A Compact ENDF (ACE) Format Specification

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LA-UR-19-29016

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1 Introduction

The ACE format consists of two *types* and many *classes* of data. The data are kept in an ACE Table. The term ACE Table and ACE file are often used interchangeably.

1.1 Types of ACE-Formatted Data

There are two types of ACE-formatted data; simply called Type 1 and Type 2.

Type 1 Standard formatted tables. These tables contain ASCII text and are machine independent; they are readable on every machine.

Type 2 Standard unformatted tables. These tables are binary and can be generated from the Type 1 files. They are more compact and faster to read than the Type 1 ACE Tables but are machine/platform dependent; they are not readable on every machine.

Traditionally Type 2 ACE files were more commonly used because they were smaller in size and faster to read. However due to the fact that they are not portable across machines and platforms they have fallen out of fashion.

1.2 Classes of ACE-Formatted Data

There are many classes of ACE-formatted data:

1. continuous-energy neutron (see Section 4),
2. discrete-reaction neutron,
3. neutron dosimetry (see Section 5),
4. $S(\alpha, \beta)$ thermal scattering (see Section 6),
5. continuous-energy photoatomic (see Section 7),
6. continuous-energy electron interaction,
7. continuous-energy photonuclear interaction,
8. multigroup-energy neutron, and
9. multigroup-energy photoatomic.

Each of these classes of data are described later in this document.

An ACE Table is an entity that contains evaluation-dependent data about one of the many classes of data for a specific material—an target isotope, isomer, or element. For a given ZAID, the data contained on a Type 1 and Type 2 tables are identical. Simulations run with one type of data should produce identical results as those run with the other type of data.

1.3 ACE Libraries

A collection of ACE data tables that derive from a single set of evaluation files are typically grouped together in a "library"—not to be confused from the evaluation library from which they derive. Multiple ACE data tables can concatenated into the same logical file on the computer, although this has fallen somewhat out of fashion due to the large amount of data on each ACE table derived from modern evaluation files. Applications that use ACE-formatted data should produce the same results regardless of whether the tables are contained in one logical file on the computer or spread across many.

2 ACE Tables

An ACE Table consists of a Header followed by an array (XSS) containing the actual data. The Header and XSS array are the same regardless of whether the ACE Table is Type 1 or Type 2. Each line in a Type 1 ACE Table is 80 characters or less.

2.1 ACE Header

The first section of an ACE Table is the Header. The ACE Header contains metadata[1] about the ACE Table. The Header consists of four parts:

1. Opening,
2. IZAW array,
3. NXS array, and
4. JXS array.

An example of an ACE Table Header (from ^{1}H in the ENDf71x library) is given in Figure 1 with each part highlighted a different color.

```
1001.80c    0.999167  2.5301E-08   12/17/12
H1 ENDF71x (jlconlin)  Ref. see jlconlin (ref 09/10/2012  10:00:53)      mat 125
      0         0.      0         0.      0         0.      0         0.
      0         0.      0         0.      0         0.      0         0.
      0         0.      0         0.      0         0.      0         0.
      0         0.      0         0.      0         0.      0         0.
    17969     1001      590        3        0        1        1        0
       0        1        1         0        0        0        0        0
       1        0     2951      2954     2957     2960     2963     4352
    4353     5644     5644      5644     6234     6235     6236     6244
    6245     6245     6246     16721        0    16722        0        0
       0        0        0         0        0    16723    16724    16725
```

Figure 1: Header example. The (Legacy) Opening (lines 1–2) is in red, the IZAW array (lines 3–6) is in blue, the NXS array (lines 7–8) is in teal, and the JXS array (lines 9–12) is in violet.

Legacy Header Opening There are two slightly different formats for the Header Opening. The most common one found is called here the Legacy Opening and is the one demonstrated in the Header example in Figure 1.

The Legacy Opening consists of several variables given over two 80-character lines. The variables and the Fortran format for reading the variable is given in Table 1

2.0.1 Header Opening

There is a limitation to the number of unique ZA IDs for a given ZA; 100 different IDs, in fact, for each class of ACE Table. To overcome this limitation, a new Header

[1] data about the data

Line	Variable	Format	Description
1	HZ	A10	ZAID (see Section 3.1)
1	AW	E12.0	Atomic weight ratio
1	TZ	E12.0	Temperature
1	—	1X	(blank space)
1	HD	A10	Processing date
2	HK	A70	Descriptive string
2	HM	A10	10-character material identifier

Table 1: Variables in the Legacy Opening part of the ACE Header.

Line	Variable	Format	Description
1	VERS	A10	Version format string
1	HZ	A24	SZAID (see Section 3.2)
1	SRC	A24	Evaluation source
2	AW	E12.0	Atomic weight ratio
2	TZ	E12.0	Temperature
2	—	1X	(blank space)
2	HD	A10	Processing date
2	N	I10	Number of comment lines to follow
3–(N+2)	—	A70	N comment lines

Table 2: Variables in the 2.0.1 Opening part of the ACE Header.

Opening[**Conlin:2012Updat-0**] was developed in 2012 and updated a few years later to correct some errors.

```
2.0.1                    1001.800nc          ENDF/B-VIII.0-B1
    0.999167   2.5301e-08 2018-05-02    2
  1001.00c    0.999167  2.5301E-08   05/02/18
H1 Lib80x (jlconlin)  Ref. see jlconlin (ref 01/29/2018 07:54)          mat 125
```

Figure 2: Header Opening example. The Legacy Opening is shown in blue while the 2.0.1 Opening consists of the red and the blue portions.

Note that a Legacy Header Opening can be contained in the comment section of the 2.0.1 Header Opening. This was designed explicitly to allow backwards compatibility while application codes were modified to be able to handle. An example of this is shown in Figure 2. Codes that cannot read the 2.0.1 Header can be told (typically via an xsdir[**Conlin:2012Updat-0**] entry) to start reading the ACE Table several lines after the beginning of the 2.0.1 Header.

Following the Opening of the Header are three arrays, IZAW, NXS, and JXS respectively. They are each described below. Immediately following the JXS array is the XSSarray.

2.1.1 IZAW Array

The IZAW array follows on the lines immediately following the Header. It consists of 16 pairs of ZA's (IZ) and atomic weight ratios (AW). The IZ entries are still needed for $S(\alpha, \beta)$ Tables to indicate for which isotope(s) the scattering data are appropriate.

The 16 pairs of numbers are spread over 4 lines. The Fortran format for reading/writing the numbers on one line is: 4(I7,F11.0).

2.1.2 NXS Array

The NXS array comes on the 2 lines after the IZAW array. The NXS array has 16 integer elements; 8 on each line. The Fortran format for reading/writing the numbers on each line is: 8I9. The first element of the NXS array indicates how many numbers are in the XSS array. The remainder of the NXS array elements (usually) indicate how many of different pieces of data there is.

2.1.3 JXS Array

The JXS array comes on the 4 lines after the NXS array. The JXS array has 32 integer elements; 8 on each line. The Fortran format for reading/writing the numbers on each line is: 8I9. The JXS array contains indices to the XSS array where difference pieces of data begins.

The specific definition of the elements of the NXS and JXS arrays are dependent on the class of data in the Table and are defined in the section of this document that describes each class of data.[2] Note that not all elements of the arrays are (currently) being used, allowing for future expansion.

2.2 The XSS Array

After the ACE Header comes the XSS array. It is typically *very* large with hundreds of thousands of elements. It is broken up into blocks with the blocks being dependent on the class of data that is contained in the table. The description and definition of each of these blocks can be found in the descriptions later in this document.

The data is written with 4 floating-point numbers on each 80-character line. All data in the XSS array can be read using the Fortran format: 4E20.0 for each line.

[2] See, for example, Table 3 and Table 4.

```
2.0.1                    1001.710nc              ENDFB-VII.1
0.999167 2.5301E-08 12/17/12     3
The next two lines are the first two lines of 'old-style' ACE.
  1001.80c    0.999167  2.5301E-08   12/17/12
H1 ENDF71x (jlconlin)  Ref. see jlconlin (ref 09/10/2012  10:00:53)      mat 125
      0         0.      0         0.      0         0.      0         0.
      0         0.      0         0.      0         0.      0         0.
      0         0.      0         0.      0         0.      0         0.
      0         0.      0         0.      0         0.      0         0.
    17969     1001      590        3        0        1        1        0
       0        1        1        0        0        0        0        0
       1        0     2951     2954     2957     2960     2963     4352
     4353     5644     5644     5644     6234     6235     6236     6244
     6245     6245     6246    16721        0    16722        0        0
       0        0        0        0        0    16723    16724    16725
   1.00000000000E-11   1.03125000000E-11   1.06250000000E-11   1.09375000000E-11
   1.12500000000E-11   1.15625000000E-11   1.18750000000E-11   1.21875000000E-11
   1.25000000000E-11   1.28125000000E-11   1.31250000000E-11   1.34375000000E-11
   1.37500000000E-11   1.43750000000E-11   1.50000000000E-11   1.56250000000E-11
   1.62500000000E-11   1.68750000000E-11   1.75000000000E-11   1.81250000000E-11
   1.87500000000E-11   1.93750000000E-11   2.00000000000E-11   2.09375000000E-11
   2.18750000000E-11   2.28125000000E-11   2.37500000000E-11   2.46875000000E-11
   2.56250000000E-11   2.65625000000E-11   2.75000000000E-11   2.84375000000E-11
   2.93750000000E-11   3.03125000000E-11   3.12500000000E-11   3.21875000000E-11
   3.31250000000E-11   3.40625000000E-11   3.50000000000E-11   3.59375000000E-11
```

Figure 3: ACE Header with beginning of XSS array for ^{1}H. Note this uses the 2.0.1 Header with backwards compatibility with the Legacy Header.

3 Unique ACE Table Identifier

This needs to be done.

Each ACE Table needs to have an identifier to uniquely distinguish the data that is contained in the Table.

3.1 ZAID

3.2 SZAID

With the introduction of the 2.0.1 ACE Header, the identifier was modified to better specify the metastable state of the material as well as expand the available space for identifiers.

The new identifier is referred to as a SZAID[3].

[3] pronounced "ess-ZAID"

4 Continuous-Energy and Discrete Neutron Transport Tables

The format of individual blocks found on neutron transport tables is identical for continuous-energy and discrete-reaction ACE Tables; the format for both are described in this section. The blocks of data are:

1. **ESZ Block**—contains the main energy grid for the Table and the total, absorption, and elastic cross sections as well as the average heating numbers. The ESZ Block always exists. See Section 4.3.1.
2. **NU Block**—contains prompt, delayed and/or total $\overline{\nu}$ as a function of incident neutron energy. The NU Block exists only for fissionable isotopes; that is, if `JXS(2)`$\neq 0$. See Section 4.3.2.
3. **MTR Block**—contains a list of ENDF MT numbers for all neutron reactions other than elastic scattering. The MTR Block exists for all isotopes that have reactions other than elastic scattering; that is, all isotopes with `NXS(4)`$\neq 0$. See Section 4.3.4.
4. **LQR Block**—contains a list of kinematic Q-values for all neutron reactions other than elastic scattering. The LTR Block exists if `NXS(4)`$\neq 0$. See Section 4.3.5.
5. **TYR Block**—contains information about the type of reaction for all neutron reactions other than elastic scattering. Information for each reaction includes the number of secondary neutrons and whether secondary neutron angular distributions are in the laboratory or center-of-masssystem. The TYR Block exists if `NXS(4)`$\neq 0$. See Section 4.3.6.
6. **LSIG Block**—contains a list of cross section locators for all neutron reacitons other than elastic scattering. The LSIG Block exists if `NXS(4)`$\neq 0$. See Section 4.3.7
7. **SIG Block**—contains cross sections for all reactions other than elastic scattering. The SIG Block exists if `NXS(4)`$\neq 0$. See Section 4.3.8.
8. **LAND Block**—contains a list of angular-distribution locators for all reactions producing secondary neutrons. The LAND Block always exists. See Section 4.3.9.
9. **AND Block**—contains list angular distributions for all reactions producing secondary neutrons. The AND Block always exists. See Section 4.3.10.
10. **LDLW Block**—contains a list of energy distributions for all reactions producing secondary neutrons except for elastic scattering. The LDLW Block exists if `NXS(5)`$\neq 0$. See Section 4.3.11.
11. **DLW Block**—contains energy distributions for all reactions producing secondary neutrons except for elastic scattering. The DLW Block exists if `NXS(5)`$\neq 0$. See Section 4.3.12.
12. **GPD Block**—contains the total photon production cross section tabulated on the ESZ energy grid and a 30$\times$ matrix of secondary photon energies. The GPD Block exists only for those older evaluations that provide coupled neutron/photon information; that is, if `JXS(12)`$\neq 0$. See Section 4.3.13.
13. **MTRP Block**—contains a list of MT numbers for all photon production reactions. The term "photon production reaction" is used for any information describing a specific neutron-in, photon-out reaction. The MTR Block exists if `NXS(6)`$\neq 6$. See Section 4.3.4.
14. **LSIGP Block**—contains a list of cross section locators for all photon production reactions. The LSIGP Block exists if `NXS(6)`$\neq 0$. See Section 4.3.7.
15. **SIGP Block**—contains cross sections for all photon production reactions. The SIGP Block

exists if `NXS(6)`$\neq 0$. See Section 4.3.14.

16. **LANDP Block**—contains a list of angular-distribution locators for all photon production reactions. The LANDP Block exist if `NXS(6)`$\neq 0$. See Section 4.3.15
17. **ANDP Block**—contains photon angular distributions for all photon production reactions. The ANDP Block exists if `NXS(6)`$\neq 0$. See Section 4.3.16.
18. **LDLWP Block**—contains a list of energy-distribution locators for all photon production reactions. The LDLWP Block exists if `NXS(6)`$\neq 0$. See Section 4.3.11.
19. **DLWP Block**—contains photon energy distributions for all photon production reactions. The DLWP Block exists if `NXS(6)`$\neq 0$. See Section 4.3.12.
20. **YP Block**—contains a list of MT identifiers of neutron reaction cross sections required as photon production yield multipliers. The YP Block exists if `NXS(6)`$\neq 0$. See Section 4.3.17.
21. **FIS Block**—contains the total fission cross section tabulated on the ESZ energy grid. The FIS Block exists if `JXS(21)`$\neq 0$. See Section 4.3.18.
22. **UNR Block**—contains the unresolved resonance range probability tables. The UNR Block exists if `JXS(23)`$\neq 0$. See Section 4.3.19.

4.1 NXS Array

Table 3: NXS array element definitions for NXS ACE Table.

Element	Name	Description
1	—	Length of second block of data (XSS array)
2	ZA	$1000 * Z + A$
3	NES	Number of energies
4	NTR	Number of reactions excluding elastic scattering
5	NR	Number of reactions having secondary neutrons excluding elastic scattering
6	NTRP	Number of photon production reactions
	...	
8	NPCR	Number of delayed neutron precurser families
9	S	Excited state[†]
10	Z	Atomic number[†]
11	A	Atomic mass number[†]
	...	
14		Reserved[‡]
15		Reserved[‡]
16		Reserved[‡]

[†] These values were introduced with the new 2.0.0 Header[**Conlin:2012Updat-0**].
[‡] These entries are reserved for the use of transport codes (i.e., MCNP).

4.2 JXS Array

Table 4: JXS array element definitions for JXS ACE Table.

Element	Name	Location Description
1	ESZ	Energy table
2	NU	Fission ν data
3	MTR	MT array
4	LQR	Q-value array
5	TYR	Reaction type array
6	LSIG	Table of cross section locators
7	SIG	Cross sections
8	LAND	Table of angular distribution locators
9	AND	Angular distributions
10	LDLW	Table of energy distribution locators
11	DLW	Energy distributions
12	GPD	Photon production data
13	MTRP	Photon production MT array
14	LSIGP	Table of photon production cross section locators
15	SIGP	Photon production cross sections
16	LANDP	Table of photon production angular distribution locators
17	ANDP	Photon production angular distributions
18	LDLWP	Table of photon production energy distribution locators
19	DLWP	Photon production energy distributions
20	YP	Table of yield multipliers
21	FIS	Total fission cross section
22	END	Last word of this table
23	LUNR	Probability tables
24	DNU	Delayed $\overline{\nu}$ data
25	BDD	Basic delayed neutron precursor data (λ's, probabilities)
26	DNEDL	Table of delayed neutron energy distribution locators
27	DNED	Delayed neutron energy distributions
	...	
32	—	

4.3 Format of Individual Data Blocks

4.3.1 ESZ Block

The format of the ESZ Block is given in Table 5.

Table 5: ESZ Block.

Location in XSS	Parameter	Description
S_{ESZ}	$E(l), l = 1, \ldots, N_E$	Energies
$S_{\mathsf{ESZ}} + N_E$	$\sigma_t(l), l = 1, \ldots, N_E$	Total cross section
$S_{\mathsf{ESZ}} + 2N_E$	$\sigma_a(l), l = 1, \ldots, N_E$	Total neutron disappearance cross section[†]
$S_{\mathsf{ESZ}} + 3N_E$	$\sigma_{el}(l), l = 1, \ldots, N_E$	Elastic cross section
$S_{\mathsf{ESZ}} + 4N_E$	$H_{ave}(l), l = 1, \ldots, N_E$	Average Heating numbers

[†] The disappearance cross section is defined in [**Trkov:2011ENDF–0**] as MT101

Note: S_{ESZ} is index of the XSS array where the ESZ Block starts, `JXS(1)`, and N_E is the number of energy energy points, `NXS(3)`.

4.3.2 NU and DNU Block

The NU Block is used to specify prompt and/or total $\overline{\nu}$ and is present only if `JXS(2)` > 0. Delayed $\overline{\nu}$ data is specified in the DNU Block (which is only present if `JXS(24)` > 0) but it shares some of the tables defined in this section.

When it is present, there are two possibilities for the NU Block:

1. **Either prompt or total $\overline{\nu}$ is given (but not both).** (`XSS(JXS(2))` > 0)
   A single $\overline{\nu}$ array is given and it begins at location `XSS(KNU)` where KNU = `JXS(2)`.
2. **Both prompt and total $\overline{\nu}$ are given.** (`XSS(JXS(2))` < 0). Two $\overline{\nu}$ arrays are given, one for prompt $\overline{\nu}$ and another for total $\overline{\nu}$. The absolute value of `XSS(JXS(2))` is the location of the total $\overline{\nu}$ array so that the locations for the two $\overline{\nu}$ arrays are as follows:
   - The prompt $\overline{\nu}$ array begins at `XSS(KNU)` where KNU = `JXS(2)` + 1.
   - The total $\overline{\nu}$ array begins at `XSS(KNU)` where KNU = `JXS(2)` + ABS(`XSS(JXS(2))`) + 1.

There are two possible forms for these $\overline{\nu}$ arrays; either polynomial (see Table 6) or tabulated (see Table 7). The format is specified by the LNU flag located in the XSS array at index KNU where KNU is defined above.

Table 6: NU Block—Polynomial function form.

Location in XSS	Parameter	Description
KNU	LNU=1	Polynomial function flag
KNU+1	N_C	Number of coefficients
KNU+2	$C(l), l = 1, \ldots, N_C$	Coefficients

When using the polynomial function form of the $\overline{\nu}$ array, $\overline{\nu}$ is reconstructed as

$$\overline{\nu}(E) = \sum_{l=1}^{N_C} C(l) E^{l-1}, \tag{1}$$

where the energy, E, is given in MeV.

Table 7: NU Block—Tabulated form.

Location in XSS	Parameter	Description
KNU	LNU=2	Tabulated data flag
KNU+1	N_R	Number of interpolation regions
KNU+2	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
KNU+2+N_R	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme†
KNU+2+2N_R	N_E	Number of energies
KNU+3+2N_R	$E(l), l = 1, \ldots, N_E$	Tabulated energy points
KNU+3+2N_R + N_E	$\overline{\nu}(l), l = 1, \ldots, N_E$	Tabulated $\overline{\nu}$ values

† If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.

For the DNU Block, the delayed $\overline{\nu}$ array begins at `XSS(KNU)` where KNU = `JXS(24)`. Delayed $\overline{\nu}$ must be given in the tabulated form as described in Table 7. The polynomial form is not allowed in the DNU Block.

4.3.3 BDD Block

The BDD Block is used to specify basic delayed neutron precursor data and is present only if KNU = `JXS(25)` > 0. For every precursor group (the total number of precursor groups is given in `NXS(8)`), a decay constant is given along with the partial probability that a delayed fission neutron is born from the current group. This data is given in the format given in table Table 8.

Table 8: Delayed $\overline{\nu}$ precursor distribution..

Location in XSS	Parameter	Description
	Data for precursor group 1	
KNU	DEC_1	Decay constant for the group 1
KNU + 1	N_R	Number of interpolation regions
KNU + 2	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters†
KNU + 2 + N_R	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme
KNU + 2 + 2N_R	N_E	Number of energies
KNU + 3 + 2N_R	$E(l), l = 1, \ldots, N_E$	Tabulated energy points

Continued on next page

Table 8: Delayed $\overline{\nu}$ precursor distribution. (continued)

Location in XSS	Parameter	Description
KNU $+ 3 + 2N_R + N_E$	$P(l), l = 1, \ldots, N_E$	Corresponding probabilities
Data for precursor group 2—same format as for group 1		
...		
Data for precursor group NPCR = NXS(8)**—same format as for group 1**		

† If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.

The BDD Block is followed by the DNEDL Block and the DNED Block blocks which gives the locators (DNEDL Block) and the delayed neutron energy distributions (DNEDL Block) for every delayed neutron precursor group.

4.3.4 MTR and MTRP Blocks

The format of the MTR Block (for incident neutron reactions) and MTRP Block (for photon production reactions) is given in Table 10. The starting index depends on whether it is the MTR Block or MTRP Block and are given in Table 9.

Block	LMT	NMT
MTR	JXS(3)	NXS(4)
MTRP	JXS(13)	NXS(6)

Table 9: LMT and NMT values for the MTR Block and MTR Block.

Table 10: MTR & MTRP Block.

Location in XSS	Parameter	Description
LMT	MT_1	First ENDF Reaction available
LMT+1	MT_2	Second ENDF Reaction available
...		
LMT+NMT-1	$\mathrm{MT}_{\mathrm{NMT}}$	Last ENDF reaction available

For the MTR Block, $\mathrm{MT}_1, \ldots, \mathrm{MT}_{\mathrm{NMT}}$ are standard ENDF MTnumbers; that is, MT=16=$(n, 2n)$; MT=17=$(n, 3n)$; etc. For a complete listing of MT numbers, see **[Trkov:2011ENDF–0]**.

For the MTRP Block, the MT numbers are somewhat arbitrary. To understand the scheme used for numbering the photon production MTs, it is necessary to realize that in the ENDF format, more than one photon can be produced by a particular neutron reaction that is itself specified by a single MT. Each of these photons is produced with an individual energy-dependent cross section. For

example, MT102 (radiative capture) might be responsible for 40 photons, each with its own cross section, angular distribution, and energy distribution. We need 40 photon MTs to represent the data; the MTs are numbered 1002001, 1002002, ..., 1002040. Therefore, if ENDF MT N is responsible for M photons, we shall number the photon MTs 1000*N+1, 1000*N+2, ..., 1000*N+M.

4.3.5 LQR Block

The format of the LQR Block, containing the reaction-specific Q-values, is given in Table 11. The index at the start of the LQR Block, S_{LQR}=JXS(4). The number of reactions, NMT, is the same through the ACE Table, NMT=NXS(4).

Table 11: LQR Block.

Location in XSS	Parameter	Description
S_{LQR}	Q_1	Q-value for reaction MT_1
S_{LQR}+1	Q_2	Q-value for reaction MT_2
...		
S_{LQR}+NMT-1	Q_{NMT}	Q-value for reaction $\mathsf{MT}_{\mathsf{NMT}}$

4.3.6 TYR Block

The format of the TYR Block is given in Table 12. The index at the start of the TYR Block, S_{TYR}=JXS(5). The number of reactions, NMT, is the same through the ACE Table, NMT=NXS(4).

Table 12: TYR Block.

Location in XSS	Parameter	Description
S_{TYR}	TY_1	Neutron release for reaction MT_1
S_{TYR}+1	TY_2	Neutron release for reaction MT_2
...		
S_{TYR}+NMT-1	$\mathsf{TY}_{\mathsf{NMT}}$	Neutron release for reaction $\mathsf{MT}_{\mathsf{NMT}}$

The possible values of TY are ±1, ±2, ±3, ±4, ±19, 0, and integers greater than 100 in absolute value; the sign indicates the system for scattering:

negative center-of-mass,

positive Lab.

Thus if TY_i=+3, three neutrons are released for reaction MT_i and the data on the cross section tables used to determine the exiting neutrons' angles are given in the Lab frame of reference. TY=19 indicates fission. The number of secondary neutrons released is determined from the fission $\overline{\nu}$ data found in the NU Block. TY_i=0 indicates absorption (ENDF reactions MT>100); no neutrons are released. $\|\mathsf{TY}_i\| > 100$ signifies reactions other than fission that have energy-dependent neutron

multiplicities. The number of secondary neutrons released is determined from the yield data found in the DLW Block. The MT$_i$s are given in the MTR Block.

4.3.7 LSIG and LSIGP Blocks

The LSIG Block and LSIGP Block give the locators for cross section array for each reaction MT. A locator is a *relative* index in the XSS array where some piece of data. In this case, the data is the cross section values. The format of the LSIG Block (for incident neutron cross sections) and LSIGP Block (for photon production cross sections) is given in Table 13. The format for the incident neutron cross section arrays is given in Section 4.3.8. The format for the photon production cross sections is given in Section 4.3.14.

All locators are relative to `JXS(7)` for the LSIG Block or `JXS(15)` for the LSIGP Block. That is, LXS=`JXS(6)` for the LSIG Block and LXS=`JXS(14)` for the LSIGP Block. So the actual cross section data begins at the index LOCA+LXS. The MTs are given in the MTR Block and the MTRP Block for the LSIG Block and the LSIGP Block respectively. LOCA$_i$ must be monotonically increasing.

Table 13: LSIG & LSIGP Block.

Location in XSS	Parameter	Description
LXS	LOCA$_1$=1	Location of cross sections for reaction MT$_1$
LXS+1	LOCA$_2$	Location of cross sections for reaction MT$_2$
...		
LXS+NMT-1	LOCA$_{NMT}$	Location of cross sections for reaction MT$_{NMT}$

4.3.8 SIG Block

The SIG Block contains the incident neutron cross section data. (The photon production cross section is in the SIGP Block.) The format of the SIG Block is given in Table 14. The cross section data begins at the index specified by the locator from the LSIG Block; the format for which is given in Table 15.

Table 14: SIG Block.

Location in XSS	Description
LXS+LOCA$_1$-1	Cross section array for reaction MT$_1$
LXS+LOCA$_2$-1	Cross section array for reaction MT$_2$
...	
LXS+LOCA$_{NMT}$-1	Cross section array for reaction MT$_{NMT}$

Note: The number of cross section arrays NMT=`NXS(4)`.

The LOCA$_i$ values are given in the LSIG Block and are all relative to `JXS(7)`. The energy grid

index IE_i corresponds to the first energy in the grid at which a cross section is given. The MT_is are defined in the MTR Block.

Table 15: Cross section array for the i-th reaction..

Location in XSS	Parameter	Description
LXS + LOCA_i-1	IE_i	Energy grid index for reaction MT_i
LXS + LOCA_i	$N_{E,i}$	Number of consecutive entries for MT_i
LXS + LOCA_i+1	$\sigma_i[E(l)]$ for $l = \mathsf{IE}_i, \ldots, \mathsf{IE}_i + N_{E,i} - 1$	Cross section for reaction MT_i

Note: The energy grid, $E(l)$ is given in the ESZ Block.

4.3.9 LAND Block

The LAND Block contains locators for the angular distributions for all reactions producing secondary neutrons. The LAND Block always exists and begins at S_{LAND}=`JXS(8)`. All locators (LOCB) are relative `JXS(9)`; that is, the angular distribution begins at `JXS(9)`+LOCB_i. The LOCB_i locators must be monotonically increasing. The format of the LAND Block is given in Table 16.

Table 16: LAND Block.

Location in XSS	Parameter	Description
S_{LAND}	LOCB_1=1	Location of angular distribution data for elastic scattering reaction
S_{LAND}+1	LOCB_2	Location of angular distribution data for reaction MT_1
...		
S_{LAND}+NMT	$\mathsf{LOCB}_{\mathsf{NMT}}$	Location of angular distribution data for reaction $\mathsf{MT}_{\mathsf{NMT}}$

Note: S_{LAND}=`JXS(8)` and NMT=`NXS(5)` is the number of reactions (excluding elastic scattering).

4.3.10 AND Block

The AND Block contains angular distribution data for all reactions that produce secondary neutrons. The format of the AND Block is given in Table 17. The angular distribution data begins at the index specified by the locator LOCB from the LAND Block. If LOCB_i=0 (given in the LAND Block), no angular distribution data are given for reaction i and isotropic scattering is assumed in either the Lab or center-of-mass system. The choice of Lab or center-of-mass system depends upon the value for reaction i in the TYR Block. If LOCB_i=-1 no angular distribution data are given for reaction i

in the AND Block. The angular distribution data are specified through law=44 in the DLW Block.

Table 17: AND Block.

Location in XSS	Description
JXS(9)+LOCB_1-1	Angular distribution array for elastic scattering
JXS(9)+LOCB_2-1	Angular distribution array for reaction MT_1
JXS(9)+LOCB_{NMT}-1	Angular distribution array for reaction MT_{NMT}

Note: The format for the angular distribution of the i-th array is given in Table 18.

Table 18: Angular distribution array for the i-th reaction.

Location in XSS	Parameter	Description
JXS(9)+LOCB_i-1	N_E	Number of energies at which angular distributions are tabulated.
JXS(9)+LOCB_i	$E(l), l = 1, \ldots, N_E$	Energy grid
JXS(9)+LOCB_i+N_E	$L_C(l), l = 1, \ldots, N_E$	Location of tables associated with $E(l)$

The angular distribution arrays (Table 18) contains additional locators, L_C; the sign of these locators is a flag:

- if $L_C(l) > 0$, then $L_C(l)$ points to a 32 equiprobable bin distribution (see Table 19);
- if $L_C(l) < 0$, then $L_C(l)$ points to a tabulated angular distribution (see Table 20);
- if $L_C(l) = 0$, then distribution is isotropic and no further data is needed.

Note: **All L_C locators point to data *relative* to JXS(9).**

Table 19: Format for the 32 equiprobable bin distribution.

Location in XSS	Parameter	Description
JXS(9)+$\lvert L_C(l)\rvert - 1$	$P(1, K)$ $K = 1, \ldots, 33$	32 equiprobable cosine bins for scattering at energy $E(l)$.

Table 20: Format for the tabulated angular distribution..

Location in XSS	Parameter	Description
$\text{LDAT}_l + 1$	JJ	Interpolation flag[†]
$\text{LDAT}_l + 2$	N_P	Number of points in the distribution

Continued on next page

Table 20: Format for the tabulated angular distribution. (continued)

Location in XSS	Parameter	Description
$\mathsf{LDAT}_l + 3$	$CS_{\text{out}}(j), j = 1, \ldots, N_P$	Cosine scattering angular grid
$\mathsf{LDAT}_l + 4$	$\text{PDF}(j), j = 1, \ldots, N_P$	Probability density function
$\mathsf{LDAT}_l + 5$	$\text{CDF}(j), j = 1, \ldots, N_P$	Cumulative density function

† 1 histogram interpolation,
2 linear-linear interpolation

Note: $\mathsf{LDAT}_l = \texttt{JXS(9)} + |L_C(l)| - 1$

4.3.11 LDLW, LDLWP and DNEDL Blocks

The LDLW Block and LDLW Block give the locators for the energy distribution for every reaction that produces secondary neutrons or secondary photons (respectively). The DNEDL Block on the other hand gives the locators for the delayed neutron energy distribution for each precursor group.

The format of the LDLW Block (for secondary neutrons), the LDLW Block (for secondary photons) and the DNEDL Block (for delayed neutrons) is given in Table 22. The format for the distributions is given in Section 4.3.12.

The LDLW Block exists only if NXS(5)$\neq 0$, the LDLWP Block exists only if NXS(6)$\neq 0$ and the LDLW Block exists only if NXS(8)$\neq 0$. The starting index in these tables, LED, depends on what data is being read; the starting values and the number of locators, NMT, are given in Table 21.

Block	LED	NMT
LDLW	JXS(10)	NXS(5)
LDLWP	JXS(18)	NXS(6)
DNEDL	JXS(26)	NXS(8)

Table 21: LED and NMT values for the LDLW Block, the LDLWP Block and DNEDL Block.

Table 22: LDLW Block.

Location in XSS	Parameter	Description
LED	LOCC_1	Location of energy distribution data for reaction MT_1 or group 1 (if delayed neutron)
LED+1	LOCC_2	Location of energy distribution data for reaction MT_2 or group 2 (if delayed neutron)
...		

Continued on next page

Table 22: LDLW Block (continued)

Location in XSS	Parameter	Description
LED+NMT-1	LOCC_{NMT}	Location of energy distribution data for reaction MT_{NMT} or group NMT (if delayed neutron)

Note: The LOCC_{i} must be monotonically increasing.

The corresponding MT values are given in the MTR Block for LDLW Block or MTRP Block for LDLWP Block.

All locators point to data *relative* to JED (see Section 4.3.12) in the XSS array.

4.3.12 DLW, DLWP and DNED Blocks

The DLW Block contains secondary neutron energy distributions for all reactions producing secondary neutrons (except for elastic scattering), the DLWP Block contains secondary photon energy distributions for all photon-producing reactions and the DNED Block contains the energy distributions for the delayed neutrons. The DLW Block, DLWP Block and DNED Block block have the same format. The energy distributions are given starting with a locator, LOCC, which were given in the LDLW Block, LDLWP Block or LDNED Block. The locators are relative to the JED parameter. The value for JED and NMT (the number of reactions or the number of delayed precursor groups) is dependent on whether it is the DLW Block, DLWP Block or DNED Block. These values are given in Table 23.

Block	JED	NMT
DLW	`JXS(11)`	`NXS(5)`
DLWP	`JXS(19)`	`NXS(6)`
DNED	`JXS(27)`	`NXS(8)`

Table 23: JED and NMT for the DLW Block and DLW Block.

Table 24: DLW Block.

Location in XSS	Description
$\text{JED}+\text{LOCC}_1\text{-}1$	Energy distribution array for reaction MT_1 or group 1 (if delayed neutron)
$\text{JED}+\text{LOCC}_2\text{-}1$	Energy distribution array for reaction MT_2 or group 2 (if delayed neutron)
...	

Continued on next page

Table 24: DLW Block (continued)

Location in XSS	Description
JED+LOCC_{NMT}-1	Energy distribution array for reaction MT_{NMT} or group NMT (if delayed neutron)

The i-th array has the form shown in

Table 25: Format for the secondary energy distribution..

Location in XSS	Parameter	Description
JED+LOCC_i-1	LNW_1	Location of next law[†] relative to JED
JED+LOCC_i	LAW_1	Name of this law
JED+LOCC_i+1	IDAT_1	Location of data for this law relative to JED
JED+LOCC_i+2	N_R	Number of interpolation regions to define law applicability regime
JED+LOCC_i+3	$\text{NBT}(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
JED+LOCC_i+3+N_R	$\text{INT}(l), l = 1, \ldots, N_R$	ENDF interpolation scheme[‡]
JED+LOCC_i+3+2N_R	N_E	Number of energies
JED+LOCC_i+4+2N_R	$E(l), l = 1, \ldots, N_E$	Tabulated energy points
JED+LOCC_i+4+2N_R + N_E	$P(l), l = 1, \ldots, N_E$	Probability of law validity[*]
JED+$\text{IDAT}_1 - 1$	$\text{LDAT}(l), l, \ldots, L$	Law data for LAW_1.
JED+$\text{LNW}_1 - 1$	LNW_2	Location of next law relative to JED
JED+LNW_1	LAW_2	Name of this law
JED+LNW+1	IDAT_2	Location of data for this law relative to JED
...		

[†] If $\text{LNW}_i = 0$ then LAW_1 is used regardless of other circumstances.
[‡] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.
[*] If the particle energy $E < E(1)$, then $P(E) = P(1)$. If $E > E(N_E)$, then $P(E) = P(N_E)$. If more than one law is given, then LAW_1 is used only if $\xi < P(E)$ where ξ is a random number between 0 and 1.

The format for the law data depends on the law. The length, L, of the law data array, LDAT, is determined from parameters with LDAT. The various LDAT arrays and their formats are given in the following tables. Laws 2 (Table 27) and 4 (Table 29) are used to describe spectra of secondary photons from neutron collisions. All laws—except for Law 2—are usd to describe the spectra of scattered neutrons.

In the following tables, we provide relative locations of data in the LDAT array rather than the absolute locations in the XSS array. Table 25 defines the starting location of the LDAT array within the XSS array.

4.3.12.1 LAW=1—Tabular Equiprobable Energy Bins

Table 26: LAW=1 (From ENDF Law 1).

Location	Parameter	Description
LDAT(1)	N_R	Number of interpolation regions between tables of E_{out}
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme[†]
LDAT(2+2N_R)	N_E	Number of incident energies tabulated
LDAT(3+2N_R)	$E_{\text{in}}(l), l = 1, \ldots, N_E$	List of incident energies for which E_{out} is tabulated
LDAT(3+2N_R + N_E)	NET	Number of outgoing energies in each E_{out} table
LDAT(4+2 * N_R + N_E)	$E_{\text{out}_1}(l), l = 1, \ldots,$ NET	E_{out} tables[‡]
	$E_{\text{out}_2}(l), l = 1, \ldots,$ NET	
	...	
	$E_{\text{out}_{N_E}}(l), l = 1, \ldots,$ NET	

[†] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.

[‡] E_{out} tables consist of NET boundaries of NET-1 equally likely energy intervals. Linear-linear interpolation is used between intervals.

4.3.12.2 LAW=2—Discrete Photon Energy

Table 27: LAW=2—Discrete Photon Energy.

Location	Parameter	Description
LDAT(1)	LP	Indicator of whether the photon is a primary or non-primary photon
LDAT(2)	EG	Photon energy or binding energy

Note: If LP=0 or LP=1, the photon energy is EG. If LP=2, the photon energy is

$$\text{EG} + \left(\frac{\text{AWR}}{\text{AWR} + 1}\right) E_N$$

where AWR is the atomic weight ratio and E_N is the incident neutron energy.

4.3.12.3 LAW=3—Level Scattering

Table 28: LAW=3—Level Scattering.

Location	Parameter	Description
LDAT(1)		$(A+1)/A\|Q\|$
LDAT(2)		$(A/(A+1))^2$

The outgoing center-of-mass energy is calculated as:

$$E_{\text{out}}^{\text{CM}} = \text{LDAT}(2) * (E - \text{LDAT}(1)), \tag{2}$$

where

$$\begin{aligned} E_{\text{out}}^{\text{CM}} &= \text{outgoing center-of-mass energy} \\ E &= \text{incident energy} \\ A &= \text{atomic weight ratio} \\ Q &= Q\text{-value} \end{aligned}$$

The outgoing neutron energy in the laboratory system is:

$$E_{\text{out}}^{\text{LAB}} = E_{\text{out}}^{\text{CM}} + \left\{ E + 2\mu_{\text{CM}}(A+1)(E \cdot E_{\text{out}}^{\text{CM}})^{1/2} \right\} / (A+1)^2 \tag{3}$$

where μ_{CM} is the cosine of the center-of-mass scattering angle

4.3.12.4 LAW=4—Continuous Tabular Distribution

Table 29: LAW=4 (From ENDF-6 LAW=1).

Location	Parameter	Description
LDAT(1)	N_R	The number of interpolation regions
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme[†]
LDAT(2+2N_R)	N_E	Number of energies at which distributions are tabulated
LDAT(3+2N_R)	$E(l), l = 1, \ldots, N_E$	Incident neutron energies
LDAT(3+2N_R + N_E)	L$(l), l = 1, \ldots, N_E$	Locations of distributions[‡]

[†] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.
[‡] Relative to `JXS(11)` (neutron reactions), `JXS(19)` (photon-producing reactions), or `JXS(27)` (delayed neutrons).

The data associated with each incident neutron energy begins at the location L(l). The format for the data is given in Table 30, where for $E(1)$ let K=3+$2N_R + 2N_E$.

Table 30: Secondary energy distribution for each incident energy in LAW=4..

Location	Parameter	Description
	Data for E(1)	
LDAT(K)	INTT′	Interpolation parameter
LDAT(K+1)	N_p	Number of points in the distribution
LDAT(K+2)	$E_{\text{out}}(l), l = 1, \ldots, N_p$	outgoing energy grid
LDAT(K+2 + N_p)	PDF(l), $l = 1, \ldots, N_p$	Probability Density Function
LDAT(K+2 + $2N_p$)	CDF(l), $l = 1, \ldots, N_p$	Cumulative Density Function
	Data for E(2)—same format for $E(1)$	
	...	
	Data for E($\mathbf{N_E}$)—same format for $E(1)$	

Combined interpolation parameter. The first element in the data is INTT′ or the interpolation parameter, which is a combination of two other parameters:

1. the number of discrete photon lines, N_D, and
2. the interpolation scheme for the subsequent data, INTT, which has two valid values:
   INTT=1 histogram distribution, and
   INTT=2 linear-linear distribution.

Given the definition of N_D and INTT, the interpolation parameter, INTT′, is defined as the combination of N_D and INTT:

$$\text{INTT}' = 10N_D + \text{INTT}. \tag{4}$$

Since N_D describe the number of *discrete* photon lines, the remaining $(N_p - N_D)$ values describe a continuous distribution. In this way, the distribution may be discrete, continuous, or a discrete distribution superimposed upon a continuous background.

4.3.12.5 LAW=5—General Evaporation Spectrum

Table 31: LAW=5 (From ENDF-6, MF=5, LF=5).

Location	Parameter	Description
LDAT(1)	N_R	Interpolation scheme between
LDAT(2)	NBT(l), $l = 1, \ldots, N_R$	T's
LDAT(2+N_R)	INT(l), $l = 1, \ldots, N_R$	

Continued on next page

Table 31: LAW=5 (From ENDF-6, MF=5, LF=5) (continued)

Location	Parameter	Description
LDAT($2+2N_R$)	N_E	Number of incident energies tabulated
LDAT($3+2N_R$)	$E(l), l = 1, \ldots, N_E$	Incident energy table
LDAT($3+2N_R+N_E$)	$\theta(l), l = 1, \ldots, N_E$	Effective temperature tabulated on incident energies
LDAT($3+2N_R+2N_E$)	NET	Number of X's tabulated
LDAT($4+2N_R+2N_E$)	$X(l), l = 1, \ldots,$ NET	Equiprobable bins

$$E_{\text{out}} = X(\xi)\theta(E) \tag{5}$$

where:
$X(\xi)$ is a randomly sampled table of X's;
$\theta(E)$ is the effective temperature tabulated on incident energy; and
E is the incident energy.

4.3.12.6 LAW=7—Simple Maxwellian Fission Spectrum

Table 32: LAW=7 (From ENDF-6, MF=5, LF=7).

Location	Parameter	Description
LDAT(1)	N_R	Interpolation scheme between T's
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	
LDAT($2+N_R$)	INT$(l), l = 1, \ldots, N_R$	
LDAT($2+2N_R$)	N_E	Number of incident energies tabulated
LDAT($3+2N_R$)	$E(l), l = 1, \ldots, N_E$	Incident energy table
LDAT($3+2N_R+N_E$)	$\theta(l), l = 1, \ldots, N_E$	Effective temperature tabulated on incident energies
LDAT($3+2N_R+2N_E$)	U	Restriction energy

The outgoing energy, E_{out}, can be calculated as

$$f(E \to E_{\text{out}}) = \frac{\sqrt{E_{\text{out}}}}{I}\, e^{-E_{\text{out}}/\theta(E)} \tag{6}$$

where:
I is the normalization constant

$$I = \theta^{3/2}\frac{\sqrt{\pi}}{2}\,\text{erf}\left(\sqrt{(E-U)/\theta}\right) - \sqrt{(E-U)/\theta}\; e^{-(E-U)/\theta}, \tag{7}$$

θ is tabulated as a function of incident energy, E; and
U is a constant introduced to define the proper upper limit for the final particle energy such that $0 \leq E_{\text{out}} \leq (E - U)$.

4.3.12.7 LAW=9—Evaporation Spectrum

Table 33: LAW=9 (From ENDF-6, MF=5, LF=9).

Location	Parameter	Description
LDAT(1)	N_R	Interpolation scheme between T's
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	
LDAT(2+2N_R)	N_E	Number of incident energies tabulated
LDAT(3+2N_R)	$E(l), l = 1, \ldots, N_E$	Incident energy table
LDAT(3+2N_R + N_E)	$\theta(l), l = 1, \ldots, N_E$	Effective temperature tabulated on incident energies
LDAT(3+2N_R + 2N_E)	U	Restriction energy

The outgoing energy, E_{out}, can be calculated as

$$f(E \rightarrow E_{\text{out}}) = \frac{\sqrt{E_{\text{out}}}}{I} \, e^{-E_{\text{out}}/\theta(E)} \tag{8}$$

where:
I is the normalization constant

$$I = \theta^2 \left[1 - e^{-(E-U)/\theta} \left(1 + \frac{E-U}{\theta} \right) \right], \tag{9}$$

θ is tabulated as a function of incident energy, E; and
U is a constant introduced to define the proper upper limit for the final particle energy such that $0 \leq E_{\text{out}} \leq (E - U)$.

Note: Equation 8 is the same as Equation 6; just the definitions of I in Equation 7 and Equation 9 are different.

4.3.12.8 LAW=11—Energy Dependent Watt Spectrum

Table 34: LAW=11 (From ENDF-6, MF=5, LF=11).

Location	Parameter	Description
LDAT(1)	N_{R_a}	Interpolation scheme between a's
LDAT(2)	$\mathsf{NBT}_a(l), l = 1, \ldots, N_{R_a}$	
LDAT(2+N_{R_a})	$\mathsf{INT}_a(l), l = 1, \ldots, N_{R_a}$	
LDAT(2+2N_{R_a})	N_{E_a}	Number of incident energies tabulated for $a(E_{\text{in}})$ table
LDAT(3+2N_{R_a})	$E_a(l), l = 1, \ldots, N_{E_a}$	Incident energy table
LDAT(3+2N_{R_a} + N_{E_a})	$a(l), l = 1, \ldots, N_{E_a}$	Tabulated a's
let $\mathsf{L} = 3 + 2\,(N_{R_a} + N_{E_a})$		
LDAT(L)	N_{R_b}	Interpolation scheme between b's
LDAT(L+1)	$\mathsf{NBT}_b(l), l = 1, \ldots, N_{R_b}$	
LDAT(L+1+N_{R_b})	$\mathsf{INT}_b(l), l = 1, \ldots, N_{R_b}$	
LDAT(L+1+2N_{R_b})	N_{E_b}	Number of incident energies tabulated for $b(E_{\text{in}})$ table
LDAT(L+2+2N_{R_b})	$E_b(l), l = 1, \ldots, N_{E_b}$	Incident energy table
LDAT(L+2+2N_{R_b} + N_{E_b})	$b(l), l = 1, \ldots, N_{E_b}$	Tabulated b's
LDAT(L+2+2N_{R_b} + 2N_{E_b}	U	Rejection energy

The outgoing energy, E_{out}, can be calculated as

$$f(E \to E_{\text{out}}) = \frac{e^{-E_{\text{out}}/a}}{I} \sinh\left(\sqrt{bE_{\text{out}}}\right) \tag{10}$$

where:

I is the normalization constant

$$I = \frac{1}{2}\sqrt{\frac{\pi a^3 b}{4}} e^{(ab/4)} \left[\text{erf}\left(\sqrt{\frac{E-U}{a}} - \sqrt{\frac{ab}{4}}\right) + \text{erf}\left(\sqrt{\frac{E-U}{a}} + \sqrt{\frac{ab}{4}}\right)\right] - ae^{-(E-U)/a} \sinh\sqrt{b(E-U)}; \tag{11}$$

a and b are tabulated energy-dependent parameters; and

U is a constant introduced to define the proper upper limit for the final particle energy such that $0 \le E_{\text{out}} \le (E - U)$.

4.3.12.9 LAW=22—Tabular Linear Functions of Incident Energy Out

Table 35: LAW=22 (From UK Law 2).

Location	Parameter	Description
LDAT(1)	N_R	
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	Interpolation parameters
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	
LDAT(2+2N_R)	N_E	Number of incident energies tabulated
LDAT(3+2N_R)	$E_{\text{in}}(l), l = 1, \ldots, N_E$	Tabulated incident energies for E_{out} tables
LDAT(3+2N_R + N_E)	LOCE$(l), l = 1, \ldots, N_E$	Locators of E_{out} tables
Data for $E_{\text{in}}(1)$ Let L = $3 + 2N_R + 2N_E$:		
LDAT(L)	NF_1	
LDAT(L+1)	$P_{1k}, k = 1, \ldots, \text{NF}_1$	
LDAT(L+1+NF_1)	$T_{1k}, k = 1, \ldots, \text{NF}_1$	
LDAT(L+1+2NF_1)	$C_{1k}, k = 1, \ldots, \text{NF}_1$	
Data for $E_{\text{in}}(2)$:		
...		

Tables of P_{ik}, C_{ik}, and T_{ik} are given at a number of incident energies, E_{in}. If

$$E_{\text{in}}(l) \leq E < E_{\text{in}}(l+1) \tag{12}$$

then the secondary neutron energy is:

$$E_{\text{out}} = C_{ik}\left(E - T_{ik}\right), \tag{13}$$

where k is chosen according to

$$\sum_{j=1}^{k} P_{ij} < \xi \leq \sum_{k=1}^{k+1} P_{ij} \tag{14}$$

for a given random number, $\xi \in [0, 1)$.

4.3.12.10 LAW=24—Tabular Energy Multipliers

Table 36: LAW=24 (From UK Law 6).

Location	Parameter	Description
LDAT(1)	N_R	Interpolation scheme between T's
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	

Continued on next page

Table 36: LAW=24 (From UK Law 6) (continued)

Location	Parameter	Description
LDAT(2+2N_R)	N_E	Number of incident energies tabulated
LDAT(3+2N_R)	$E_{\text{in}}(l), l = 1, \ldots, N_E$	List of incident energies for which T is tabulated
LDAT(3+2N_R + N_E)	NET	Number of outgoing values in each table
LDAT(4+2N_R + N_E)	$T_1(l), l = 1, \ldots,$ NET	Tables have NET boundaries
	$T_2(l), l = 1, \ldots,$ NET	with NET-1 equally likely
	...	intervals. Linear-linear
	$T_{N_E}(l), l = 1, \ldots,$ NET	interpolation is used between intervals.

The outgoing energy, E_{out} can be calculated as:

$$E_{\text{out}} = T_k(l) * E \tag{15}$$

where:
$T_k(l)$ is sampled from the tables and
E is the incident energy.

4.3.12.11 LAW=44—Kalbach-87 Formalism

Table 37: LAW=44 (From ENDF-6 MF=6 LAW=1, LANG=2).

Location	Parameter	Description
LDAT(1)	N_R	Interpolation scheme between tables of E_{out}
LDAT(2)	NBT(l), $l = 1, \ldots, N_R$	ENDF interpolation parameters
LDAT(2+N_R)	INT(l), $l = 1, \ldots, N_R$	ENDF interpolation scheme[†]
LDAT(2+2N_R)	N_E	Number of energies at which distributions are tabulated
LDAT(3+2N_R)	$E(l), l = 1, \ldots, N_E$	Incident neutron energies
LDAT(3+2N_R + N_E)	L(l), $l = 1, \ldots, N_E$	Locations of distributions[‡]

[†] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.
[‡] Relative to `JXS(11)` (neutron reactions), `JXS(19)` (photon-producing reactions), or `JXS(27)` (delayed neutrons).

The data associated with each incident neutron energy begins at the location L(l). The format for the data is given in Table 38, where for $E(1)$ let K=3+2N_R + 2N_E.

Table 38: Secondary energy distribution for each incident energy in LAW=44.

Location	Parameter	Description
	Data for E(1)	
LDAT(K)	INTT′	Interpolation parameter
LDAT(K+1)	N_p	Number of points in the distribution
LDAT(K+2)	$E_{\text{out}}(l), l = 1, \ldots, N_p$	outgoing energy grid
LDAT(K+2 + N_p)	PDF$(l), l = 1, \ldots, N_p$	Probability Density Function
LDAT(K+2 + 2N_p)	CDF$(l), l = 1, \ldots, N_p$	Cumulative Density Function
LDAT(K+2 + 3N_p)	$R(l), l = 1, \ldots, N_p$	Precompound fraction r
LDAT(K+2 + 4N_p)	$A(l), l = 1, \ldots, N_p$	Angular distribution slope value a
	Data for E(2)—same format for $E(1)$	
	...	
	Data for E(N_E)—same format for $E(1)$	

The interpolation parameter, INTT′ has the same definition as in LAW=4, described in Paragraph 4.3.12.4.

The angular distributions for neutrons are sampled from:

$$p(\mu, E_{\text{in}}, E_{\text{out}}) = \frac{1}{2}\frac{a}{\sinh(a)}\left[\cosh(a\mu) + r\sinh(a\mu)\right]. \tag{16}$$

4.3.12.12 LAW=61—Like LAW=44, but tabular angular distribution instead of Kalbach-87

Table 39: LAW=61.

Location	Parameter	Description
LDAT(1)	N_R	Number of interpolation regions
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme†
LDAT(2+2N_R)	N_E	Number of energies at which distributions are tabulated
LDAT(3+2N_R)	$E(l), l = 1, \ldots, N_E$	Incident neutron energies
LDAT(3+2N_R + N_E)	L$(l), l = 1, \ldots, N_E$	Locations of distributions‡

† If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.

‡ Relative to JXS(11) (neutron reactions), JXS(19) (photon-producing reactions), or JXS(27) (delayed neutrons).

The data associated with each incident neutron energy begins at the location L(l). The format for the data is given in Table 40, where for $E(1)$ let K=3+2N_R + 2N_E.

Table 40: Secondary energy distribution for each incident energy in LAW=61.

Location	Parameter	Description
	Data for E(1)	
LDAT(K)	INTT′	Interpolation parameter
LDAT(K+1)	N_p	Number of points in the distribution
LDAT(K+2)	$E_{\text{out}}(l), l = 1, \ldots, N_p$	outgoing energy grid
LDAT(K+2 + N_p)	PDF(l), $l = 1, \ldots, N_p$	Probability Density Function
LDAT(K+2 + 2N_p)	CDF(l), $l = 1, \ldots, N_p$	Cumulative Density Function
LDAT(K+2 + 3N_p)	LC(l), $l = 1, \ldots, N_p$	Location of tables associated with incident energies $E(l)$. See Table 41
	Data for E(2)—same format for $E(1)$	
	...	
	Data for E($\mathbf{N_E}$)—same format for $E(1)$	

The interpolation parameter, INTT′ has the same definition as in LAW=4, described in Paragraph 4.3.12.4.

The J-th array for the tabular angular distribution has the form shown in Table 41. For the angular distribution, the locators L are relative to `JXS(11)` for neutron reactions or `JXS(19)` for photon-producing reactions. Thus,

$$\text{L} = \texttt{JXS(11)} + |\text{LC}(J)| - 1 \text{ (for neutron reactions)},$$
$$\text{L} = \texttt{JXS(19)} + |\text{LC}(J)| - 1 \text{ (for photon-producing reactions)}.$$

Table 41: Angular distribution for LAW=61.

Location	Parameter	Description
LDAT(L+1)	JJ	Interpolation flag
LDAT(L+2)	N_P	Number of points in the distribution
LDAT(L+3)	$CS_{\text{out}}(j), j = 1, \ldots, N_P$	Cosine scattering angular grid
LDAT(L+3+N_P)	PDF(j), $j = 1, \ldots, N_P$	Probability density function
LDAT(L+3+2N_P)	CDF(j), $j = 1, \ldots, N_P$	Cumulative density function

Valid values for the interpolation flag, JJ, are the same as for INTT:
JJ=1 histogram distribution, and

JJ=2 linear-linear distribution.

4.3.12.13 LAW=66—N-body phase space distribution

Table 42: LAW=66 (From ENDF-6 MF=6 LAW=6).

Location	Parameter	Description
LDAT(1)	NPSX	Number of bodies in the phase space
LDAT(2)	A_P	Total mass ratio for the NPSX particles.

The outgoing energy is

$$E_{\text{out}} = T(\xi)E_i^{\max} \tag{17}$$

where

$$E_i^{\max} = \frac{A_p - 1}{A_p}\left(\frac{A}{A+1}E_{\text{in}} + Q\right) \tag{18}$$

and $T(\xi)$ is sampled from:

$$P_i(\mu, E_{\text{in}}, T) = C_n\sqrt{T}\,(E_i^{\max} - T)^{3n/2-4} \tag{19}$$

4.3.12.14 LAW=67—Laboratory Angle-Energy Law

Table 43: LAW=67 (From ENDF-6 MF=6 LAW=7).

Location	Parameter	Description
LDAT(1)	N_R	Number of interpolation regions
LDAT(2)	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
LDAT(2+N_R)	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme[†]
LDAT(2+2N_R)	N_E	Number of energies at which distributions are tabulated
LDAT(3+2N_R)	$E(l), l = 1, \ldots, N_E$	Incident neutron energies
LDAT(3+2N_R + N_E)	L$(l), l = 1, \ldots, N_E$	Locations of distributions[‡]

[†] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.

[‡] Relative to `JXS(11)` (neutron reactions), `JXS(19)` (photon-producing reactions), or `JXS(27)` (delayed neutrons).

The data associated with each distribution begins at location L(l). The format for the data is given in Table 44, where for $E(1)$ let $\mathsf{K} = 3 + 2N_R + 2N_e$.

Table 44: Angular distribution for LAW=67.

Location	Parameter	Description
LDAT(K)	INTMU	Interpolation scheme†
LDAT(K+1)	NMU	Number of secondary cosines
LDAT(K+2)	XMU(l), $l = 1, \ldots,$ NMU	Secondary cosines
LDAT(K+2+NMU)	LMU(l), $l = 1, \ldots,$ NMU	Locations of data for each secondary cosine. See Table 45

† **INTMU=1** histogram distribution,
INTMU=2 linear-linear distribution.

The format for the secondary energy distribution (for each cosine bin, XMU) is given in Table 45. For the energy distribution, the locators, LMU, are relative to `JXS(11)` or `JXS(19)`. Thus,

$$\mathsf{L}_l = \texttt{JXS(11)} + \mathsf{LMU}(l) \text{ (for neutron reactions)},$$
$$\mathsf{L}_l = \texttt{JXS(19)} + \mathsf{LMU}(l) \text{ (for photon-producing reactions)}.$$

Table 45: Secondary energy distribution for each cosine bin in LAW=67.

Location	Parameter	Description
LDAT(L_l)	INTEP	Interpolation parameter between secondary energies†
LDAT($\mathsf{L}_l + 1$)	NPEP	Number of secondary energies
LDAT($\mathsf{L}_l + 2$)	$E_P(l), l = 1, \ldots,$ NPEP	Secondary energy grid
LDAT($\mathsf{L}_l + 2 +$ NPEP)	PDF(l), $l = 1, \ldots,$ NPEP	Probability density function
LDAT($\mathsf{L}_l + 2 +$ 2NPEP)	CDF(l), $l = 1, \ldots,$ NPEP	Cumulative density function

† **INTEP=1** histogram distribution,
INTEP=2 linear-linear distribution.

4.3.12.15 Energy-Dependent Neutron Yields

There are additional numbers to be found for neutrons in the DLW Block and DLWP Block. For those reactions with entries in the TYR Block that are greater than 100 in absolute value, there must be neutron yields, $Y(E)$ provided as a function of neutron energy. The neutron yields are handled similarly to the average number of neutrons per fission, $\nu(E)$ that is given for the fission reactions.

These yields are a part of the coupled energy-angle distributions given in File 6 of ENDF-6 data.

The i-th array has the form given in Table 46, where $\mathsf{KY} = \mathsf{JED} + |\mathsf{TY}_i| - 101$.

Table 46: Energy-Dependent Neutron Yields.

Location	Parameter	Description
KY	N_R	Number of interpolation regions
KY+1	$\mathsf{NBT}(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
KY+1+N_R	$\mathsf{INT}(l), l = 1, \ldots, N_R$	ENDF interpolation scheme[†]
KY+1+2N_R	N_E	Number of energies
KY+2+2N_R	$E(l), l = 1, \ldots, N_E$	Tabular energy points
KY+2+$N_R + N_E$	$Y(l), l = 1, \ldots, N_E$	Corresponding energy-dependent yields

[†] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is assumed.

4.3.13 GPD Block

The GPD Block contains the *total* photon production cross section, tabulated on the energy grid given in the ESZ Block, the size of which is given by `NXS(3)`. The GPD Block only exists if `JXS(12)`$\neq 0$ and is shown in Table 47.

Table 47: GPD Block.

Location in XSS	Parameter	Description
S_{GPD}	$\sigma_\gamma(l), l = 1, \ldots, \mathsf{NES}$	Total photon production cross section

In addition to the total photon production cross section, the outgoing photon energies *may* be given.[4] There are 30 groups for the incident neutron energies, the boundaries of which are shown in Table 48.

For each incident neutron energy group, the outgoing photon energies are discretized into 20 equiprobable energy groups, thus creating a 30×20 matrix. The outgoing energies are given in the GPD Block, after the total photon production cross section as shown in Table 49. Note that this matrix is only used for older tables that do not provide expanded photon production data. The format of this Block is given in Table 49. The XSS array index at the start of the GPD Block, S_{GPD}=`JXS(12)`.

[4]Note that this is an obsolete format. It only exists when `JXS(12)` $\neq 0$ and `JXS(13)` $= 0$.

Table 48: Discrete neutron energy boundaries.

Group #	Upper Boundary (MeV)	Group #	Upper Boundary (MeV)
1	1.39×10^{-10}	16	0.184
2	1.52×10^{-7}	17	0.303
3	4.14×10^{-7}	18	0.500
4	1.13×10^{-6}	19	0.823
5	3.06×10^{-6}	20	1.353
6	8.32×10^{-6}	21	1.738
7	2.26×10^{-5}	22	2.232
8	6.14×10^{-5}	23	2.865
9	1.67×10^{-4}	24	3.68
10	4.54×10^{-4}	25	6.07
11	1.235×10^{-3}	26	7.79
12	3.35×10^{-3}	27	10.0
13	9.23×10^{-3}	28	12.0
14	2.48×10^{-2}	29	13.5
15	6.76×10^{-2}	30	15.0

Table 49: Outgoing photon energies in GPD Block..

Location in XSS	Parameter	Description
S_{GPD}+NES	$E_1(K), K = 1, 20$	20 equiprobable outgoing photon energies for incident neutron $E < E_N(2)$
S_{GPD}+NES+20	$E_2(K), K = 1, 20$	20 equiprobable outgoing photon energies for incident neutron $E_N(2) \leq E < E_N(3)$
...		
S_{GPD}+NES+(i-1)*20	$E_i(K), K = 1, 20$	20 equiprobable outgoing photon energies for incident neutron $E_N(i) \leq E < E_N(i+1)$
...		
S_{GPD}+NES+(30-1)*20	$E_N(K), K = 1, 20$	20 equiprobable outgoing photon energies for incident neutron $E \geq E_N(30)$

4.3.14 SIGP Block

The SIGP Block contains the photon production cross section data. The format of the SIGP Block is given in Table 50. The cross section data begins at the index specified by the locator, LOCA_i, given in the LSIG Block (see Section 4.3.7). The MTs are defined in the MTRP Block (see Section 4.3.4). All indices to the XSS array are *relative* to `JXS(15)`.

Table 50: SIGP Block.

Location in XSS	Parameter	Description
`JXS(15)`+LOCA_1-1	MFTYPE_1	Cross section array for reaction MT_1
`JXS(15)`+LOCA_2-1	MFTYPE_2	Cross section array for reaction MT_2
...		
`JXS(15)`+LOCA_{NMT}-1	$\text{MFTYPE}_{\text{NMT}}$	Cross section array for reaction MT_{NMT}

Table 51: Photon production array if MFTYPE=12 or 16.

Location in XSS	Parameter	Description
JXS(15)+LOCA$_i$-1	MFTYPE	12 or 16
JXS(15)+LOCA$_i$	MTMULT	Neutron MT whose cross section should multiply the yield
JXS(15)+LOCA$_i$+1	N_R	Number of interpolation regions
JXS(15)+LOCA$_i$+2	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters[†]
JXS(15)+LOCA$_i$+2 $+N_R$	INT$(l), l = 1, \ldots, N_R$	ENDF interpolation scheme
JXS(15)+LOCA$_i$+2 $+2 * N_R$	N_E	Number of energies at which the yield is tabulated
JXS(15)+LOCA$_i$+3 $+2 * N_R$	$E(l), l = 1, \ldots, N_E$	Energies
JXS(15)+LOCA$_i$+3 $+2 * N_R + N_E$	$Y(l), l = 1, \ldots, N_E$	Yields

[†] If $N_R = 0$, NBT and INT are omitted and linear-linear interpolation is used.

Table 52: Photon production cross section array if MFTYPE=13.

Location in XSS	Parameter	Description
JXS(15)+LOCA$_i$-1	MFTYPE	13
JXS(15)+LOCA$_i$	IE	Energy grid index
JXS(15)+LOCA$_i$+1	N_E	Number of consecutive entries
JXS(15)+LOCA$_i$+2	$\sigma_{\gamma,i}[E(K)]$, $K = \text{IE}, \ldots, \text{IE} + N_E - 1$	Photon production cross sections for reaction MT$_i$

Note: The MT$_i$s are defined in the MTRP Block.

4.3.15 LANDP Block

The LANDP Block gives locator information for angular distribution arrays for photon production reactions and exists if NXS(6) $\neq 0$. All locators (LOCB) in the LANDP Block are *relative* to JXS(17); that is, the angular distribution arrays begin at JXS(17)+LOCB$_i$. The number of photon-producing reactions is NMT=NXS(6). The LOCB$_i$ must be monotonically increasing. The MTs are defined in the MTRP Block (see Section 4.3.4). The format of the LANDP Block is given in Table 53.

Table 53: LANDP Block.

Location in XSS	Parameter	Description
JXS(16)	LOCB_1=1	Location of angular distribution data for reaction MT_1
JXS(16)+1	LOCB_2	Location of angular distribution data for reaction MT_2
...		
JXS(16)+NMT-1	LOCB_{NMT}	Location of angular distribution data for reaction MT_{NMT}

Note: The LOCB_i must be monotonically increasing. The format for the angular distribution of the i-th reaction is given in Table 55.

4.3.16 ANDP Block

The ANDP Block contains angular distribution data for all photon-producing reactions and exists if NXS(6) $\neq 0$. The format of the ANDP Block is given in Table 54; the format of each angular distribution array is given in Table 55. The angular distribution data begins at the index specified by the locator, LOCB, from the LANDP Block; if $\text{LOCB}_i = 0$, there are no angular distribution data given for reaction i and isotropic scattering is assumed in the Lab system.

Table 54: ANDP.

Location in XSS	Description
JXS(17)+LOCB_1-1	Angular distribution array for reaction MT_1
JXS(17)+LOCB_2	Angular distribution array for reaction MT_2
...	
JXS(17)+LOCB_{NMT}-1	Angular distribution array for reaction MT_{NMT}

Note: NMT=NXS(6) is the number of photon-producing reactions.

Table 55: Angular distribution array for the i-th photon-producing reaction.

Location in XSS	Parameter	Description
JXS(17)+LOCB_i-1	N_E	Number of energies at which angular distributions are tabulated.
JXS(17)+LOCB_i	$E(l), l = 1, N_E$	Energy grid

Continued on next page

Table 55: Angular distribution array for the i-th photon-producing reaction (continued)

Location in XSS	Parameter	Description
JXS(17)+LOCB$_i$+N_E	$L_C(l), l = 1, \ldots, N_E$	Location of tables associated with $E(l)$[†]
JXS(17)+$L_C(1)-1$	$P_1(K), K = 1, \ldots, 33$	32 equiprobable cosine bins for scattering at energy $E(1)$
JXS(17)+$L_C(2)-1$	$P_2(K), K = 1, \ldots, 33$	32 equiprobable cosine bins for scattering at energy $E(2)$
...		
JXS(17)+$L_C(N_E)-1$	$P_{N_E}(K), K = 1, \ldots, 33$	32 equiprobable cosine bins for scattering at energy $E(N_E)$

[†] All values of $L_C(l)$ are *relative* to JXS(17). If $L_C(l) = 0$, no table is given for energy $E(l)$ and scattering is assumed to be isotropic in the Lab system.

4.3.17 YP Block

The YP Block contains a list of MT identifiers of neutron cross sections that are used as yield multipliers in Equation 20 to calculate the photon production cross sections and are referenced by the MTMULT parameter in Table 51. The YP Block exists if NXS(6) $\neq 0$. The format of the YP Block is given in Table 56.

Table 56: YP Block.

Location in XSS	Parameter	Description
JXS(20)	NYP	Number of neutron MTs to follow
JXS(20)+1	MTY$(l), l = 1, \ldots,$ NYP	Neutron MTs.

4.3.18 FIS Block

The FIS Block contains the total fission cross section. The FIS Block exists if JXS(21) $\neq 0$, but is generally not provided; the total fission cross section is redundant as the total fission cross section is the summation of first-, second-, third-, and fourth-chance fission (MT=19, 20, 21, and 38);

$$\sigma_{f,\mathrm{t}}(E) = \sigma_{(n,f)} + \sigma_{(n,nf)} + \sigma_{(n,2nf)} + \sigma_{(n,3nf)}. \tag{21}$$

The format of the FIS Block is given in Table 57.

Table 57: FIS Block.

Location in XSS	Parameter	Description
JXS(21)	IE	Energy grid index
JXS(21)+1	N_E	Number of consecutive entries
JXS(21)+2	$\sigma_f[E(l)], K = \mathsf{IE}, \ldots, \mathsf{IE} + N_E - 1$	Total fission cross sections

Note: The energy $E(l)$ is given in the ESZ Block.

4.3.19 UNR Block

The UNR Block contains the unresolved resonance range probability tables. It exists if JXS(23) $\neq 0$ and begins at location JXS(23) in XSS. The UNR Block has several flags that have special meaning:

ILF The ILF flag is the inelastic competition flag.
- **ILF** < 0 The inelastic cross section is zero within the entire unresolved energy range.
- **ILF** > 0 The value of ILF is a special MT number whose tabulation is the sum of the inelastic levels.
- **ILF** $= 0$ The sum of the contribution of the inelastic reactions will be made using a balance relationship involving the smooth cross sections.

An exception to this scheme is typically made when there is only one inelastic level within the unresolved energy range, because the flag can then just be set to its MT number and the special tabulation is not needed.

IOA The IOA is the other absorption flag for determining the contribution of "other absorptions" (no neutron out or destruction reactions).
- **IOA** < 0 The "other absorption" cross section is zero within the entire unresolved resonance range.
- **IOA** > 0 The value of IOA is a special MT number whose tabulation is the sum of the "other absorption" reactions.
- **IOA** $= 0$ The sum of the contribution of the "other absorption" reactions will be made using a balanced relationship involving the smooth cross sections.

An exception to this scheme is typically made when there is only one "other absorption" reaction within the unresolved energy range, because the flag can then just be set to its MT number and the special tabulation is not needed.

IFF The IFF is the factors flag.
- **IFF** $= 0$ The tabulations in the probability tables are cross sections.
- **IFF** $= 1$ The tabulations in the probability tables are factors that must be multiplied by the corresponding "smooth" cross sections to obtain the actual cross sections.

The format of the UNR Block is given in Table 59. The $P(i, j, k)$ values, where
- $i = 1, \ldots, N$,
- $j = 1, \ldots, 6$,
- $k = 1, \ldots, M$,

Table 58: Possible values for the j argument.

j	Description
1	cumulative probability
2	total cross section/factor
3	elastic cross section/factor
4	fission cross section/factor
5	(n,γ) cross section/factor
6	neutron heating number/factor

are what make up the probability tables. The argument j has special meaning depending on its value as shown in Table 58.

Table 59: UNR Block.

Location in XSS	Parameter	Description
JXS(23)	N	Number of incident energies where there is a probability table.
JXS(23)+1	M	Length of probability table.
JXS(23)+2	INT	Interpolation parameter between tables.†
JXS(23)+3	ILF	Inelastic competition flag.
JXS(23)+4	IOA	Other absorption flag.
JXS(23)+5	IFF	Factors flag.
JXS(23)+6	$E(i), i = 1, \ldots, N$	Incident energies.
JXS(23)+6+N	$P(i, j, k)$	Probability tables.

† 2 linear-linear interpolation,
5 log-log interpolation

The ordering of the probability table entries, $P(i, j, k)$ is given in Table 60, which begins at PTABLE = JXS(23) + 6 + N.

Table 60: Order of probability table elements $P(i, j, k)$.

Location in XSS	Parameter	Description
	Data for E(1)	
PTABLE	$\mathrm{CDF}_1(l), l = 1, \ldots, M$	Cumulative probabilities†for energy $i = 1$
PTABLE+M	$\sigma_{t,1}(l), l = 1, \ldots, M$	Total cross section/factors for energy $i = 1$
PTABLE+2M	$\sigma_{s,1}(l), l = 1, \ldots, M$	Elastic cross section/factors for energy $i = 1$
PTABLE+3M	$\sigma_{f,1}(l), l = 1, \ldots, M$	Fission cross section/factors for energy $i = 1$
PTABLE+4M	$\sigma_{(n,\gamma),1}(l), l = 1, \ldots, M$	(n,γ) cross section/factors for energy $i = 1$
PTABLE+5M	$H_1(l), l = 1, \ldots, M$	Heating number/factors for energy $i = 1$
	Data for incident energy 2—same format for $E(1)$	
	⋮	
	Data for incident energy N**—same format for** $E(1)$	

† The cumulative probabilities are monotonically increasing from an implied (but not included) lower value of zero to the upper value of $P(i, 1, k = M) = 1.0$.

5 Neutron Dosimetry

5.1 NXS Array

Table 61: NXS array element definitions for NXS ACE Table.

Element	Name	Description
1	—	Length of second block of data (XSS array)
2	ZA	$1000 * Z + A$
3	—	
4	NTR	Number of reactions
	...	
16	—	

5.2 JXS Array

Table 62: JXS array element definitions for JXS ACE Table.

Element	Name	Location Description
1	LONE	First word of table
2	—	
3	MTR	MT array
	...	
6	LSIG	Table of cross section locators
7	SIGD	Cross sections
	...	
22	END	Last word of this table
	...	
32	—	

6 Thermal Scattering $S(\alpha, \beta)$

Data from thermal $S(\alpha, \beta)$ tables provide a complete representation of thermal neutron scattering by molecules and crystalline solids. Cross sections for (coherent and incoherent) elastic and (incoherent) inelastic scattering are found on the tables. A coupled energy/angle representation is used to describe the spectra of inelastically scattered neutrons. Angular distributions for elastic scattering are also provided.

Four unique blocks of data are associated with $S(\alpha, \beta)$ tables. We now briefly describe each of the four data blocks and reference the sections in which their formats are detailed.

1. **ITIE Block**—contains the energy-dependent incoherent inelastic scattering cross sections. The ITIE Block always exists. See Section 6.3.1.
2. **ITCE Block** and **ITCEI Block**—contains the energy-dependent elastic scattering cross sections. The ITCE Block exists if the material has coherent and/or incoherent elastic scattering (`NXS(5)`$\neq 0$ and `JXS(4)`$\neq 0$). The ITCEI Block only exists for mixed mode elastic scattering (`NXS(5)`$= 5$ and `JXS(7)`$\neq 0$). See Section 6.3.3.
3. **ITXE Block**—contains coupled energy/angle distributions for incoherent inelastic scattering. The ITXE Block always exists. See Section 6.3.2.
4. **ITCA Block** and **ITCAI Block**—contains angular distributions for elastic scattering. The ITCA Block exists if the material has coherent and/or incoherent elastic scattering (`NXS(5)`$\neq 0$, `JXS(6)`$\neq 0$ and `NXS(6)`$\neq -1$). The ITCEI Block only exists for mixed mode elastic scattering (`NXS(5)`$= 5$, `JXS(9)`$\neq 0$ and `NXS(6)`$\neq -1$). See Section 6.3.4.

6.1 NXS Array

Table 63: NXS array element definitions for NXS ACE Table.

Element	Name	Description
1	—	Length of second block of data (XSS array)
2	IDPNI	Inelastic scattering mode
3	NIL	Inelastic dimensioning parameter
4	NIEB	Number of inelastic exiting energies
5	IDPNC	Elastic scattering mode (no elastic data=0, incoherent=3, coherent=4, mixed=5)
6	NCL	Elastic dimensioning parameter for the first elastic block
7	IFENG	Secondary energy mode (discrete=0, skewed=1, continuous=2)
8	NCLI	Elastic dimensioning parameter for the second elastic block
	...	
16	—	

6.2 JXS Array

Table 64: JXS array element definitions for JXS ACE Table.

Element	Name	Location Description
1	ITIE	Inelastic energy table
2	ITIX	Inelastic cross sections
3	ITXE	Inelastic energy/angle distributions
4	ITCE	Elastic energy table (used for coherent elastic scattering if NXS(5)=4 or 5, and used for incoherent elastic scattering if NXS(5)=3)
5	ITCX	Elastic cross sections (used for coherent elastic scattering if NXS(5)=4 or 5, and used for incoherent elastic scattering if NXS(5)=3)
6	ITCA	Elastic angular distributions (used for coherent elastic scattering if NXS(5)=4 or 5, and used for incoherent elastic scattering if NXS(5)=3)
7	ITCEI	Elastic energy table (used for incoherent elastic scattering if NXS(5)=5)
8	ITCXI	Elastic cross sections (used for incoherent elastic scattering if NXS(5)=5)
9	ITCAI	Elastic angular distributions (used for incoherent elastic scattering if NXS(5)=5)
	...	
32	—	

When a single mode of elastic scattering is used (either coherent or incoherent), then only the first elastic block will be used. This is the way data was stored in the ACE format prior to the introduction of mixed mode elastic scattering in thermal scattering evaluations that combines both coherent and incoherent elastic scattering.

When using mixed mode elastic scattering (both coherent and incoherent elastic scattering are given, NXS(5) = 5), the JXS array will contain an additional set of indices for a second elastic data block. In mixed mode, the first elastic block pointed to by JXS(4) to JXS(6) are used for the coherent part and the second elastic block pointed to by JXS(7) to JXS(9) are used for the incoherent part.

6.3 Format of Individual Data Blocks

6.3.1 ITIE Block

The format of the ITIE Block is given in Table 65. The index at the start of the block is S_{ITIE}=JXS(1). Note that JXS(2)=JXS(1)+1+N_{in}. Linear-linear interpolation is assumed between adjacent energies.

Table 65: ITIE Block.

Location in XSS	Parameter	Description
S_{ITIE}	N_{in}	Number of inelastic energies

Continued on next page

Table 65: ITIE Block (continued)

Location in XSS	Parameter	Description
S_{ITIE}+1	$E_{in}(l), l = 1, \ldots, N_{in}$	Energies
S_{ITIE}+1+N_{in}	$\sigma_{in}(l), l = 1, \ldots, N_{in}$	Inelastic cross sections

6.3.2 ITXE Block

The format of the coupled energy/angle distribution for incoherent inelastic scattering is governed by the value of NXS(7). There are three possibilities:

NXS(7) = 0 equally-likely discrete cosines and energies (Table 66)

NXS(7) = 1 skewed distribution of discrete cosines and energies (Table 66)

NXS(7) = 2 continuous distribution of outgoing energies and equally-likely discrete cosines (Table 67 and Table 68)

The format of the ITXE Block for NXS(7) < 2 is given in Table 66. The index at the start of the block is S_{ITXE}=JXS(3). For each incident energy from the ITIE Block, N' =NXS(4) discrete outgoing energies are given. For each pair of incident and outgoing energies, N_μ =NXS(3)+1 discrete cosines are given. The incident inelastic energy grid $E_{in}(l)$ is given in the ITIE Block, and linear-linear interpolation is assumed between adjacent values of E_{in}.

Table 66: ITXE Block for NXS(7) < 2.

Location in XSS	Parameter	Description
S_{ITXE}	$E_1^{out}[E_{in}(1)]$	First of NIEB† outgoing energies for inelastic scattering at $E_{in}(1)$
S_{ITXE}+1	$\mu_l(1 \to 1), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_1^{out}[E_{in}(1)]$
S_{ITXE}+1+N_μ	$E_2^{out}[E_{in}(1)]$	Second of NIEB outgoing energies for inelastic scattering at $E_{in}(1)$
S_{ITXE}+2+N_μ	$\mu_l(1 \to 2), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_2^{out}[E_{in}(1)]$
⋮	⋮	⋮
S_{ITXE}+(N'-1)(1+N_μ)	$E_{N'}^{out}[E_{in}(1)]$	Last of NIEB outgoing energies for inelastic scattering at $E_{in}(1)$
S_{ITXE}+(N'-1)(1+N_μ)+1	$\mu_l(1 \to N'), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_{N'}^{out}[E_{in}(1)]$
(Repeat for all remaining values of E_{in})		

† The number of outgoing energies NIEB is determined as NXS(4).

When NXS(7) = 0, each of the NXS(4) discrete outgoing energies for a given incident energy are equally probable. When NXS(7) = 1, the selection of the discrete outgoing energies is skewed such that the first two and last two outgoing energies have a lower probability of being selected than all other outgoing energies. The first and last energies have a relative probability of 1, the second and second-to-last energies have a relative probability of 4, and all other energies have a relative probability of 10.

Because the use of discrete outgoing energies and cosines can result in unphysical spikes in the neutron flux spectrum at thermal energies, some Monte Carlo codes attempt to "smear" the outgoing energies and cosines to produce a smoother distribution (that more closely approximates a continuous distribution with NXS(7) = 2).

When NXS(7) = 2, the distribution of outgoing energies for each incident energy is continuous in energy and specified by a probability density function and cumulative distribution function. The format of the ITXE Block in this case is given in Table 67 and Table 68. As before, the index at the start of the block is S_{ITXE}=JXS(3). Unlike in the NXS(7) < 2 cases, the number of outgoing energies for each incident energy is allowed to vary. The number of discrete cosines, N_μ =NXS(3)-1, remains the same for each pair of incident and outgoing energies, however.

Table 67: ITXE Block for NXS(7) = 2.

Location in XSS	Parameter	Description
S_{ITXE}	$\mathsf{L}(l), l = 1, \ldots, N_{in}$ †	Location in XSS of distribution for incident energy l
$S_{\mathsf{ITXE}}+N_{in}$	$N'(l), l = 1, \ldots, N_{in}$	Number of outgoing energies for incident energy l

† The number of incoming energies N_{in} for incoherent inelastic scattering is given in the ITIE Block.

Table 68: ITXE Block for NXS(7) = 2 (continued).

Location in XSS	Parameter	Description
L(1)+1	$E_1^{out}[E_{in}(1)]$	First of NIEB outgoing energies for inelastic scattering at $E_{in}(1)$
L(1)+2	$\mathrm{PDF}_1[E_{in}(1)]$	Probability density function value for $E_1^{out}[E_{in}(1)]$
L(1)+3	$\mathrm{CDF}_1[E_{in}(1)]$	Cumulative distribution function value for $E_1^{out}[E_{in}(1)]$
L(1)+4	$\mu_l(1 \to 1), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_1^{out}[E_{in}(1)]$
L(1)+4+N_μ	$E_2^{out}[E_{in}(1)]$	Second of NIEB outgoing energies for inelastic scattering at $E_{in}(1)$

Continued on next page

Table 68: ITXE Block for NXS(7) = 2 (continued) (continued)

Location in XSS	Parameter	Description
L(1)+5+N_μ	$\text{PDF}_2[E_{in}(1)]$	Probability density function value for $E_2^{out}[E_{in}(1)]$
L(1)+6+N_μ	$\text{CDF}_2[E_{in}(1)]$	Cumulative distribution function value for $E_2^{out}[E_{in}(1)]$
L(1)+7+N_μ	$\mu_l(1 \to 2), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_2^{out}[E_{in}(1)]$
⋮	⋮	⋮
L(1)+1+(N'(1)-1)(3+N_μ)	$E^{out}_{N'(1)}[E_{in}(1)]$	Last of $N'(1)$ outgoing energies for inelastic scattering at $E_{in}(1)$
L(1)+2+(N'(1)-1)(3+N_μ)	$\text{PDF}_{N'(1)}[E_{in}(1)]$	Probability density function value for $E^{out}_{N'(1)}[E_{in}(1)]$
L(1)+3+(N'(1)-1)(3+N_μ)	$\text{CDF}_{N'(1)}[E_{in}(1)]$	Cumulative distribution function value for $E^{out}_{N'(1)}[E_{in}(1)]$
L(1)+4+(N'(1)-1)(3+N_μ)	$\mu_l(1 \to N'(1)), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E^{out}_{N'(1)}[E_{in}(1)]$
(Repeat for all remaining values of E_{in})		

6.3.3 ITCE Block

The format of the ITCE Block and ITCEI Block is given in Table 69. The index at the start of the ITCE Block and ITCEI Block is respectively S_{ITCE}=JXS(4) and S_{ITCE}=JXS(7).

Table 69: ITCE Block.

Location in XSS	Parameter	Description
S_{ITCE}	N_{el}	Number of elastic energies
S_{ITCE}+1	$E_{el}(l), l = 1, \ldots, N_{el}$	Energies
S_{ITCE}+1+N_{el}	$P(l), l = 1, \ldots, N_{el}$	(See below)

For incoherent elastic scattering (stored in ITCE Block if NXS(5) = 4 and stored in ITCEI Block if NXS(5) = 5),

$$P(l) = \sigma_{el}(E_{el}(l)) \tag{22}$$

with linear-linear interpolation between points. For coherent elastic scattering (stored in ITCE Block if NXS(5)= 4or5),

$$P(l) = E \cdot \sigma_{el}(E), \qquad E_{el}(l) \leq E < E_{el}(l+1). \tag{23}$$

In this case, the energies $E_{el}(l)$ correspond to Bragg edges, and between two energies the cross

section is determined by inverting Equation 23:

$$\sigma_{el}(l) = \frac{P(l)}{E}, \qquad E_{el}(l) \leq E < E_{el}(l+1). \tag{24}$$

Also note that $\sigma_{el}(E) = 0$ below $E_{el}(1)$. However, above $E_{el}(N_{el})$, $\sigma_{el}(E) = P(N_{el})/E$.

6.3.4 ITCA Block

The format of the ITCA Block and ITCAI Block is given in Table 70. The index at the start of the ITCA Block and ITCAI Block is respectively S_{ITCA}=`JXS(6)` and S_{ITCA}=`JXS(9)`. For each incident energy from the ITCE Block and ITCEI Block respectively, N_μ =`NXS(6)`+1 and N_μ =`NXS(8)`+1 discrete cosines are given.

Table 70: ITCA Block.

Location in XSS	Parameter	Description
S_{ITCA}	$\mu_l[E_{el}(1)], l = 1, \ldots, N_\mu$	Discrete cosines for elastic scattering at $E_{el}(1)$
$S_{\text{ITCA}}+N_\mu$	$\mu_l[E_{el}(2)], l = 1, \ldots, N_\mu$	Discrete cosines for elastic scattering at $E_{el}(2)$
⋮	⋮	⋮
$S_{\text{ITCA}}+(N_{el}\text{-}1)N_\mu$	$\mu_l[E_{el}(N_{el})], l = 1, \ldots, N_\mu$	Discrete cosines for elastic scattering at $E_{el}(N_{el})$

The incident elastic energy grid $E_{el}(l)$ is given in the ITCE Block or ITCEI Block. Linear-linear interpolation is assumed between adjacent values of E_{el}.

7 Continuous-Energy Photon

7.1 NXS Array

Table 71: NXS array element definitions for NXS ACE Table.

Element	Name	Description
1	—	Length of second block of data (XSS array)
2	Z	Atomic number
3	NES	Number of energies
4	NFLC	Length of the flourescence data divided by 4
5	NSH	Number of electron shells
	...	
16	—	

7.2 JXS Array

Table 72: JXS array element definitions for JXS ACE Table.

Element	Name	Location Description
1	ESZG	Energy table
2	JINC	Incoherent form factors
3	JCOH	Coherent form factors
4	JFLO	Fluorescence data
5	LHNM	Heating numbers
6	LNEPS	Number of electrons per shell
7	LBEPS	Binding energy per shell
8	LPIPS	Probability of interaction per shell
9	LSWD	Array of offsets to the shell-wise data
10	SWD	Shell-wise data in PDF and CDF form
	...	
32	—	