14. 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 appearing in Files 12 and 13, even if the distributions are isotropic.

The structure of File 14 is, with the exception of isotropic flag (LI), 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,

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

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,

$$\begin{aligned} p_k(\mu,E) &= \frac{2\pi}{\sigma_k^{\gamma}(E)}\frac{d\sigma_k^{\gamma}}{d\Omega}(\Omega,E) \\ &= \sum_{l=0}^{NL}\frac{2l+1}{2}a_l^k(E)P_l(\mu) \end{aligned} \qquad (14.1)$$

where

μ	=	cosine of the reaction angle in the lab system,
E	=	energy of the incident neutron in the laboratory system,
$\sigma_k^{\gamma}(E)$	=	photon production cross section for the discrete photon or photon continuum specified by k, as given in either File 13 or in File 2, 3, and 12 combined,
l	=	order of the Legendre polynomial,
$d\sigma_k^{\gamma}/d\Omega$	=	differential photon production cross section in barns/steradian,
$a_l^k(E)$	=	the l-th Legendre coefficient associated with the discrete photon or photon continuum specified by k. (It is understood that $a_0^k(E) \equiv 1.0$.)

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

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, $a_l^k(E)$. 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.

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

14.1. Formats

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

LI LI=0, distribution is not isotropic for all photons from this reaction type, but may be for some photons.
LI=1, distribution is isotropic for ***all*** photons from this reaction type.

LTT LTT=1, data are given as Legendre coefficients, where $a_0^k(E) \equiv 1.0$ is understood.
LTT=2, data are given as a tabulation.

NK Number of discrete photons including the continuum (must equal the value given in File 12 or 13).

NI 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.

NE Number of neutron energy points given in a TAB2 record.

NL_i Highest value of *l* required at each neutron energy E_i.

ES_k 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 Photon energy as given in File 12 or 13.
For a continuous photon energy distribution, EG_k,=0.0 should be used.

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, and thus needless isotropic distribution data are not entered 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,   0,  NK,   0] HEAD              (LI=1)
[MAT, 14, 0 / 0.0, 0.0,   0,   0,   0,   0] SEND
```

b. LI=0: Anisotropic Distribution

If LI=0, there are two possible structures for a section, depending upon the value of LTT.

i. LTT=1: Legendre Coefficient Representation

The structure of a section with LI=0 and LTT=1 is

```
[MAT, 14, MT/  ZA,  AWR,  LI, LTT, NK,  NI] HEAD       (LI=0, LTT=1)
          <subsection for k=1>
          <subsection for k=2>
                .........
                .........
                .........
          <subsection for k=NK>
[MAT, 14,  0/ 0.0,  0.0,   0,   0,  0,   0] SEND
```

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

```
[MAT, 14, MT/  EGk, ESk,  0,  0,  0,  0] CONT
```

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 (photon energy), and the continuum, if present and isotropic, appears last, with EG_k=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. The continuum, if present and anisotropic, appears last, with EG_k=0.0. The structure for the last NK-NI subsections is

```
[MAT, 14, MT/  EGk, ESk,   0,   0,   NR,  NE/ Eint ] TAB2
[MAT, 14, MT/  0.0,  E1,   0,   0,  NL1,   0/ a1k(E1)] LIST
[MAT, 14, MT/  0.0,  E2,   0,   0,  NL2,   0/ a1k(E2)] LIST
           ----------------------------------
           ----------------------------------
           ----------------------------------
[MAT, 14, MT/  0.0, ENE,   0,   0,  NLNE,  0/ a1k(ENE)] LIST
```

Note that lists of the $a_l^k(E)$ start at l=1 because $a_0^k(E) \equiv 1.0$ is always understood.

ii. LTT=2: Tabulated Angular Distributions

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

```
[MAT, 14, MT/  ZA, AWR,  LI, LTT,  NK,  NI] HEAD       (LI=0, LTT=2)
               <subsection for k=1>
               <subsection for k=2>
           ----------------------------
           ----------------------------
           ----------------------------
               <subsection for k=NK>
[MAT, 14,  0/ 0.0, 0.0,   0,   0,   0,   0] SEND
```

The structure of the first block of NI subsection (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. The continuum, if present and isotropic, appears last, with $EG_k \equiv 0.0$.

The structure of the first Ni subsections is

```
[MAT, 14, MT/ EGk,  ESk,  0,   0,  0,  0] CONT
```

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

```
[MAT, 14, MT/  EGk, Esk,   0,   0,  NR,  NE/ Eint ] TAB2
[MAT, 14, MT/  0.0,  E1,   0,   0,  NR,  NP/ μint / pk(μ,E1)] TAB1
[MAT, 14, MT/  0.0,  E2,   0,   0,  NR,  NP/ μint / pk(μ,E2)] TAB1
               ------------------------------------------------
               ------------------------------------------------
[MAT, 14, MT/  0.0, ENE,   0,   0,  NR,  NP/ μint / pk(μ,ENE)] TAB1
```

14.2. 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. 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=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, for every photon appearing in File 12 or 13 an angular distribution must be given in File 14. The neutron energy range for 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, ≤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 4) 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 the number of photons in that section and should be consistent with the NK values in Files 12 and 13.
11. The minimum amount of data should be used that will accurately represent the angular distribution as a function of both m 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 $a_l^k(E) \equiv 0$, $l \geq 1$.
13. Angular distributions for photons must be given for all discrete and continuum photons. This can be done by specifying the data explicitly (by giving distributions) or implicitly by using a flag meaning that all photons for a particular reaction (MT number) are isotropic. Isotropic angular distributions should be specified unless the anisotropy is ≥ 20%.