A Compact ENDF (ACE) Format Specification

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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)`$\neq 0$. 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 4.3.9
17. **ANDP Block**—contains photon angular distributions for all photon production reactions. The ANDP Block exists if NXS(6)$\neq 0$. See Section **??**.
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 4.3.15.
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 4.3.16.
22. **UNR Block**—contains the unresolved resonance range probability tables. The UNR Block exists if JXS(23)$\neq 0$. See Section 4.3.17.
23. **PTYPE Block**—contains a list of particle types for which production data will be given. The PTYPE Block exists if JXS(30)$\neq 0$. See Section 4.3.18.
24. **NTRO Block**—contains the number of reactions that produce the corresponding particle type given in the PTYPE Block. The NTRO Block exists if JXS(31)$\neq 0$. See Section 4.3.19.
25. **IXS Block**—particle production data locators for each particle type given in the PTYPE Block. The IXS Block exists if JXS(32)$\neq 0$. See Section 4.3.21.
26. **HPD Block**—total particle production cross section and average heating numbers for the current particle type. The HPD Block for a given particle type i exists if JXS(32)$+10*(i-1) \neq 0$. See Section **??**.
27. **MTRH Block**—contains a list of ENDF MT numbers for all reactions that produce the current particle. The MTR Block for a given particle type i exists if JXS(32) $+ 10 * (i - 1) + 1 \neq 0$. See Section 4.3.4.
28. **TYRH Block**—contains the reaction types for all reactions that produce the current particle. The TYRH Block for a given particle type i exists if JXS(32) $+ 10 * (i - 1) + 2 \neq 0$. See Section 4.3.6.
29. **LSIGH Block**—contains the cross section locators for all reactions that produce the current particle. The LSIGH Block for a given particle type i exists if JXS(32) $+ 10 * (i - 1) + 3 \neq 0$. See Section **??**.
30. **SIGH Block**—contains the cross section data for all reactions that produce the current particle. The SIGH Block for a given particle type i exists if JXS(32) $+ 10 * (i - 1) + 4 \neq 0$. See Section 4.3.14.
31. **LANDH Block**—contains the angular distribution locators for all reactions that produce the current particle. The LANDH Block for a given particle type i exists if JXS(32)$+10*(i-1)+5 \neq 0$. See Section 4.3.9.
32. **ANDH Block**—contains the angular distribution data for all reactions that produce the current particle. The ANDH Block for a given particle type i exists if JXS(32)$+10*(i-1)+6 \neq 0$. See Section **??**.

33. **LDLWH Block**—contains the energy distribution locators for all reactions that produce the current particle. The LDLWH Block for a given particle type i exists if `JXS(32)`$+10*(i-1)+7 \neq 0$. See Section 4.3.11.
34. **DLWH Block**—contains the energy distribution data for all reactions that produce the current particle. The DLWH Block for a given particle type i exists if `JXS(32)` $+ 10 * (i - 1) + 8 \neq 0$. See Section **??**.
35. **YH Block**—contains the particle production yield multiplier for all reactions that produce the current particle. The YH Block for a given particle type i exists if `JXS(32)`$+10*(i-1)+9 \neq 0$. See Section **??**.

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
7	NTYPE	Number of particle types for which production data is given
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 the conventional table (last word of photon production data)
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
	...	
30	PTYPE	Particle type array
31	NTRO	Array containing the number of particle production reactions
32	NEXT	Table of particle production locators (IXS array)

4.3 Format of Individual Data Blocks

4.3.1 ESZ Block

The ESZ Block provides the common incident energy table for all reactions defined in the ACE Table, cross section tables for fundamental cross sections (total, absorption, and elastic scattering) and average heating numbers. The format of the ESZ Block is given in Table 5. The starting index ESZ for this block is given by `JXS(1)`.

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 `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. The starting index BDD for this block is given by `JXS(25)`.

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

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

4.3.4 MTR, MTRP and MTRP Blocks

The format of the MTR Block (for incident neutron reactions), MTRP Block (for photon production reactions) and MTRH Block (for particle production reactions) is given in Table 10 and provides a list of MT numbers for which data is available in other blocks of the ACE Table. The starting index depends on whether it is the MTR Block, MTRP Block or MTRH Block and are given in Table 9. For the particle production MTRH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	LMT	NMT
MTR	`JXS(3)`	`NXS(4)`
MTRP	`JXS(13)`	`NXS(6)`
MTRH	`XSS(JXS(32)+10*(i-1)+1)`	`XSS(JXS(31)+i-1)`

Table 9: LMT and NMT values for the MTR Block and MTRH 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 and MTRH Block, $\mathsf{MT}_1, \ldots, \mathsf{MT}_{\mathsf{NMT}}$ 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 MTR Block, every MTnumber may be appear only once. In the MTRH Block, it is possible for a given MTnumber to appear twice if the same particle is also produced as the residual after the reaction (e.g. d + t -> d + d).

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 and TYRH Block

The format of the TYR Block (for incident neutron reactions) and TYRH Block (for particle production reactions) is given in Table 13. The starting index LTYR depends on whether it is the TYR Block or TYRH Block and are given in Table 12. For the particle production TYRH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	LTYR	NMT
TYR	`JXS(3)`	`NXS(4)`
TYRH	`XSS(JXS(32)+10*(i-1)+2)`	`XSS(JXS(31)+i-1)`

Table 12: LTYR and NMT values for the TYR Block and TYRH Block.

Table 13: TYR Block.

Location in XSS	Parameter	Description
S_{LTYR}	TY_1	Particle release for reaction MT_1
S_{LTYR}+1	TY_2	Particle release for reaction MT_2
...		
S_{LTYR}+NMT-1	$\mathsf{TY}_{\mathsf{NMT}}$	Particle 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 particles 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 (only used in the TYR Block). The number of secondary neutrons released is determined from the fission $\bar{\nu}$ data found in the NU Block. TY_i=0 indicates absorption; no particles are released. $\|\mathsf{TY}_i\| > 100$ signifies reactions other than fission that have energy-dependent multiplicities (currently only used in the TYR Block). The number of secondary particles released is determined from the yield data found in the DLW Block or DLWH Block. The MT_is are given in the MTR Block or MTRH Block.

4.3.7 LSIG, LSIGP and LSIGH Blocks

The LSIG Block (for incident neutron cross sections), LSIGP Block (for photon production cross sections) and LSIGH Block (for particle production cross sections) give the locators for the cross section array for each reaction MT. A locator is a *relative* index in the XSS array where some piece of data can be found. In this case, the data are the cross section values. The format of the LSIG Block, LSIGP Block and LSIGH Block is given in Table 19. 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 and the format for the particle production cross sections is given in Section 4.3.14.

The starting index LXS depends on whether it is the LSIG Block, LSIGP Block or LSIGH Block and are given in Table 55. For the particle production LSIGH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	LXS	NMT
LSIG	`JXS(6)`	`NXS(4)`
LSIGP	`JXS(14)`	`NXS(6)`
LSIGH	`XSS(JXS(32)+10*(i-1)+3)`	`XSS(JXS(31)+i-1)`

Table 14: TYR and NMT values for the TYR Block and TYRH Block.

The MTs are given in the MTR Block, the MTRP Block and MTRH Block respectively for the LSIG Block, the LSIGP Block and LSIGH Block respectively. LOCA_i must be monotonically increasing. All locators (LOCA) are *relative* to SIG=`JXS(7)` for the LSIG Block, *relative* to SIGP=`JXS(14)` for the LSIGP Block and relative to ANDH=`XSS(JXS(32)+10*(i-1)+4)` for the LSIGH Block for particle index i.

Table 15: LSIG & LSIGP Block.

Location in XSS	Parameter	Description
LXS	LOCA_1	Location of cross sections for reaction MT_1
LXS+1	LOCA_2	Location of cross sections for reaction MT_2
...		
LXS+NMT-1	$\mathsf{LOCA}_\mathsf{NMT}$	Location of cross sections for reaction MT_NMT

4.3.8 SIG Block

The SIG Block contains the incident neutron cross section data (photon production cross sections are given in the SIGP Block and particle production cross sections are given in SIGH Block). The format of the SIG Block is given in Table 16. The starting index LXS of the SIG Block is given by `JXS(7)`. The cross section data for each reaction begins at an index defined by the corresponding relative locator from the LSIG Block, which are given in Table 17.

Table 16: SIG Block.

Location in XSS	Description
$\mathsf{LXS}+\mathsf{LOCA}_1\text{-}1$	Cross section array for reaction MT_1
$\mathsf{LXS}+\mathsf{LOCA}_2\text{-}1$	Cross section array for reaction MT_2
...	
$\mathsf{LXS}+\mathsf{LOCA}_\mathsf{NMT}\text{-}1$	Cross section array for reaction MT_NMT

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

Table 17: Cross section array for the i-th reaction..

Location in XSS	Parameter	Description
$\mathsf{LXS} + \mathsf{LOCA}_\mathsf{i}\text{-}1$	IE_i	Energy grid index for reaction MT_i
$\mathsf{LXS} + \mathsf{LOCA}_\mathsf{i}$	$N_{E,i}$	Number of consecutive entries for MT_i
$\mathsf{LXS} + \mathsf{LOCA}_\mathsf{i}+1$	$\sigma_i[E(l)]$ 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.

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.

4.3.9 LAND, LANDP and LANDH Block

The LAND Block (for incident neutron reactions), LANDP Block (for photon production reactions) and LANDH Block (for particle production reactions) give the locators for the angular distribution array for each reaction MT. A locator is a *relative* index in the XSS array where some piece of data can be found. In this case, the data are the angular distributions. The format of the LAND Block, LANDP Block and LANDH Block is given in Table **??**.

The starting index LAND depends on whether it is the LAND Block, LANDP Block or LANDH Block and are given in Table 20. For the particle production LANDH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	LAND	NMT
LAND	`JXS(8)`	`NXS(5)`
LANDP	`JXS(16)`	`NXS(6)`
LANDH	`XSS(JXS(32)+10*(i-1)+5)`	`XSS(JXS(31)+i-1)`

Table 18: LAND and NMT values for the TYR Block and TYRH Block.

The MTs are given in the MTR Block, the MTRP Block and MTRH Block respectively for the LAND Block, the LANDP Block and LANDH Block respectively. LOCB_i must be monotonically increasing. All locators (LOCB) are *relative* to AND=`JXS(9)` for the LAND Block, *relative* to ANDP=`JXS(17)` for the LANDP Block and relative to ANDH=`XSS(JXS(32)+10*(i-1)+6)` for the LANDH Block for particle index i.

Table 19: LAND, LANDP and LANDH Block.

Location in XSS	Parameter	Description
LAND	LOCB_1	Location of angular distributions for reaction MT_1
LAND+1	LOCB_2	Location of angular distributions for reaction MT_2
...		
LAND+NMT-1	$\mathsf{LOCB}_{\mathsf{NMT}}$	Location of angular distributions for reaction $\mathsf{MT}_{\mathsf{NMT}}$

4.3.10 AND, ANDP and ANDH Block

The AND Block, ANDP Block and ANDH Block contains angular distribution data for all reactions that produce secondary particles (neutrons for the AND Block, photons for the ANDP Block and

a specific particle for the ANDH Block). The format of these blocks is given in Table **??** and Table 22. The angular distribution data begins at the index specified by the locator LOCB from the LAND Block, LANDP Block or LANDH Block. If LOCB_i=0, no angular distribution data are given for reaction i and isotropic scattering is assumed in either the Lab or center-of-mass system. If LOCB_i=-1 no angular distribution data is given for reaction i (this can only happen for the the AND Block or ANDH Block). In this case, the angular distribution data are specified through law=44 in the DLW Block or DLWH Block.

The starting index LAND depends on whether it is the AND Block, ANDP Block or ANDH Block and are given in Table 20. For the particle production LANDH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	LAND	NMT
AND	`JXS(9)`	`NXS(5)`
ANDP	`JXS(17)`	`NXS(6)`
ANDH	`XSS(JXS(32)+10*(i-1)+6)`	`XSS(JXS(31)+i-1)`

Table 20: LAND and NMT values for the AND Block and ANDH Block.

Table 21: AND Block.

Location in XSS	Description
$\text{LAND}+\text{LOCB}_1$-1	Angular distribution array for elastic scattering
$\text{LAND}+\text{LOCB}_2$-1	Angular distribution array for reaction MT_1
...	
$\text{LAND}+\text{LOCB}_{\text{NMT}}$-1	Angular distribution array for reaction MT_{NMT}

Note: The format for the angular distribution of the i-th array is given in Table 23.

Table 22: ANDP Block and ANDH Block.

Location in XSS	Description
$\text{LAND}+\text{LOCB}_1$-1	Angular distribution array for reaction MT_1
...	
$\text{LAND}+\text{LOCB}_{\text{NMT}}$-1	Angular distribution array for reaction MT_{NMT}

Note: The format for the angular distribution of the i-th array is given in Table 23.

Table 23: Angular distribution array for the i-th reaction.

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

The angular distribution arrays (Table 23) contains additional locators, L_C; the sign of these locators is a flag:

- if LOCC$_l$=0, then distribution is isotropic and no further data is needed;
- if LOCC$_l$>0, then LOCC$_l$ points to a 32 equiprobable bin distribution (see Table 24);
- if LOCC$_l$<0, then LOCC$_l$ points to a tabulated angular distribution (see Table 25).

Table 24: Format for the 32 equiprobable bin distribution.

Location in XSS	Parameter	Description
LAND+|LOCC$_l$|-1	$P(1, K)$ $K = 1, \ldots, 33$	32 equiprobable cosine bins for scattering at energy $E(l)$.

Table 25: Format for the tabulated angular distribution..

Location in XSS	Parameter	Description
LAND+|LOCC$_l$| $- 1$	JJ	Interpolation flag[†]
LAND+|LOCC$_l$|	N_P	Number of points in the distribution
LAND+|LOCC$_l$| $+ 1$	$CS_{\text{out}}(j), j = 1, \ldots, N_P$	Cosine scattering angular grid
LAND+|LOCC$_l$| $+ 1 + N_P$	PDF$(j), j = 1, \ldots, N_P$	Probability density function
LAND+|LOCC$_l$| $+ 1 + 2N_P$	CDF$(j), j = 1, \ldots, N_P$	Cumulative density function

[†] 1 histogram interpolation,
2 linear-linear interpolation

The AND Block and ANDH Block can use both options (either a 32 equiprobable bin or tabulated distribution). The ANDP Block on the other hand can only use 32 equiprobable bin distributions.

4.3.11 LDLW, LDLWP, DNEDL and LDLWH Blocks

The LDLW Block, LDLWP Block and LDLWH Block give the locators for the energy distribution for every reaction that produces secondary neutron, secondary photons or other secondary particles (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), the LDLWH Block (for secondary particles) and the DNEDL Block (for delayed neutrons) is given in Table 27. The format for the distributions is given in Section 4.3.12.

The starting index LED depends on whether it is the LDLW Block, LDLWP Block, LDLWH Block or DNEDL Block and are given in Table **??**. For the particle production LDLWH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE. These blocks are given only if the starting index LED is different from zero.

Block	LED	NMT
LDLW	`JXS(10)`	`NXS(5)`
LDLWP	`JXS(18)`	`NXS(6)`
LDLWH	`XSS(JXS(32)+10*(i-1)+7)`	`XSS(JXS(31)+i-1)`
DNEDL	`JXS(26)`	`NXS(8)`

Table 26: LED and NMT values for the LDLW Block, the LDLWP Block, the LDLWH Block and DNEDL Block.

Table 27: 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)
...		
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 MTs are given in the MTR Block, the MTRP Block and MTRH Block respectively for the LDLW Block, the LDLWP Block and LDLWH Block respectively. LOCC_i must be monotonically increasing. All locators (LOCC) are *relative* to JED=`JXS(19)` for the LDLW Block, *relative* to JED=`JXS(19)` for the LDLWP Block and relative to JED=`XSS(JXS(32)+10*(i-1)+8)` for the LDLWH Block for particle index i.

4.3.12 DLW, DLWP, DLWH 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, the DLWH Block contains secondary particle energy distributions for all secondary particle producing reactions and the DNED Block contains the energy distributions for the delayed neutrons. The DLW Block, DLWP Block, DLWH Block and DNED Block block have the same format (although there may be restrictions on which laws are allowed in these blocks). 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, DLWH Block or DNED Block. These values are given in Table 28. For the particle production DLWH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	JED	NMT
DLW	`JXS(11)`	`NXS(5)`
DLWP	`JXS(19)`	`NXS(6)`
DLWH	`XSS(JXS(32)+10*(i-1)+8)`	`XSS(JXS(31)+i-1)`
DNED	`JXS(27)`	`NXS(8)`

Table 28: JED and NMT for the DLW Block, DLWP Block and DLWH Block.

Table 29: DLW Block.

Location in XSS	Description
JED+LOCC_1-1	Energy distribution array for reaction MT_1 or group 1 (if delayed neutron)
JED+LOCC_2-1	Energy distribution array for reaction MT_2 or group 2 (if delayed neutron)
...	
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 30: 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	NBT$(l), l = 1, \ldots, N_R$	ENDF interpolation parameters
JED+LOCC$_i$+3+N_R	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+IDAT$_1$ − 1	LDAT$(l), l, \ldots, L$	Law data for LAW$_1$.
JED+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 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 32) and 4 (Table 34) are used to describe spectra of secondary photons from neutron collisions. All laws—except for Law 2—are used 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 30 defines the starting location of the LDAT array within the XSS array.

TODO: add law=33 and other charged particle related laws, specify which laws are used for which type of outgoing particle

4.3.12.1 LAW=1—Tabular Equiprobable Energy Bins

Table 31: 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 $E_{\text{out}_2}(l), l = 1, \ldots,$ NET ... $E_{\text{out}_{N_E}}(l), l = 1, \ldots,$ NET	E_{out} tables[‡]

[†] 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 32: 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 33: 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 34: 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 LDAT(l). The format for the data is given in Table 35, where for $E(1)$ let K=3+$2N_R + 2N_E$.

Table 35: 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 36: 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 36: 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 37: 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 38: 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 39: 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 40: 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 41: 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 41: 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+2$N_R + N_E$)	NET	Number of outgoing values in each table
LDAT(4+2$N_R + N_E$)	$T_1(l), l = 1, \ldots,$ 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 42: 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+2$N_R + N_E$)	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 43, where for $E(1)$ let K=3+2N_R + 2N_E.

Table 43: 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($\mathbf{N_E}$)—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 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 44: 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 LOC(l). The format for the data is given in Table 45, where for $E(1)$ let K=3+2N_R + 2N_E.

Table 45: 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 46
	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 J-th array for the tabular angular distribution has the form shown in Table 46. 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 46: 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 47: 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:

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

4.3.12.14 LAW=67—Laboratory Angle-Energy Law

Table 48: 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 49, where for $E(1)$ let $\mathsf{K} = 3 + 2N_R + 2N_e$.

Table 49: 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 50

† **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 50. 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 50: 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 51, where $\mathsf{KY} = \mathsf{JED} + |\mathsf{TY}_i| - 101$.

Table 51: 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 52.

Table 52: 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 53.

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 54. 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 54. 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 53: 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 54: 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 and SIGH Block

The SIGP Block contains the photon production cross section data and the SIGH Block contains the particle production cross section data. The format of the SIGP Block and SIGH Block is given in Table 56. The starting index depends on whether it is the LSIGP Block or LSIGH Block and are given in Table **??**. For the particle production SIGH Block, i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE.

Block	SIG		NMT
SIGP	`JXS(15)`	37	`NXS(6)`
SIGH	`XSS(JXS(32)+10*(i-1)+4)`		`XSS(JXS(31)+i-1)`

Table 55: SIG and NMT values for the SIGP Block and SIGH Block.

The format of the i-th cross section array has two possible forms depending on the first number in the array, MFTYPE.

1. If MFTYPE=12 or MFTYPE=16, yield data taken from ENDF File 12 or 6, respectively (see Table 57). With this format, the photon or particle production cross section can be constructed using Equation 20:
$$\sigma_i(E) = Y(E) * \sigma_{\mathsf{MTMULT}}(E). \tag{20}$$
2. If MFTYPE=13, photon production cross section data from ENDF File 13 (see Table 58). This form is only allowed for the SIGP Block.

Table 57: 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 58: 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	$\sigma_{\gamma,i}[E(K)]$, $K = \mathsf{IE}, \ldots, \mathsf{IE} + N_E - 1$	Photon production cross sections for reaction MT$_i$

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

4.3.15 YP and YH Block

The YP Block and YH Block contains a list of MT identifiers of cross sections that are used as yield multipliers in Equation 20 to calculate the photon production cross sections (for the YP Block) and the secondary particle production cross sections (for the YH Block) and are referenced by the MTMULT parameter in Table 57. The format of the YP Block and YH Block is given in Table 59.

The starting index LY depends on whether it is the YP Block or YH Block. For the YP Block, LY = `NXS(6)`. For the particle production YH Block, JED = `XSS(JXS(32)+10*(i-1)+8)` in which i refers to the index of the corresponding particle type defined on the PTYPE Block and is between 1 and NTYPE. These blocks are given only if the starting index LY is different from zero.

Table 59: YP Block.

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

4.3.16 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 60.

Table 60: 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	$\sigma_f[E(l)], K =$ IE$, \ldots,$ IE$+N_E-1$	Total fission cross sections

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

4.3.17 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.

Table 61: 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

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 62. The $P(i, j, k)$ values, where

- $i = 1, \ldots, N$,
- $j = 1, \ldots, 6$,
- $k = 1, \ldots, M$,

are what make up the probability tables. The argument j has special meaning depending on its value as shown in Table 61.

Table 62: 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 63, which begins at PTABLE = JXS(23) + 6 + N.

Table 63: Order of probability table elements $P(i, j, k)$.

Location in XSS	Parameter	Description
	Data for E(1)	
PTABLE	$\text{CDF}_1(l), l = 1, \ldots, M$	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 $P(i, 1, k = M) = 1.0$.

4.3.18 PTYPE Block

The PTYPE Block is the first of the particle production blocks used for neutron and charged particle production data. These particle production blocks are given only if the number of particles NTYPE = NXS(7) is different from zero. If the PTYPE Block is present, the PTYPE Block starts at the

index LTYPE = JXS(30).

Question: The particle type can be neutron, when is this actually used?

The PTYPE Block gives a list of particle types for which particle production data is available. This includes cross section data (given in the SIGH Block), angular distribution data (given in the ANDH Block) and secondary particle energy distribution data (given in the DLWH Block).

The format of the PTYPE Block is given in Table 65.

Table 64: PTYPE Block.

Location in XSS	Parameter	Description
LTYPE	IP_1	First particle type
LTYPE+1	IP_2	Second particle type
...		
LTYPE+NTYPE-1	IP_{NMT}	Last particle type

$IP_1, \ldots, IP_{NMT}$ are particle identifiers given as follows:

- IP = 1 for neutrons
- IP = 9 for protons
- IP = 31 for deuterons
- IP = 32 for tritons
- IP = 33 for helions
- IP = 34 for aphas

4.3.19 NTRO Block

The NTRO Block gives the number of reactions for each of the particle types defined in the PTYPE Block. If the NTRO Block is present, the NTRO Block starts at the index LTYPE = JXS(31).

The format of the NTRO Block is given in Table **??**.

Table 65: NTRO Block.

Location in XSS	Parameter	Description
LTYPE	NP_1	Number of reactions producing the first particle type
LTYPE+1	NP_2	Number of reactions producing the second particle type
...		
LTYPE+NTYPE-1	NP_{NMT}	Number of reactions producing the last particle type

4.3.20 IXS Block

The IXS Block gives 10 particle production locators for each of the particle types defined in the PTYPE Block. If the IXS Block is present, the IXS Block starts at the index NEXT = JXS(32). The IXS Block serves a similar function as the JXS Block, in that it provides the locators to specific blocks of data, as laid out in Table 66.

Table 66: IXS array for particle type j, with LTYPE = NEXT + 10NTYPE$(j-1)$ Block.

Location in XSS	Parameter	Description
LTYPE	HPD	Location of the total particle production and heating data
LTYPE+1	MTRH	Location of the particle production MT array
LTYPE+2	TYRH	Location of the particle production TYR data
LTYPE+3	LSIGH	Location of the particle production cross section locators
LTYPE+4	SIGH	Location of the particle production cross sections
LTYPE+5	LANDH	Location of the particle production angular distribution locators
LTYPE+6	ANDH	Location of the particle production angular distributions
LTYPE+7	LDLWH	Location of the particle production energy distribution locators
LTYPE+8	DLWH	Location of the particle production energy distributions
LTYPE+9	YH	Location of the particle production yield multipliers

With the exception of the HPD Block, all other locators point to blocks similar to the ones already defined for neutrons and photons.

4.3.21 HPD Block

The HPD Block gives the total particle production cross section and the associated heating number for a given particle. If the particle production data is given (i.e. the NTYPE $\neq 0$, and the PTYPE Block, the NTRO Block and IXS Block are given), the HPD Block is present. The HPD Block starts at the location index HPD = XSS()NEXT + $10 * (j-1)$).

Table 67: HPD Block.

Location in XSS	Parameter	Description
HPD	IE	Energy grid index
HPD+1	N_E	Number of consecutive energies
HPD+2	$\sigma[E(K)]$,	Total particle production cross section
HPD+2+NE	$E(l), l = 1, \ldots, N_E$	Average heating numbers

5 Neutron Dosimetry

5.1 NXS Array

Table 68: 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 69: 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**—contains the energy-dependent elastic scattering cross sections. The ITCE Block exists if the material has coherent or incoherent elastic scattering; that is, if `JXS(4)`$\neq 0$. See Section 6.3.2.
3. **ITXE Block**—contains coupled energy/angle distributions for incoherent inelastic scattering. The ITXE Block always exists. See Section 6.3.3.
4. **ITCA Block**—contains angular distributions for elastic scattering. The ITCA Block exists if `JXS(4)`$\neq 0$ and `NXS(6)`$\neq -1$. See Section 6.3.4.

6.1 NXS Array

Table 70: 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 (coherent=4, incoherent≠4)
6	NCL	Elastic dimensioning parameter
7	IFENG	Secondary energy mode (discrete=0, skewed=1, continuous=2)
	...	
16	—	

6.2 JXS Array

Table 71: 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
5	ITCX	Elastic cross sections
6	ITCA	Elastic angular distributions
	...	
32	—	

6.3 Format of Individual Data Blocks

6.3.1 ITIE Block

The format of the ITIE Block is given in Table 72. 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 72: ITIE Block.

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

6.3.2 ITCE Block

The format of the ITCE Block is given in Table 73. The index at the start of the block is S_{ITCE}=JXS(4).

Table 73: ITCE Block.

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

For incoherent elastic scattering (NXS(5)$\neq 4$),

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

with linear-linear interpolation between points. For coherent elastic scattering (NXS(5)$= 4$),

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

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 $E_{el}(N_{el})$, $\sigma_{el}(E) = P(N_{el})/E$.

6.3.3 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 74)
NXS(7) $= 1$ skewed distribution of discrete cosines and energies (Table 74)
NXS(7) $= 2$ continuous distribution of outgoing energies and equally-likely discrete cosines (Table 75 and Table 76)

The format of the ITXE Block for NXS(7) < 2 is given in Table 74. 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 74: 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 $E_{in}(1)$
$S_{\text{ITXE}}+1$	$\mu_l(1 \to 1), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_1^{out}[E_{in}(1)]$
$S_{\text{ITXE}}+1+N_\mu$	$E_2^{out}[E_{in}(1)]$	Second of NIEB outgoing energies for inelastic scattering at $E_{in}(1)$
$S_{\text{ITXE}}+2+N_\mu$	$\mu_l(1 \to 2), l = 1, \ldots, N_\mu$	Discrete cosines for scattering from $E_{in}(1)$ to $E_2^{out}[E_{in}(1)]$
⋮	⋮	⋮

Continued on next page

Table 74: ITXE Block for NXS(7) < 2 (continued)

Location in XSS	Parameter	Description
S_{ITXE}+(N'-1)(1+N_μ)	$E^{out}_{N'}[E_{in}(1)]$	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 $E^{out}_{N'}[E_{in}(1)]$
(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 75 and Table 76. 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 75: 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_{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 76: 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	$\text{PDF}_1[E_{in}(1)]$	Probability density function value for $E_1^{out}[E_{in}(1)]$
L(1)+3	$\text{CDF}_1[E_{in}(1)]$	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 $E_{in}(1)$
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)	$E_{N'(1)}^{out}[E_{in}(1)]$	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 $E_{N'(1)}^{out}[E_{in}(1)]$
L(1)+3+($N'(1)$-1)(3+N_μ)	$\text{CDF}_{N'(1)}[E_{in}(1)]$	Cumulative distribution function value for $E_{N'(1)}^{out}[E_{in}(1)]$
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 $E_{N'(1)}^{out}[E_{in}(1)]$
(Repeat for all remaining values of E_{in})		

6.3.4 ITCA Block

The format of the ITCA Block is given in Table 77. The index at the start of the block is S_{ITCA}=JXS(6). For each incident energy from the ITCE Block, N_μ =NXS(6)+1 discrete cosines are given.

Table 77: 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 $E_{el}(1)$

Continued on next page

Table 77: ITCA Block (continued)

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

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

7 Continuous-Energy Photon

7.1 NXS Array

Table 78: 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 79: 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	—	