. Otherwise the distribution as given in File 15 could not in general be uniquely associated with a corresponding multiplicity or production cross section.

7. The minimum amount of data should be used that will accurately represent the energy distribution as a function of both E_γ and E. However, caution must be exercised not to use too coarse a mesh for E, even if the distributions are slowly varying functions of E. This is due to the fact that the interpolated distribution will always have a nonzero component up to the maximum energy to which either of the original distributions has a nonzero component.

8. The limit on the number of neutron energy points for either $p_j(E)$ or $g(E_\gamma \leftarrow E)$ is 200. The limit on the number of photon energy points for $g(E_\gamma \leftarrow E)$ is 1000.

2.5. File 16: Photon Energy-Angle Distributions

If the photon energy dependence and angular dependence of the cross section for production of the continuous spectrum are not separable, then a file analogous to File 6 is required instead of Files 14 and 15. The energy-angle distributions for discrete photons are completely determined in File 14 and should never appear in File 16. A knowledge of the formats for Files 14 and 15 is assumed in this discussion.

Consider a nonnormalized energy-angle distribution function $F(E_\gamma \leftarrow E,\mu)$, where the angular dependence is normalized such that

$$\int_{-1}^{1} F(E_\gamma \leftarrow E,\mu)\, d\mu = y(E_\gamma \leftarrow E) \quad .$$

Then the multiplicity (yield) can be separated out, leaving a function, $h(E_\gamma \leftarrow E,\mu)$, normalized in both E_γ and μ.

$$F(E_\gamma \leftarrow E,\mu) = y(E)\ h(E_\gamma \leftarrow E,\mu) \quad .$$

The differential photon production cross section is then obtained from

$$\frac{\partial^2\ \sigma(E_\gamma \leftarrow E,\mu)}{\partial E_\gamma\ \partial\mu} = \sigma(E)\ y(E)\ h(E_\gamma \leftarrow E,\mu) \qquad \text{(b-photons/eV)},$$

where $\sigma(E)$ is the cross section for the reaction type being considered, as determined by Files 2 and 3.

As in File 14, the angular part of the distribution may be specified either in tabular form or as Legendre coefficients, $\eta_\ell(E_\gamma \leftarrow E)$. The Legendre expansion is

$$h(E_\gamma \leftarrow E,\mu) = \sum_{\ell=0}^{NL} \frac{2\ell + 1}{2}\, \eta_\ell(E_\gamma \leftarrow E)\ P_\ell(\mu) \quad .$$

Now consider the structure of a section for the two possible forms of the angular distribution.

2.5.1. File 16 Format

Two options are allowed, corresponding to the options in File 14, i.e., the angular distribution can be represented by either Legendre coefficients (LTT = 1) or by tabulated angular distributions (LTT = 2).

LTT = 1: Legendre Coefficient Representation. In this option, the Legendre coefficients are tabulated as functions of both incident neutron energy and photon energy. The structure of a section for LTT = 1 is

[MAT, 16, MT/ZA, AWR; b, LTT=1; b, b]HEAD
[MAT, 16, MT/ b, b; b, b; NL, b]CONT
$\langle$ subsection for $\ell = 0$ $\rangle$
$\langle$ subsection for $\ell = 1$ $\rangle$
.
.
.
$\langle$ subsection for ℓ = NL $\rangle$
[MAT, 16, 0/ b, b; b, b; b, b]SEND .

The subsections contain the energy distributions, and the structure of a subsection is identical to the structure of a section for a continuous energy distribution (File 15), with the following exceptions

a. The SEND record is deleted.

b. The HEAD record is changed to read

[MAT, 16, MT/b, b; b, b; NC, b]CONT .

c. $g(E_\gamma \leftarrow E)$ is replaced by $\eta_\ell(E_\gamma \leftarrow E)$.

LTT = 2: Tabulated Angular Distribution. In this option, the subsections consist of tabulations for $h(E_\gamma \leftarrow E,\mu_m)$, m = 1(1)NA. The structure of a section for LTT = 2 is

[MAT, 16, MT/ZA, AWR; b, LTT=2; b, b]HEAD
[MAT, 16, MT/ b, b; b, b; NR, NA/μ_{int}]TAB2
$\langle$ subsection for m = 1 $\rangle$
$\langle$ subsection for m = 2 $\rangle$
.
.
.
$\langle$ subsection for m = NA $\rangle$
[MAT, 16, 0/ b, b; b, b; b, b]SEND .

As in the case of the Legendre coefficient representation, this section for a tabulation contains subsections. The structure of a subsection is identical to the structure of a section for File 15, with the following exceptions

a. The SEND record is deleted.

b. The HEAD record is changed to read

$$[MAT, 16, MT/b, \mu_m; b, b; NC, b]CONT \quad .$$

c. $g(E_\gamma \leftarrow E)$ is replaced by $g(E_\gamma \leftarrow E,\mu_m)$, where each subsection is for a particular value of μ_m, m = 1(1)NA.

2.5.2. File 16 Procedures

The procedures for this file are the same as those listed for Files 14 and 15, where applicable.

3. PHOTON INTERACTION

Photon interaction data are divided into five files, the first four of which are analogous to Files 3 through 6.

File	Description
23	"Smooth" cross sections
24	Secondary angular distributions
25	Secondary energy distributions
26	Secondary energy-angle distributions
27	Form factors for coherent and incoherent scattering.

As with the photon production data files, the photon interaction data formats were kept as closely parallel as possible to those for the neutron data files of the same number (modulo 10). This facilitates the use of existing retrieval routines in processing codes for photon interaction data (as in CHECKER).[4] Also, the format is kept as consistent as possible with the United Kingdom Atomic Energy Authority data file.[5] For Compton scattering at higher energies ($\gtrsim$1 MeV), the energy and angular distribution files would not normally be used because a simple analytical representation of these distributions is available. Also, provision is made for the entry of coherent scattering form factors as well as incoherent scattering form factors (incoherent scattering functions). The secondary energy and angular distribution files can be used for both photon secondaries or particulate secondaries (e.g., photoneutrons).

Procedures are given for Files 23 and 27, but none will be given for Files 24, 25, and 26 until those files are activated. There are, at present, no data in these files.

3.1. File 23: "Smooth" Cross Sections

This file is for the integrated photon interaction cross sections, including those usually called microscopic attenuation or energy-deposition coefficients, as well as photonuclear reaction cross sections. The reaction type (MT) numbers for photon interaction are in the 500 and 600 series. Several common photon interactions have been assigned MT numbers as follows

MT	Reaction Description
501	Total
502	Coherent scattering
504	Incoherent scattering
515	Pair production, electron field
516	Pair production, nuclear and electron field (i.e., pair plus triplet production)
517	Pair production, nuclear field
518	Photofission (γ,F)
532	Photoneutron (γ,n)
533	Total photonuclear
602	Photoelectric

Photon cross sections, such as the total cross section, coherent elastic-scattering cross section, and incoherent (Compton) cross section, are given in File 23, which is essentially the same in structure as File 3. These data are given as a function of energy, E_γ, where E_γ is the energy of the incident photon (in eV). The data are given as energy-cross-section pairs. An interpolation scheme is given that specifies the energy variation of the cross section for photon energies between a given energy point and the next higher energy point. The photon cross sections are given in one or more energy ranges. Within any one energy range, the interpolation scheme is unchanged. The interpolation scheme may change from one to another energy range.

File 23 is divided into sections with each section containing the data for a particular reaction type (MT number). The sections are ordered by increasing reaction type numbers.

3.1.1. File 23 Format

The format is almost identical to that of File 3, as follows

[MAT, 23, MT/ZA, AWR; b, b; b, b]HEAD

[MAT, 23, MT/ b, b; b, b; NR, NP/$E_{\gamma\ int}$/$\sigma(E_\gamma)$]TAB1

[MAT, 23, 0/ b, b; b, b; b, b]SEND .

3.1.2. File 23 Procedures

1. Values are usually for elements, hence, except for monoisotopic elements, ZA = Z x 1000; also, AWR should be for the naturally occurring element.

2. Photoelectric edges will not be multivalued. That is, the edge will be defined by two energies different in the fourth or fifth significant figure.

3. The total pair production values are given for reaction type MT = 516. Reaction type 517 is reserved for the portion of the pair production cross section due to the nuclear field, i.e., excluding triplet production.

4. Interpolation is normally log-log (INT = 5).

5. Kerma factor (energy deposition coefficients) libraries will normally be local because there is no universal definition. The application will determine whether annihilation or other radiation fractions are subtracted.

3.2. File 24: Secondary Angular Distribution

The structure of File 24 is identical to that for File 4, so the pertinent discussion from Vol. I of this report will be reviewed here for convenience.

Secondary angular distributions are expressed as probability density functions, $p(\mu,E_\gamma)$. These functions can be represented either as a tabulation or as the Legendre coefficients, $f_\ell(E_\gamma)$, in

$$\frac{d\sigma(E_\gamma,\mu)}{d\mu} = \sigma(E_\gamma) \sum_{\ell=0}^{NL} \frac{2\ell+1}{2} f_\ell(E_\gamma)\, P_\ell(\mu) \quad ,$$

$$f_o(E_\gamma) = 1.0 \quad .$$

Here, $\mu = \cos\theta$, where θ is the polar angle of scattering in either the center-of-mass (C) or the laboratory (L) system. The secondary may be either a photon (coherently scattered) or a particle (e.g., photoneutrons). For the case where the secondary distribution is for a photon, the laboratory system is always used.

3.2.1. File 24 Format

The format is identical to that for File 4 and will not be reproduced here (see Vol. I). However, for the case where the secondary distribution is for a photon, the LCT flag is not relevant, and the following arbitrary convention is adopted

a. LCT = 1 [data are given in the laboratory (L) system].

b. LVT = 0 [transformation matrix is not given].

3.3. File 25: Secondary Energy Distributions

The structure of the analogous File 5 appears to be entirely adequate (see Vol. I). Thus, the format will not be reproduced here, but will be adopted by reference to File 5.

3.4. File 26: Secondary Energy-Angle Distributions

The structure of the analogous File 6 appears to be entirely adequate (see Vol. I). Thus, the format will not be reproduced here but adopted by reference to File 6. The inclusion of File 26 (as well as Files 6 and 16) is, at the present stage of development of cross-section data, strictly *pro forma*.

3.5 File 27: Atomic Form Factors or Scattering Functions

The ENDF system for neutron and photon production data allows two alternatives for storing angular distribution data. One is by probability per unit cos θ vs cos θ, and the other is by Legendre coefficients. Actually, neither of these is a "natural" method for photons. The natural method for storing photon distributions would be atomic form factors or incoherent scattering functions. These are discussed briefly below.

a. Incoherent Scattering. The cross section for incoherent scattering is given by

$$\frac{d\sigma_i}{d\mu} = Z\ K(q;Z)\ \frac{d\sigma_c}{d\mu} \quad ,$$

where $d\sigma_c/d\mu$ is the Klein-Nishina cross section, which can be written in closed form. The factor K(q;Z) is the incoherent scattering function, which is often symbolized as S(q;Z) in the literature. At high ($\gtrsim$1 MeV) energies, K approaches unity. The quantity q is the momentum of the recoil electron (in units of $m_o c$),

$$q = \alpha \left[1 + \left(\frac{\alpha'}{\alpha}\right)^2 - 2\mu\left(\frac{\alpha'}{\alpha}\right) \right]^{\frac{1}{2}} \quad ,$$

where

$\alpha = E_\gamma/m_o c^2$,

E'_γ = scattered photon energy, and

$\mu = \cos\theta$.

The angular distribution can then easily be calculated, given a table of K(q;Z). Because K is a smoothly varying function of q, it can be represented by a reasonably small array of numbers. The quantities K(q;Z) will be tabulated as a function of q in File 27. The user presumably will have subroutines available for calculating q for energies and angles of interest and for calculating Klein-Nishina cross sections. He will then generate his cross sections for the appropriate cases by calculating q's, looking up the appropriate values of K, and substituting them into the above formula.

b. Coherent Scattering. The coherent scattering cross section is given by

$$\frac{d\sigma_{coh}}{d\mu} = \pi r_o^2 \, Z^2 (1 + \mu^2) \, G(q;Z) \quad ,$$

where

$q = \alpha[2(1 - \mu)]^{1/2}$, the recoil momentum of the atom (in units of $m_o c$), and

$r_o = e^2/m_o c^2$, the classical radius of the electron.

The quantity $G(q;Z)$ is a form factor which is often symbolized as $F(q;Z)$ in the literature. This quantity is also easily tabulated. At high ($\gtrsim$1 MeV) energies, G approaches zero.

An alternative way of presenting the photon scattering data, then, would be to tabulate incoherent scattering functions and form factors. Users could then provide processing codes to generate the cross sections from this information. The calculation is quite straightforward and allows the user to generate all his scattering data from a relatively small table of numbers. The incoherent and coherent scattering data should always be presented as scattering functions and form factors, respectively, regardless of whether or not data are included in Files 24, 25, or 26.

3.5.1. File 27 Format

The structure of a section is then very similar to File 3 (and 23), as follows.

$$\begin{cases} \text{[MAT, 27, MT/ZA, AWR; b, b; b, b]HEAD} \\ \text{[MAT, 27, MT/ b, Z; b, b; NR, NP/}q_{int}\text{/H(q;Z)]TAB1} \\ \text{[MAT, 27, 0/ b, b; b, b; b, b]SEND.} \end{cases}$$

The general symbol H(q;Z) is used for either G(q;Z) or K(q;Z) for coherent and incoherent scattering, respectively.

3.5.2. File 27 Procedures

1. Values of G(q;Z) and K(q;Z) should be entered for the respective entire energy range for which integrated coherent and incoherent cross sections are given in File 23. This is true even though the value may be 0.0 or 1.0, respectively, over most of the (higher) energy range.

2. The value of Z is entered in floating-point format.

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REFERENCES

1. Donald J. Dudziak (Ed.), "ENDF/B Format Requirements for Shielding Applications," LA-3801 (ENDF-111), Los Alamos Scientific Laboratory (1967).

2. Henry C. Honeck, "ENDF/B Specifications for an Evaluated Nuclear Data File for Reactor Application," BNL-50066 (ENDF-102), Brookhaven National Laboratory (1966; Revised July 1967 by S. Pearlstein).

3. Donald J. Dudziak, Alan H. Marshall, and Robert E. Seamon, "LAPH, A Multigroup Photon Production Matrix and Source Vector Code for ENDF/B," LA-4337, Los Alamos Scientific Laboratory (1969). Also LAPHAN, a Los Alamos Scientific Laboratory P_4 version of LAPH (to be published).

4. Henry C. Honeck, "Retrieval Subroutines for the ENDF/B System," in BNL-13582 (ENDF-110), Brookhaven National Laboratory (1967; Revised 1969).

5. Susan M. Miller and K. Parker, "List of Data Files Available in the UKAEA Nuclear Data Library as of 15th April 1965," Report No. 0-55/65, Atomic Weapons Research Establishment, England (1965).

6. Donald J. Dudziak and John F. Romero, "VIXEN, A Physical Consistency Checking Code for Photon Production Data in Revised ENDF Format," a Los Alamos Scientific Laboratory code (to be published).

APPENDIX A

GLOSSARY OF VARIABLE NAMES AND SYMBOLS

$A_{j,i}$ — $\equiv (TP_{j,i})(GP_{j,i})$, the probability of photon emission by a direct transition from level j to level i.

$a_\ell^k(E)$ — The (neutron) energy-dependent Legendre coefficients in the Legendre expansion of the kth photon angular distribution.

AWR — The atomic weight ratio of the target nucleus, i.e., the ratio of the atomic mass to the mass of the neutron.

b — A blank field or the unit "barns."

E — Incident neutron energy (eV).

$E\gamma$ — Photon energy (eV).

EG_k — The photon energy for the kth subsection within a reaction type (eV).

ES_k, ES_i — The energy of the level from which a photon originates. In a transition probability array, ES_i is the energy of the ith level (eV).

$F(E_\gamma \leftarrow E,\mu)$ — An energy-angle distribution function for photon production (photons/eV).

$f_k(E_\gamma \leftarrow E)$ — A normalized (to unity) photon energy distribution (or probability density) function at incident neutron energy E for the kth subsection within a reaction type (eV^{-1}).

$f_\ell(E_\gamma)$ — The (photon) energy-dependent Legendre coefficients in the Legendre expansion of the secondary angular distribution.

$g(E_\gamma \leftarrow E)$ — A particular class of the functions $q_j(E_\gamma \leftarrow E)$ in File 15; those which are tabulated (eV^{-1}).

$G(q;Z)$ — The form factor for coherent photon scattering.

$GP_{j,i} \equiv GP_i$ — The conditional probability of photon emission in a direct transition from level j to level i, $i < j$.

$h(E_\gamma \leftarrow E,\mu)$ — A normalized (to unity) energy-angle distribution function for photon production (eV^{-1}).

$H(q;Z)$ — A general symbology for a form factor or incoherent scattering function; either $G(q;Z)$ or $K(q;Z)$, respectively.

x_{int}	The interpolation table for variable x (cf. Ref. 2, pp. 3.8, 4.5, and 4.6).
K(q;Z)	The incoherent scattering function for incoherent photon scattering.
LF	The photon energy distribution law number.
LG	The transition probability array flag for distinguishing between doublet and triplet arrays in File 12.
LI	The isotropy flag in File 14.
LØ	The option flag to determine whether multiplicities or transition probability arrays are to be given in File 12.
LCT	The option flag to determine whether secondary angular or energy data are given in the laboratory or center-of-mass system.
LFS	The final state number (Ref. 2, p. 7.1).
LTT	The option flag to determine whether angular distributions are to be given as Legendre coefficients or as tabulations.
LVT	The flag to determine whether or not a transformation matrix is given for converting between the laboratory and the center-of-mass systems.
m_o	The mass of the electron ($eV\text{-}sec^2/cm^2$).
MF	The file number (positive integer < 100).
MT	The reaction type number (positive integer < 1000).
MAT	The material number (positive integer < 10,000).
NA	A count of the number of subsections in File 16 for an energy-angle distribution that has tabulated angular distributions, (for $h(E_\gamma \leftarrow E,\mu_m)$, m = 1(1)NA).
NC	A count of the number of subsections in File 15 for normalized continuous photon energy distributions, (for $q_j(E_\gamma \leftarrow E)$, j = 1(1)NC).
NE	A count of the number of energy tabulation points in a TAB2 record.
NI	A count of the number of isotropic photon angular distributions given in a section for which LI = 0; i.e., a section with at least one anisotropic distribution.

NK	A count of the number of subsections in Files 12 and 13 for photon production multiplicities or cross sections, i.e., for $y_k(E)$ or $\sigma_k^\gamma(E)$, respectively, k = 1(1)NK.
NL	A count of the order of the Legendre expansion in Files 14, 16, 24, and 26, i.e., ℓ = 0(1)NL.
NP	A count of the number of points in a tabulation in a TAB1 record.
NR	A count of the number of interpolation regions in a tabulation in either a TAB1 or a TAB2 record.
NS	A count of the number of levels (including the ground state) below a level for which a transition probability array is being given in File 12. Thus, NS is the order number of the level being considered.
NT	A count of the number of transitions for which data are given in a LIST record in File 12, Option 2 (LØ = 2).
$p_k(\mu,E)$	A normalized (to unity) photon angular distribution function at incident neutron energy E for the kth subsection.
$p_j(E)$	The occurrence probability of the jth piecewise continuous and normalized photon energy distribution function in File 15, $q_j(E_\gamma \leftarrow E)$.
q	The momentum of the recoil electron after an incoherent photon scattering event or the momentum of the recoil atom after a coherent photon scattering event (m_oc^2 units).
Q	The reaction energy balance; the usual "Q-value" (eV).
$q_j(E_\gamma \leftarrow E)$	A normalized (to unity) piecewise continuous photon energy distribution function that comprises the jth component of the total such function (eV^{-1}).
$TP_{j,i}$	$\equiv$ TP_i, the probability of a direct transition from level j to level i, i < j.
$y(E_\gamma \leftarrow E)$	A total photon yield (multiplicity) energy distribution function for photon production (photons/eV).
Y(E)	The total photon yield (multiplicity) for a reaction type (photons).
$y_k(E)$	The partial photon yield (multiplicity) for the kth subsection within a reaction type (photons).
Z	The atomic number of a material in File 27.
ZA	= 1000.0 x Z + A, where A is the atomic mass number. For polyisotopic materials, A is set to 0.0.

α $= \frac{E_\gamma}{m_o c^2}$, a dimensionless energy unit.

$\eta_\ell (E_\gamma \leftarrow E)$ The neutron- and photon-energy-dependent Legendre coefficients in the Legendre expansion of the photon energy-angle distribution (eV^{-1}).

μ $= \cos \theta$, the cosine of the polar angle of scattering.

σ_c The integrated Klein-Nishina cross section (b).

σ_{coh} The integrated coherent photon scattering cross section (b).

σ_i The integrated incoherent photon scattering cross section (b).

$\sigma^\gamma_{TOT}(E)$ The total photon production cross section in File 13 for a reaction type MT (b).

$\sigma^\gamma_k(E)$ The partial photon production cross section in File 13 for the kth photon energy distribution subsection (b).

$\sigma_{j,i}(E)$ The cross section to produce the photon that arises from decay of level j to level i, $i < j$ (b).

$\sigma_k(E)$ The neutron interaction cross section for inelastic scattering to level k (b).

APPENDIX B

BCD CARD-IMAGE FORMATS

FILE 12: Multiplicities and Transition Probability Arrays

LØ = 1 (Option 1, Multiplicities)

NK the total number of subsections for a reaction type section (MT number), i.e., the number of discrete photons, plus one if a photon continuum is given.

NR the number of interpolation ranges given.

NP the total number of neutron energy (E) points in the tabulation to follow, i.e., the number of energy-multiplicity pairs.

NBT_i, INT_i the interpolation scheme for the ith interpolation range.

E_i the neutron energy for the ith pair in the tabulation.

$Y(E_i)$ the total yield for all subsections (not given if NK = 1).

$$Y(E) = \sum_{k=1}^{NK} y_k(E).$$

$y_k(E_i)$ the partial multiplicity or yield for the kth subsection within a reaction type section, i.e., for a particular discrete photon or a photon continuum. In the case of a continuum, it is the integrated (over photon energy) multiplicity; the normalized photon energy distribution is given in File 15.

ES_k the energy of the level from which the photon originates. If the level is unknown or if a continuous photon spectrum is produced, then $ES_k \equiv 0.0$ should be used.

EG_k the photon energy. For a continuous photon energy distribution, $EG_k \equiv 0.0$ should be used.

LF the photon energy distribution law number, which presently has only two values defined:

LF = 1, a normalized tabulated function (in File 15), and
= 2, a discrete photon energy.

BCD CARD-IMAGE FORMAT FOR FILE 12

MULTIPLICITIES AND TRANSITION PROBABILITY ARRAYS

LØ = 1 (Option 1, Multiplicities)

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	LØ=1	b	NK	b	HEAD
b	b	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
E_1	$Y(E_1)$	E_2	$Y(E_2)$	E_3	$Y(E_3)$	
---	---	---	---	---	---	
---	---	---	---	E_{NP}	$Y(E_{NP})$	TAB1[a]
EG_1	ES_1	b	LF	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
E_1	$y_1(E_1)$	E_2	$y_1(E_2)$	E_3	$y_1(E_3)$	
---	---	---	---	---	---	
---	---	---	---	E_{NP}	$y_1(E_{NP})$	TAB1
EG_2	ES_2	b	LF	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
E_1	$y_2(E_1)$	E_2	$y_2(E_2)$	E_3	$y_2(E_3)$	
---	---	---	---	---	---	
---	---	---	---	E_{NP}	$y_2(E_{NP})$	TAB1
===	===	===	===	===	===	
EG_{NK}	ES_{NK}	b	LF	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
E_1	$y_{NK}(E_1)$	E_2	$y_{NK}(E_2)$	E_3	$y_{NK}(E_3)$	
---	---	---	---	---	---	
---	---	---	---	E_{NP}	$y_{NK}(E_{NP})$	TAB1
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 12
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number

[a]This record is omitted if NK = 1 (only one subsection).


```
19039.0    3.8766 +01          1                          3         500512103  170
                                                          1       21500512103  171
         21          2                                              500512103  172
1.7      +06 1.0     -20 1.8       +06 2.43902-02 2.0       +06 2.52100-02500512103  173
2.2      +06 5.20693-02 2.4        +06 5.91657-02 2.6       +06 9.68443-02500512103  174
2.8      +06 1.04603-01 3.0        +06 1.36469-01 3.2       +06 1.42693-01500512103  175
3.4      +06 1.66827-01 3.6        +06 2.03428-01 3.8       +06 2.41745-01500512103  176
4.0      +06 2.45522-01 4.5        +06 2.15197-01 5.0       +06 1.74247-01500512103  177
5.5      +06 1.41290-01 6.0        +06 1.11875-01 6.5       +06 8.93938-02500512103  178
7.0      +06 6.69615-01 7.5        +06 5.47975-01 8.0       +06 4.53520-02500512103  179
1.52     +06 1.52    +06                          2       1       19500512103  180
         19          2                                              500512103  181
2.0      +06 1.0     -20 2.2       +06 9.34570-03 2.4       +06 1.16391-02500512103  182
2.6      +06 1.95865-02 2.8        +06 2.09205-02 3.0       +06 2.62143-02500512103  183
3.2      +06 [illegible].58918-02 3.4        +06 2.78846-02 3.6       +06 3.24561-02500512103  184
3.8      +06 3.78048-02 4.0        +06 3.84328-02 4.5       +06 3.81625-02500512103  185
5.0      +06 3.44481-02 5.5        +06 3.06451-02 6.0       +06 2.65625-02500512103  186
6.5      +06 2.21212-02 7.0        +06 1.79941-02 7.5       +06 1.46551-02500512103  187
8.0      +06 1.26760-02                                             500512103  188
1.27     +06 1.27    +06                          2       1       21500512103  189
         21          2                                              500512103  190
1.7      +06 1.0     -20 1.8       +06 2.43902-02 2.0       +06 2.52100-02500512103  191
2.2      +06 3.20427-02 2.4        +06 3.49175-02 2.6       +06 5.76713-02500512103  192
2.8      +06 6.27615-02 3.0        +06 8.40400-02 3.2       +06 9.09090-02500512103  193
3.4      +06 1.10577-01 3.6        +06 1.35965-01 3.8       +06 1.65322-02500512103  194
4.0      +06 1.67910-01 4.5        +06 1.38516-01 5.0       +06 1.04682-01500512103  195
5.5      +06 7.96774-02 6.0        +06 5.81250-02 6.5       +06 4.48484-02500512103  196
7.0      +06 3.06784-02 7.5        +06 2.47126-02 8.0       +06 1.97183-02500512103  197
2.5      E+5 1.52    E+6                          2       1       19500512103  198
         19          2                                              500512103  199
2.0      +06 1.0     -20 2.2       +06 1.06809-02 2.4       +06 1.26091-02500512103  200
2.6      +06 1.95865-02 2.8        +06 2.09205-02 3.0       +06 2.62143-02500512103  201
3.2      +06 2.58918-02 3.4        +06 2.83653-02 3.6       +06 3.24561-02500512103  202
3.8      +06 3.86178-02 4.0        +06 3.91791-02 4.5       +06 3.85159-02500512103  203
5.0      +06 3.51170-02 5.5        +06 3.09677-02 6.0       +06 2.71875-02500512103  204
6.5      +06 2.24242-02 7.0        +06 1.82890-02 7.5       +06 1.52298-02500512103  205
8.0      +06 1.29577-02                                             500512103  206
                                                                    500512  0  207
```

FILE 12: Multiplicities and Transition Probability Arrays

LØ = 1 (Option 1, Multiplicities)

$$y_k(E) = \frac{\sigma_k^\gamma(E)}{\sigma(E)}$$

$\sigma(E)$ is given in File 3 for same MT number.

$$y_k(E_\gamma \leftarrow E) = y_k(E)\; f_k(E_\gamma \leftarrow E)$$

$$\int_0^{E_\gamma^{max}} f_k(E_\gamma \leftarrow E)\; dE_\gamma = 1.000$$

$$Y(E) = \sum_{k=1}^{NK} y_k(E) \;.$$

FILE 12: Multiplicities and Transition Probability Arrays

LØ = 2 (Option 2, Transition Probability Arrays)

LG = 1, simple case (all transitions are γ emission).
= 2, complex case (internal conversion or other competing processes occur).

NS number of levels below the present one, including the ground state. (The present level is also uniquely defined by the MT number and by its energy level.)

ES_{NS} energy of the present (NS) level for which the decay scheme (transition probabilities) is being specified.

NT number of transitions for which data are given in a list to follow (i.e., number of nonzero transition probabilities), NT $\leq$ NS.

B_i If LG = 1, B_i is the doublet (ES_i,TP_i).
If LG = 2, B_i is the triplet (ES_i,TP_i,GP_i).

ES_i energy of the ith level, i = 0(1)NS. ($ES_o \equiv 0.0$, the ground state.)

$TP_i \equiv TP_{NS,i}$, the probability of a direct transition from level NS to level i, i = 0(1)NS - 1.

$GP_i \equiv GP_{NS,i}$, the probability that, given a transition from level NS to level i, the transition is a photon transition (i.e., the conditional probability of photon emission).

BCD CARD-IMAGE FORMAT FOR FILE 12

MULTIPLICITIES AND TRANSITION PROBABILITY ARRAYS

LØ = 2 (Option 2, Transition Probability Arrays).

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	LØ=2	LG	NS	b	HEAD
ES_{NS}	b	b	b	(LG+1)*NT	NT	
ES_1	TP_1	(GP_1)	ES_2	TP_2	(GP_2)	
---	---	---	---	---	---	
---	---	---	ES_{NT}	TP_{NT}	(GP_{NT})	LIST
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 12
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number


```
   12024.0 2.4103E+01          2          1         14          500212 64 7627
6.0000E+06                                           6         3500212 64 7628
4.2320F+06 0.045       4.1200E+06 0.045       1.3680E+06 0.91    500212 64 7629
                                                                 500212  0 7630
```

FILE 12: Multiplicities and Transition Probability Arrays

LØ = 2 (Option 2, Transition Probability Arrays)

$$A_i = (TP_i)(GP_i)$$

$$\frac{d\sigma}{dE_\gamma}(E_\gamma, E) = \sum_{j=1}^{N}\sum_{i=0}^{j-1}\sum_{m_o=j}^{N} \delta(E_\gamma - \varepsilon_j + \varepsilon_i)\, A_{j,i}\, \sigma_{m_o}(E) \prod_{\ell=1}^{m_o-j} \sum_{m_\ell=j}^{m_{\ell-1}-1} TP_{m_{\ell-1},m_\ell}$$

$$\sum_{i=0}^{NS-1} TP_i = 1.0000 \quad .$$

FILE 13: Photon Production Cross Sections

NK the total number of subsections for a reaction type section (MT number); i.e., the number of discrete photons, plus one if a photon continuum is given.

NR the number of interpolation ranges given.

NP the total number of neutron energy (E) points in the TAB1 tabulation to follow; i.e., the number of energy-cross-section pairs.

NBT_i, INT_i the interpolation scheme for the ith interpolation region.

E_i the neutron energy for the ith pair in the tabulation.

$\sigma^\gamma_{TOT}(E_i)$ the total photon production cross section for all subsections (not given if NK = 1),

$$\sigma^\gamma_{TOT}(E_i) = \sum_{k=1}^{NK} \sigma^\gamma_k(E_i).$$

$\sigma^\gamma_k(E_i)$ the partial photon production cross section for the kth subsection within a reaction type section; i.e., for a particular discrete photon or a photon continuum. In the case of a continuum, it is the integrated (over photon energy) cross section; the normalized photon energy distribution is given in File 15.

EG_k the photon energy. For a continuous photon energy distribution, $EG_k \equiv 0.0$ should be used.

ES_k the energy of the level from which the photon originates. If the level is unknown or if a continuous photon spectrum is produced, then $ES_k \equiv 0.0$ should be used.

LF the photon energy distribution law number, which presently has only two values defined.

LF = 1, a normalized tabulated function (in File 15), and
= 2, a discrete photon energy.

BCD CARD-IMAGE FORMAT FOR FILE 13

PHOTON PRODUCTION CROSS SECTIONS

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	b	b	NK	b	HEAD
b	b	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
—	—	—	—	NBT_{NR}	INT_{NR}	
E_1	$\sigma^{\gamma}_{TOT}(E_1)$	E_2	$\sigma^{\gamma}_{TOT}(E_2)$	E_3	$\sigma^{\gamma}_{TOT}(E_3)$	
—	—	—	—	—	—	
—	—	—	—	E_{NP}	$\sigma^{\gamma}_{TOT}(E_{NP})$	TAB1[a]
EG_1	ES_1	b	LF	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
—	—	—	—	NBT_{NR}	INT_{NR}	
E_1	$\sigma^{\gamma}_{1}(E_1)$	E_2	$\sigma^{\gamma}_{1}(E_2)$	E_3	$\sigma^{\gamma}_{1}(E_3)$	
—	—	—	—	—	—	
—	—	—	—	E_{NP}	$\sigma^{\gamma}_{1}(E_{NP})$	TAB1
EG_2	ES_2	b	LF	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
—	—	—	—	NBT_{NR}	INT_{NR}	
E_1	$\sigma^{\gamma}_{2}(E_1)$	E_2	$\sigma^{\gamma}_{2}(E_2)$	E_3	$\sigma^{\gamma}_{2}(E_3)$	
—	—	—	—	—	—	
—	—	—	—	E_{NP}	$\sigma^{\gamma}_{2}(E_{NP})$	TAB1
⋮	⋮	⋮	⋮	⋮	⋮	
EG_{NK}	ES_{NK}	b	LF	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
—	—	—	—	NBT_{NR}	INT_{NR}	
E_1	$\sigma^{\gamma}_{NK}(E_1)$	E_2	$\sigma^{\gamma}_{NK}(E_2)$	E_3	$\sigma^{\gamma}_{NK}(E_3)$	
—	—	—	—	—	—	
—	—	—	—	E_{NP}	$\sigma^{\gamma}_{NK}(E_{NP})$	TAB1
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 13
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number

[a] This record omitted if NK = 1 (only one subsection).


```
19039.0     3.8766 +01                                      2          500513  3  218
                                                            2         6500513  3  219
           2           3           6           2                       500513  3  220
3.6        +06 1.0     -20 4.0     +06 1.6     -02 5.0     +06 2.4    -02500513  3  221
7.0        +06 3.2     -02 1.0     +07 2.87    -03 1.5     +07 2.62   -02500513  3  222
3.02       +06 3.02    +06                     2           2          6500513  3  223
           2           3           6           2                       500513  3  224
3.6        +06 1.0     -20 4.0     +06 1.5     -02 5.0     +06 2.1    -02500513  3  225
7.0        +06 2.3     -02 1.0     +07 2.0     -02 1.5     +07 1.8    -02500513  3  226
1.35       +06 3.88    +06                     2           1          4500513  3  227
           4           2                                               500513  3  228
4.0        +06 1.0     -03 5.0     +06 3.0     -03 7.0     +06 9.0    -03500513  3  229
1.5        +07 8.2     -03                                             500513  3  230
                                                                       500513  0  231
```

FILE 13: Photon Production Cross Sections

$$\frac{d\sigma_k^\gamma}{dE_\gamma}(E_\gamma \leftarrow E) = \sigma_k^\gamma(E)\ f_k(E_\gamma \leftarrow E)$$

$$\int_0^{E_\gamma^{max}} f_k(E_\gamma \leftarrow E)\ dE_\gamma = 1.000$$

$$\sigma_{TOT}^\gamma(E) = \sum_{k=1}^{NK} \sigma_k^\gamma(E) \quad .$$

FILE 14: Photon Angular Distributions

LI = 1 (Isotropic Distributions for all Photons)

NK the total number of subsections for a reaction type section (MT number); i.e., the number of discrete photons, plus one if a photon continuum is given.

BCD CARD-IMAGE FORMAT FOR FILE 14

PHOTON ANGULAR DISTRIBUTIONS

LI = 1 (Isotropic Distribution for All Photons)

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	LI=1	b	NK	b	HEAD
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 14
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number


```
1.2024E 04 2.4103E 01         1                    1          500214 51 6680
                                                              500214  0 6681
```

FILE 14: Photon Angular Distributions

LI = 1 (Isotropic Distributions for all Photons)

$$\left.\begin{array}{ll} p_k(\mu,E) \equiv 0.5 & \\ a_\ell^k(E) \equiv 0.0, & \ell = 1(1)NL \end{array}\right\} \text{ all } k \;.$$

FILE 14: Photon Angular Distributions

LI = 0 (Anisotropic Distributions for Some Photons)

LTT = 1 (Legendre Coefficient Representation

NK the total number of subsections for a reaction type section (MT number); i.e., the number of discrete photons, plus one if a photon continuum is given.

NI the number of isotropic photon angular distributions given in a section (MT number).

EG_k the photon energy. For a continuous photon energy distribution, $EG_k \equiv 0.0$ should be used.

ES_k the energy of the level from which the photon originates. If the level is unknown or if a continuous photon spectrum is produced, then $ES_k \equiv 0.0$ should be used.

NR the number of interpolation ranges given.

NE the number of neutron energy points given in a TAB2 record.

NBT_i, INT_i the interpolation scheme for the ith interpolation region.

E_i the neutron energy for the ith LIST record in a subsection.

NL_i the number of Legendre coefficients used to represent the angular distribution at neutron energy E_i, excluding $a_0^k(E) \equiv 1.0$ that is understood; that is, $\ell = 1(1)NL$.

$a_\ell^k(E_i)$ the ℓth Legendre coefficient for the angular distribution of the kth photon at incident neutron energy E_i.

BCD CARD-IMAGE FORMAT FOR FILE 14

PHOTON ANGULAR DISTRIBUTIONS

LI = 0 (Anisotropic Distributions for Some Photons)
LTT = 1 (Legendre Coefficient Representation)

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	LI=0	LTT=1	NK	NI	HEAD
EG_1	ES_1	b	b	b	b	CONT
EG_2	ES_2	b	b	b	b	CONT
===	===	===	===	===	===	
EG_{NI}	ES_{NI}	b	b	b	b	CONT
EG_{NI+1}	ES_{NI+1}	b	b	NR	NE	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	TAB2
b	E_1	b	b	NL_1	b	
$a_1^{NI+1}(E_1)$	$a_2^{NI+1}(E_1)$	---	---	---	$a_{NL}^{NI+1}(E_1)$	LIST
b	E_2	b	b	NL_2	b	
$a_1^{NI+1}(E_2)$	$a_2^{NI+1}(E_2)$	---	---	---	$a_{NL}^{NI+1}(E_2)$	LIST
===	===	===	===	===	===	
b	E_{NE}	b	b	NL_{NE}	b	
$a_1^{NI+1}(E_{NE})$	$a_2^{NI+1}(E_{NE})$	---	---	---	$a_{NL}^{NI+1}(E_{NE})$	LIST
EG_{NI+2}	ES_{NI+2}	b	b	NR	NE	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	TAB2
b	E_1	b	b	NL_1	b	
$a_1^{NI+2}(E_1)$	$a_2^{NI+2}(E_1)$	---	---	---	$a_{NL}^{NI+2}(E_1)$	LIST
b	E_2	b	b	NL_2	b	
$a_1^{NI+2}(E_2)$	$a_2^{NI+2}(E_2)$	---	---	---	$a_{NL}^{NI+2}(E_2)$	LIST
===	===	===	===	===	===	
b	E_{NE}	b	b	NL_{NE}	b	
$a_1^{NI+2}(E_{NE})$	$a_2^{NI+2}(E_{NE})$	---	---	---	$a_{NL}^{NI+2}(E_{NE})$	LIST
===	===	===	===	===	===	
EG_{NK}	ES_{NK}	b	b	NR	NE	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	TAB2
b	E_1	b	b	NL_1	b	
$a_1^{NK}(E_1)$	$a_2^{NK}(E_1)$	---	---	---	$a_{NL}^{NK}(E_1)$	LIST
b	E_2	b	b	NL_2	b	
$a_1^{NK}(E_2)$	$a_2^{NK}(E_2)$	---	---	---	$a_{NL}^{NK}(E_2)$	LIST
===	===	===	===	===	===	
b	E_{NE}	b	b	NL_{NE}	b	
$a_1^{NK}(E_{NE})$	$a_2^{NK}(E_{NE})$	---	---	---	$a_{NL}^{NK}(E_{NE})$	LIST
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 14
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number

FILE 14:

This page left blank because no data presently exist in ENDF format under the LTT = 1 option.

FILE 14: Photon Angular Distributions

LI = 0 (Anisotropic Distributions for Some Photons)

LTT = 1 (Legendre Coefficient Representation)

$$p_k(\mu,E) = \frac{2\pi}{\sigma_k^\gamma(E)} \frac{d\sigma_k^\gamma}{d\underline{\Omega}}(\underline{\Omega},E)$$

$$= \sum_{\ell=0}^{NL} \frac{2\ell+1}{2} a_\ell^k(E)\, P_\ell(\mu)$$

$$P_\ell(\mu) = \frac{1}{2^\ell \ell!} \frac{d^\ell}{d\mu^\ell}(\mu^2 - 1)^\ell$$

$$a_\ell^k(E) = \int_{-1}^{1} p_k(\mu,E)\, P_\ell(\mu)\, d\mu$$

$$\int_{-1}^{1} p_k(\mu,E)\, d\mu = 1.000 \quad .$$

FILE 14: Photon Angular Distributions

LI = 0 (Anisotropic Distributions for Some Photons)

LTT = 2 (Tabulated Angular Distributions)

NK the total number of subsections for a reaction type section (MT number); i.e., the number of discrete photons, plus one if a photon continuum is given.

NI the number of isotropic photon angular distributions given in a section (MT number).

EG_k the photon energy. For a continuous photon energy distribution, $EG_k \equiv 0.0$ should be used.

ES_k the energy of the level from which the photon originates. If the level is unknown or if a continuous photon spectrum is produced, then $ES_k \equiv 0.0$ should be used.

NR the number of interpolation ranges given.

NE the number of neutron energy points given in a TAB2 record.

NBT_i, INT_i the interpolation scheme for the ith interpolation region.

E_i the neutron energy for the ith TAB1 record in a subsection.

μ the cosine of the reaction angle, $\mu = \cos\theta$.

$p_k(\mu,E_i)$ probability distribution function (normalized) at μ of photons produced by a neutron of incident energy E_i for the kth photon energy.

BCD CARD-IMAGE FORMAT FOR FILE 14

PHOTON ANGULAR DISTRIBUTIONS

LI = 0 (Anisotropic Distributions for Some Photons)
LTT = 2 (Tabulated Angular Distributions)

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	LI=0	LTT=2	NK	NI	HEAD
EG_1	ES_1	b	b	b	b	CONT
EG_2	ES_2	b	b	b	b	CONT
⋮	⋮	⋮	⋮	⋮	⋮	
EG_{NI}	ES_{NI}	b	b	b	b	CONT
EG_{NI+1} NBT_1 —	ES_{NI+1} INT_1 —	b NBT_2 —	b INT_2 —	NR NBT_3 NBT_{NR}	NE INT_3 INT_{NR}	TAB2
b NBT_1 — μ_1 —	E_1 INT_1 — $P_{NI+1}(\mu_1,E_1)$ —	b NBT_2 — μ_2 —	b INT_2 — $P_{NI+1}(\mu_2,E_1)$ —	NR NBT_3 NBT_{NR} μ_3 μ_{NP}	NP INT_3 INT_{NR} $P_{NI+1}(\mu_3,E_1)$ $P_{NI+1}(\mu_{NP},E_1)$	TAB1
b NBT_1 — μ_1 —	E_2 INT_1 — $P_{NI+1}(\mu_1,E_2)$ —	b NBT_2 — μ_2 —	b INT_2 — $P_{NI+1}(\mu_2,E_2)$ —	NR NBT_3 NBT_{NR} μ_3 μ_{NP}	NP INT_3 INT_{NR} $P_{NI+1}(\mu_3,E_2)$ $P_{NI+1}(\mu_{NP},E_2)$	TAB1
⋮	⋮	⋮	⋮	⋮	⋮	
b NBT_1 — μ_1 —	E_{NE} INT_1 — $P_{NI+1}(\mu_1,E_{NE})$ —	b NBT_2 — μ_2 —	b INT_2 — $P_{NI+1}(\mu_2,E_{NE})$ —	NR NBT_3 NBT_{NR} μ_3 μ_{NP}	NP INT_3 INT_{NR} $P_{NI+1}(\mu_3,E_{NE})$ $P_{NI+1}(\mu_{NP},E_{NE})$	TAB1
⋮	⋮	⋮	⋮	⋮	⋮	
EG_{NK} NBT_1 —	ES_{NK} INT_1 —	b NBT_2 —	b INT_2 —	NR NBT_3 NBT_{NR}	NE INT_3 INT_{NR}	TAB2
b NBT_1 — μ_1 —	E_1 INT_1 — $P_{NK}(\mu_1,E_1)$ —	b NBT_2 — μ_2 —	b INT_2 — $P_{NK}(\mu_2,E_1)$ —	NR NBT_3 NBT_{NR} μ_3 μ_{NP}	NP INT_3 INT_{NR} $P_{NK}(\mu_3,E_1)$ $P_{NK}(\mu_{NP},E_1)$	TAB1
b NBT_1 — μ_1 —	E_2 INT_1 — $P_{NK}(\mu_1,E_2)$ —	b NBT_2 — μ_2 —	b INT_2 — $P_{NK}(\mu_2,E_2)$ —	NR NBT_3 NBT_{NR} μ_3 μ_{NP}	NP INT_3 INT_{NR} $P_{NK}(\mu_3,E_2)$ $P_{NK}(\mu_{NP},E_2)$	TAB1
⋮	⋮	⋮	⋮	⋮	⋮	
b NBT_1 — μ_1 —	E_{NE} INT_1 — $P_{NK}(\mu_1,E_{NE})$ —	b NBT_2 — μ_2 —	b INT_2 — $P_{NK}(\mu_2,E_{NE})$ —	NR NBT_3 NBT_{NR} μ_3 μ_{NP}	NP INT_3 INT_{NR} $P_{NK}(\mu_3,E_{NE})$ $P_{NK}(\mu_{NP},E_{NE})$	TAB1
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 14
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number


```
 1.2024 +04 2.4103 +01          0          2          3       2500214 64 7467
 1.88   +06 6.0    +06                                           500214 64 7468
 1.768  +06 6.0    +06                                           500214 64 7469
 4.632  E+6 6.00   E+6                                1         3500214 64 7470
          3          2                                           500214 64 7471
            6.2520E 06                                1        21500214 64 7472
         21          2                                           500214 64 7473
-1.0000E 00 6.2066E-01-9.0000E-01 6.2571E-01-8.0000E-01 6.0872E-01500214 64 7474
-7.0000E-01 5.7916E-01-6.0000E-01 5.3735E-01-5.0000E-01 5.3000E-01500214 64 7475
-4.0000E-01 4.5185E-01-3.0000E-01 4.1589E-01-2.0000E-01 3.8834E-01500214 64 7476
-1.0000E-01 3.7035E-01 0.         3.6463E-01 1.0000E-01 3.7035E-01500214 64 7477
 2.0000E-01 3.8834E-01 3.0000E-01 4.1589E-01 4.0000E-01 4.5185E-01500214 64 7478
 5.0000E-01 5.3000E-01 6.0000E-01 5.3735E-01 7.0000E-01 5.7916E-01500214 64 7479
 8.0000E-01 6.0872E-01 9.0000E-01 6.2571E-01 1.0000E 00 6.2066E-01500214 64 7480
            6.5000E 06                                1        21500214 64 7481
         21          2                                           500214 64 7482
-1.0000E 00 6.2748E-01-9.0000E-01 6.2969E-01-8.0000E-01 6.1154E-01500214 64 7483
-7.0000E-01 5.7819E-01-6.0000E-01 5.3927E-01-5.0000E-01 4.9664E-01500214 64 7484
-4.0000E-01 4.5589E-01-3.0000E-01 4.2067E-01-2.0000E-01 3.9286E-01500214 64 7485
-1.0000E-01 3.7619E-01 0.         3.7063E-01 1.0000E-01 3.7619E-01500214 64 7486
 2.0000E-01 3.9286E-01 3.0000E-01 4.2067E-01 4.0000E-01 4.5589E-01500214 64 7487
 5.0000E-01 4.9664E-01 6.0000E-01 5.3927E-01 7.0000E-01 5.7819E-01500214 64 7488
 8.0000E-01 6.1154E-01 9.0000E-01 6.2969E-01 1.0000E 00 6.2748E-01500214 64 7489
            7.0000E 06                                1        21500214 64 7490
         21          2                                           500214 64 7491
-1.0000E 00 6.2433E-01-9.0000E-01 6.2209E-01-8.0000E-01 6.0499E-01500214 64 7492
-7.0000E-01 5.7078E-01-6.0000E-01 5.3174E-01-5.0000E-01 4.9083E-01500214 64 7493
-4.0000E-01 4.5328E-01-3.0000E-01 4.1944E-01-2.0000E-01 4.3134E-01500214 64 7494
-1.0000E-01 3.7743E-01 0.         3.7184E-01 1.0000E-01 3.7743E-01500214 64 7495
 2.0000E-01 4.3134E-01 3.0000E-01 4.1944E-01 4.0000E-01 4.5328E-01500214 64 7496
 5.0000E-01 4.9083E-01 6.0000E-01 5.3174E-01 7.0000E-01 5.7078E-01500214 64 7497
 8.0000E-01 6.0499E-01 9.0000E-01 6.2209E-01 1.0000E 00 6.2433E-01500214 64 7498
                                                                 500214  0 7499
```

FILE 14: Photon Angular Distributions

LI = 0 (Anisotropic Distributions for Some Photons)

LTT = 2 (Tabulated Angular Distributions)

$$p_k(\mu,E) = \frac{2\pi}{\sigma_k^\gamma(E)} \frac{d\sigma_k^\gamma}{d\Omega}(\underline{\Omega},E)$$

$$\int_{-1}^{1} p_k(\mu,E)\,d\mu = 1.000 \quad .$$

FILE 15: Continuous Photon Energy Spectra

NC number of partial distributions used to represent a normalized energy distribution, $f(E_\gamma \leftarrow E)$.

LF the photon energy distribution law number, which presently has only one continuous distribution defined: LF = 1, a normalized tabulated function.

NR the number of interpolation ranges given.

NP the total number of neutron or photon energy points in the tabulation to follow.

NBT_i, INT_i the interpolation scheme for the ith interpolation range.

E_i the neutron energy for the ith TAB1 record.

$p_1(E_i)$ the probability given to the first partial distribution [$p_1(E_i) \equiv 1.0$ because only one distribution law is presently defined].

NE the number of neutron energy points given in a TAB2 record.

$E_{\gamma k}$ the photon energy for the kth pair in a TAB1 record for the tabulated photon energy distribution.

$g(E_{\gamma k} \leftarrow E_i)$ the probability distribution tabulated at photon energy $E_{\gamma k}$ for an incident neutron energy E_i (units of eV^{-1}).

BCD CARD-IMAGE FORMAT FOR FILE 15

CONTINUOUS PHOTON ENERGY SPECTRA

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	b	b	NC[a]	b	HEAD
b	b	b	LF=1	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
E_1	$p_1(E_1)$	E_2	$p_1(E_2)$	E_3	$p_1(E_3)$	
---	---	---	---	E_{NP}	$p_1(E_{NP})$	TAB1
b	b	b	b	NR	NE	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	TAB2
b	E_1	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
$E_{\gamma 1}$	$g(E_{\gamma 1} \leftarrow E_1)$	$E_{\gamma 2}$	$g(E_{\gamma 2} \leftarrow E_1)$	$E_{\gamma 3}$	$g(E_{\gamma 3} \leftarrow E_1)$	
---	---	---	---	$E_{\gamma NP}$	$g(E_{\gamma NP} \leftarrow E_1)$	TAB1
b	E_2	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
$E_{\gamma 1}$	$g(E_{\gamma 1} \leftarrow E_2)$	$E_{\gamma 2}$	$g(E_{\gamma 2} \leftarrow E_2)$	$E_{\gamma 3}$	$g(E_{\gamma 3} \leftarrow E_2)$	
---	---	---	---	$E_{\gamma NP}$	$g(E_{\gamma NP} \leftarrow E_2)$	TAB1
===	===	===	===	===	===	
b	E_{NE}	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
$E_{\gamma 1}$	$g(E_{\gamma 1} \leftarrow E_{NE})$	$E_{\gamma 2}$	$g(E_{\gamma 2} \leftarrow E_{NE})$	$E_{\gamma 3}$	$g(E_{\gamma 3} \leftarrow E_{NE})$	
---	---	---	---	$E_{\gamma NP}$	$g(E_{\gamma NP} \leftarrow E_{NE})$	TAB1
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 15
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number

[a]Because only one law is presently defined, only NC = 1 is possible.


```
1.2024E+04 2.4103E+01                                  1          500215 15 1080
                                            1          1         2500215 15 1081
         2          2                                             500215 15 1082
4.0    E+06 1.0        2.0    E+07 1.0                            500215 15 1083
0.0                               0                    1         9500215 15 1084
         9          2                                             500215 15 1085
           4.0000E+06                                  1         6500215 15 1086
         6          2                                             500215 15 1087
1.0000E+05 9.9280E-26 2.5000E+05 7.9424E-08 7.5000E+05 2.4820E-07500215 15 1088
1.2500E+06 3.5741E-07 1.7500E+06 9.4316E-07 2.5000E+06 2.1842E-07500215 15 1089
           6.0000E+06                                  1         8500215 15 1090
         8          2                                             500215 15 1091
1.0000E+05 5.3512E-26 2.5000E+05 4.4950E-08 7.5000E+05 1.4047E-07500215 15 1092
1.2500E+06 2.0228E-07 1.7500E+06 5.3378E-07 2.5000E+06 2.0228E-07500215 15 1093
3.5000E+06 1.6856E-07 4.5000E+06 2.6970E-07                       500215 15 1094
           8.0000E+06                                  1        10500215 15 1095
        10          2                                             500215 15 1096
1.0000E+05 2.9539E-26 2.5000E+05 2.7176E-08 7.5000E+05 8.4925E-08500215 15 1097
1.2500E+06 1.2229E-07 1.7500E+06 3.2286E-07 2.5000E+06 2.7516E-07500215 15 1098
3.5000E+06 2.0382E-07 4.5000E+06 1.6306E-07 5.5000E+06 7.1337E-08500215 15 1099
6.5000E+06 1.3588E-08                                             500215 15 1100
           1.0000E+07                                  1        11500215 15 1101
        11          2                                             500215 15 1102
1.0000E+05 1.4736E-26 2.5000E+05 1.4582E-08 7.5000E+05 4.5577E-08500215 15 1103
1.2500E+06 6.5618E-08 1.7500E+06 1.7314E-07 2.5000E+06 3.5351E-07500215 15 1104
3.5000E+06 2.3327E-07 4.5000E+06 1.4942E-07 5.5000E+06 9.1140E-08500215 15 1105
6.5000E+06 4.7390E-08 7.5000E+06 1.8228E-09                       500215 15 1106
           1.2000E+07                                  1        12500215 15 1107
        12          2                                             500215 15 1108
1.0000E+05 1.4386E-26 2.5000E+05 1.2982E-08 7.5000E+05 4.0569E-08500215 15 1109
1.2500E+06 5.8422E-08 1.7500E+06 1.5422E-07 2.5000E+06 3.2124E-07500215 15 1110
3.5000E+06 2.2399E-07 4.5000E+06 1.4280E-07 5.5000E+06 9.4114E-08500215 15 1111
6.5000E+06 6.6536E-08 7.5000E+06 3.8943E-08 8.5000E+06 4.8682E-09500215 15 1112
           1.4000E+07                                  1        14500215 15 1113
        14          2                                             500215 15 1114
1.0000E+05 1.4273E-26 2.5000E+05 1.1419E-08 7.5000E+05 3.5684E-08500215 15 1115
1.2500E+06 5.1385E-08 1.7500E+06 1.3560E-07 2.5000E+06 2.8975E-07500215 15 1116
3.5000E+06 2.1125E-07 4.5000E+06 1.3703E-07 5.5000E+06 9.1350E-08500215 15 1117
6.5000E+06 6.7085E-08 7.5000E+06 5.2812E-08 8.5000E+06 3.5684E-09500215 15 1118
9.5000E+06 1.8556E-08 1.0500E+07 1.4273E-09                       500215 15 1119
           1.6000E+07                                  1        15500215 15 1120
        15          2                                             500215 15 1121
1.0000E+05 1.7168E-26 2.5000E+05 7.2928E-09 7.5000E+05 2.2799E-09500215 15 1122
1.2500E+06 5.3426E-07 1.7500E+06 8.6610E-08 2.5000E+06 1.8695E-07500215 15 1123
3.5000E+06 1.4313E-07 4.5000E+06 1.0119E-07 5.5000E+06 7.2018E-08500215 15 1124
6.5000E+06 5.5606E-08 7.5000E+06 4.5580E-08 8.5000E+06 3.6464E-09500215 15 1125
9.5000E+06 2.6438E-08 1.0500E+07 1.7322E-08 1.1500E+07 7.2928E-09500215 15 1126
           1.8000E+07                                  1        17500215 15 1127
        17          2                                             500215 15 1128
1.0000E+05 1.7403E-26 2.5000E+05 6.5157E-09 7.5000E+05 2.0362E-09500215 15 1129
1.2500E+06 4.7719E-07 1.7500E+06 7.7374E-08 2.5000E+06 1.7022E-07500215 15 1130
3.5000E+06 1.3275E-07 4.5000E+06 1.0181E-07 5.5000E+06 7.9010E-08500215 15 1131
6.5000E+06 6.1903E-08 7.5000E+06 4.9686E-08 8.5000E+06 4.0723E-08500215 15 1132

9.5000E+06 3.1761E-08 1.0500E+07 2.4434E-08 1.1500E+07 1.7104E-09500215 15 1133
1.2500E+07 1.0588E-08 1.3500E+07 4.0723E-09                       500215 15 1134
           2.0000E+07                                  1        19500215 15 1135
        19          2                                             500215 15 1136
1.0000E+05 1.8057E-26 2.5000E+05 5.7203E-09 7.5000E+05 1.7876E-08500215 15 1137
1.2500E+06 4.1910E-07 1.7500E+06 6.7929E-08 2.5000E+06 1.5159E-07500215 15 1138
3.5000E+06 1.2441E-07 4.5000E+06 1.0011E-07 5.5000E+06 8.0081E-08500215 15 1139
6.5000E+06 6.5076E-08 7.5000E+06 5.3628E-08 8.5000E+06 4.5051E-08500215 15 1140
9.5000E+06 3.7901E-08 1.0500E+07 3.1455E-08 1.1500E+07 2.5027E-08500215 15 1141
1.2500E+07 1.9303E-08 1.3500E+07 1.3586E-08 1.4500E+07 7.8655E-09500215 15 1142
1.5500E+07 2.1451E-09                                             500215 15 1143
                                                                  500215  0 1144
```

FILE 15: Continuous Photon Energy Spectra

$$f(E_\gamma \leftarrow E) = \sum_{j=1}^{NC} p_j(E)\, q_j(E_\gamma \leftarrow E_i)$$

$$\sum_{j=1}^{NC} p_j(E) = 1.000$$

$$\int_0^{E_\gamma^{max}} f(E_\gamma \leftarrow E)\, dE_\gamma = 1.000$$

$$\int_0^{E_\gamma^{max}} q_j(E_\gamma \leftarrow E)\, dE_\gamma = 1.000 \ .$$

FILE 23: "Smooth" Cross Sections

NR — the number of interpolation ranges given.

NP — the total number of photon energy (E_γ) points given in the tabulation to follow; i.e., the number of energy-cross-section pairs.

NBT_i, INT_i — the interpolation scheme for the ith interpolation range.

$E_{\gamma j}$ — the photon energy for the jth pair in the tabulation.

$\sigma(E_{\gamma j})$ — the photon interaction cross section.

$B_{\overline{B}}8$

BCD CARD-IMAGE FORMAT FOR FILE 23

"SMOOTH" CROSS SECTIONS

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	b	b	b	b	HEAD
b	b	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
—	—	—	—	NBT_{NR}	INT_{NR}	
$E_{\gamma 1}$	$\sigma(E_{\gamma 1})$	$E_{\gamma 2}$	$\sigma(E_{\gamma 2})$	$E_{\gamma 3}$	$\sigma(E_{\gamma 3})$	
—	—	—	—	—	—	
—	—	—	—	$E_{\gamma NP}$	$\sigma(E_{\gamma NP})$	TAB1
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 23
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number

$B_{\overline{C}}8$

```
5.00000+ 4 1.17670+ 2          0          0          0          0 5023602  283
0.00000+ 0 0.00000+ 0          0          0          1         49 5023602  284
        49          5                                             5023602  285
1.00000+ 3 1.59000+ 6 1.50000+ 3 6.43000+ 5 2.00000+ 3 3.21000+ 5 5023602  286
3.00000+ 3 1.18000+ 5 3.92900+ 3 6.00000+ 4 3.92939+ 3 1.97000+ 5 5023602  287
4.00000+ 3 1.84000+ 5 4.15600+ 3 1.66000+ 5 4.15642+ 3 2.28000+ 5 5023602  288
4.46500+ 3 1.90000+ 5 4.46545+ 3 2.19000+ 5 5.00000+ 3 1.65000+ 5 5023602  289
6.00000+ 3 1.03000+ 5 8.00000+ 3 4.81000+ 4 1.00000+ 4 2.64000+ 4 5023602  290
1.50000+ 4 8.69000+ 3 2.00000+ 4 3.91000+ 3 2.92000+ 4 1.37000+ 3 5023602  291
2.92029+ 4 8.51000+ 3 3.00000+ 4 7.87000+ 3 4.00000+ 4 3.70000+ 3 5023602  292
5.00000+ 4 2.01000+ 3 6.00000+ 4 1.22000+ 3 8.00000+ 4 5.43000+ 2 5023602  293
1.00000+ 5 2.87000+ 2 1.50000+ 5 8.97000+ 1 2.00000+ 5 3.92000+ 1 5023602  294
3.00000+ 5 1.25000+ 1 4.00000+ 5 5.71000+ 0 5.00000+ 5 3.21000+ 0 5023602  295
6.00000+ 5 2.06000+ 0 8.00000+ 5 1.06000+ 0 1.00000+ 6 6.63000- 1 5023602  296
1.50000+ 6 3.05000- 1 2.00000+ 6 1.87000- 1 3.00000+ 6 9.97000- 2 5023602  297
4.00000+ 6 6.65000- 2 5.00000+ 6 4.98000- 2 6.00000+ 6 3.89000- 2 5023602  298
8.00000+ 6 2.72000- 2 1.00000+ 7 2.10000- 2 1.50000+ 7 1.32000- 2 5023602  299
2.00000+ 7 9.55000- 3 3.00000+ 7 6.14000- 3 4.00000+ 7 4.55000- 3 5023602  300
5.00000+ 7 3.61000- 3 6.00000+ 7 2.98000- 3 8.00000+ 7 2.23000- 3 5023602  301
1.00000+ 8 1.77000- 3                                             5023602  302
                                                                  5023  0  303
```

FILE 23: "Smooth" Cross Sections

FILE 27: Atomic Form Factors or Scattering Functions

NR	the number of interpolation ranges given.
NP	the total number of recoil momentum (q) points given in the tabulation to follow; i.e., the number of momentum-form-factor pairs.
NBT_i, INT_i	the interpolation scheme for the ith interpolation range.
q_i	momentum of the recoil electron for incoherent scattering, or momentum of the atom for coherent scattering (in units of m_oc).
$H(q_i;Z)$	is $K(q_i;Z)$, the incoherent scattering function in the case of Compton scattering; or $G(q_i;Z)$, the form factor in the case of coherent scattering.

BCD CARD-IMAGE FORMAT FOR FILE 27

ATOMIC FORM FACTORS OR SCATTERING FUNCTIONS

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Record Type
ZA	AWR	b	b	b	b	HEAD
b	Z	b	b	NR	NP	
NBT_1	INT_1	NBT_2	INT_2	NBT_3	INT_3	
---	---	---	---	NBT_{NR}	INT_{NR}	
q_1	$H(q_1;Z)$	q_2	$H(q_2;Z)$	q_3	$H(q_3;Z)$	
---	---	---	---	---	---	
---	---	---	---	q_{NP}	$H(q_{NP};Z)$	TAB1
b	b	b	b	b	b	SEND

Field 7 (Cols. 67 through 70) = MAT
Field 8 (Cols. 71 through 72) = MF = 27
Field 9 (Cols. 73 through 75) = MT (except for SEND card, where MT = 0)
Field 10 (Cols. 76 through 80) = card sequence number

FILE 27:

This page left blank because no data presently exist in ENDF File 27.

FILE 27: Atomic Form Factors or Scattering Functions

E'_γ is the scattered photon energy.

$\mu = \cos\theta$

$\alpha = E_\gamma / m_o c^2$

$$q = \alpha\left[1 + \left(\frac{\alpha'}{\alpha}\right)^2 - 2\mu\left(\frac{\alpha'}{\alpha}\right)\right]^{1/2} \text{ , incoherent scattering}$$

$$= \alpha[2(1-\mu)2]^{1/2} \text{ , coherent scattering.}$$

$$\frac{d\sigma_i}{d\mu} = ZK(q;Z)\,\frac{d\sigma_c}{d\mu}$$

$$\frac{d\sigma_{coh}}{d\mu} = \pi r_o^2\, Z^2 (1 + \mu^2)\, G(q;Z) \text{ .}$$

ALT/bd:858(600)