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VIXEN:  
a Code to Check Physical Consistency  
of Photon-Production Data  
in Revised ENDF Format



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Printed in the United States of America. Available from  
National Technical Information Service  
U. S. Department of Commerce  
5285 Port Royal Road  
Springfield, Virginia 22151  
Price: Printed Copy \$3.00; Microfiche \$0.95

LA-4739  
(ENDF-155)  
UC-32 and -80

ISSUED: October 1971



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Donald J. Dudziak  
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Work supported by the Division of Reactor Development and Technology, Reactor Physics Branch.



**VIXEN:  
A CODE TO CHECK PHYSICAL CONSISTENCY  
OF PHOTON-PRODUCTION DATA IN REVISED ENDF FORMAT**

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**ABSTRACT**

The VIXEN code reads the neutron cross-section and photon-production data files in ENDF format, checking them for format syntax, consistency, and physical realism. The code is intended to help cross-section evaluators and reviewers produce an ENDF data set free of typographical, syntactical, and simple physics errors. Suspected errors are flagged on the output listing, and quantities useful to the reviewer (e.g., total photon energy released and average photon energy of a continuum) are listed. The code, written in FORTRAN IV, is presently operational on CDC 6600, CDC 7600, and IBM 360 computers, and requires a 42k<sub>10</sub> core memory. It is available from the Radiation Shielding Information Center at Oak Ridge National Laboratory.

## I. Introduction

The VIXEN code was written to check the photon-production data files (Files 12 through 15) in the Evaluated Nuclear Data File (ENDF). The code also performs some minor checks on the neutron cross-section file (File 3), which are necessary for further processing in Files 12 through 15. A familiarity with the photon-production data formats, as described in Ref. 1, is presumed in this report, and the reader may find it useful to acquaint himself with the neutron cross-section data format given in Ref. 2.

VIXEN is a revision and extension of an older code,<sup>3</sup> PHOXE, which it supersedes. Revision of the ENDF formats for the neutron and photon-production data necessitated the revision of PHOXE. VIXEN is intended to help cross-section evaluators and reviewers produce an ENDF data set free of typographical, syntactical, and simple physics errors. Although the code does detect some format syntax errors, the user may find it advantageous to run the data through the CHECKER code<sup>4</sup> first. VIXEN operates only on those ENDF data in Mode 1 (Standard

Binary Arrangement) or Mode 3 (BCD).

We have tried to include any reasonable check that can be automated and does not require interaction with any system outside the ENDF. Typical checks are (1) threshold energies vs Q values, (2) reasonable sign and magnitude of Q, (3) consistency and reasonableness of level and photon energies, and (4) total photon energy released vs reaction energetics. Suspected errors are flagged on the output listing immediately following the record in which they are detected. Also given on the output listing are computed quantities useful to the reviewer (e.g., total photon energy released and average photon energies of continua).

The code is written completely in FORTRAN IV and is currently operational on the CDC 6600, CDC 7600, and IBM 360 computers. A 41,472<sub>10</sub> (121,000<sub>8</sub>) core memory, a magnetic tape unit, and two scratch files (disk or extended core storage) are required to run the code. The central processor time on a CDC 6600 for the silicon data, the sample problem in the code package, is slightly less than 1 min. The code package containing the FORTRAN listing of the BCD source deck, the sample

problem card input, the sample problem output, and an INDEX (cross reference) listing of the code is available.\*

## II. Organization of the Code

Figure 1 is a schematic of the overall logical structure of the code. Not all of the subroutines are shown in the schematic, but a functional description of the main program and all the subroutines is given in Sec. IV.

The main calling program, VIXEN, performs very few data checks and serves a primarily executive function. Almost all data checks are made in the appropriate subroutines.

The code begins by processing the File 3 (neutron cross sections) data. Although a few format syntax and simple physics checks (Q-value reasonableness, etc.) are made, the main reason for processing the File 3 data is to store the Q values, threshold energies, maximum neutron energies, and reaction (MT) numbers for later reference in Files 12 through 15. To keep the code's memory-storage requirements as low as possible, the File 3 neutron energies and cross sections are not stored if more than 1000 neutron energies per MT number are given or if the data tape is written in Binary (Mode 1). The list of neutron energies and their corresponding cross sections is not printed on the output listing.

Files 14 (Photon Angular Distributions) and 15 (Continuous Photon Energy Spectra) are processed before Files 12 (Multiplicities and Transition Probability Arrays) and 13 (Photon Production Cross Sections). This processing order is essential because of the great amount of cross-referencing of data necessary to check the photon-production data, especially in regard to the "EG-ES pairs." We use the term "EG-ES pairs" throughout this report to refer to photon energies and the corresponding nuclear excited level energies from which the photons arise. The files are printed in order on the output listing. This is accomplished as follows.

1. Files 12 and 13 are read.
2. Files 12 and 13 are copied onto a scratch tape in binary.
3. Files 14 and 15 are read and processed.
4. The processed output is written onto a second scratch tape in BCD with 110 characters per record.
5. The first scratch tape (Files 12 and 13 data) is rewound.

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\*To obtain the code package and an abstract of the code, write to: Codes Coordinator, Radiation Shielding Information Center, Oak Ridge National Laboratory, Post Office Box X, Oak Ridge, Tennessee 37831.

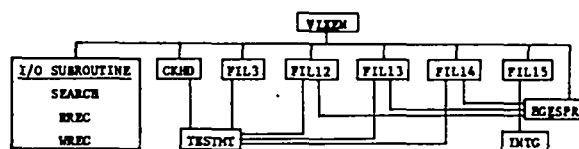


Fig. 1.  
Schematic structure of VIXEN.

6. Files 12 and 13 are read and processed.
7. The processed output of Files 12 and 13 is listed.
8. The second scratch tape (processed output of Files 14 and 15) is rewound.
9. The processed output of Files 14 and 15 is listed.

All the EG-ES pairs from File 14 are stored there in arrays for later reference in Files 12 and 13, because all the EG-ES pairs appearing in Files 12 and 13 must appear in File 14. Anisotropic and isotropic angular distributions are checked to be truly anisotropic and isotropic. The neutron energies for which EG-ES pairs are tabulated are given a host of tests, as they are in Files 12 and 13, to determine if they lie in the proper energy ranges determined from File 3. MT numbers are checked to determine that they appear in File 3 as they are in Files 12, 13, and 15. The MT numbers are stored in File 3 for later reference in Files 12, 13, and 15.

In File 15, the normalization of the probability distributions is checked. The maximum photon energy is compared to the maximum energy theoretically allowed by the Q value from File 3 for a given MT number.

The average photon energy is computed at each neutron energy for every reaction given in File 15 and is stored there for later reference in File 12.

File 12 has two major options in which to represent the data: Multiplicities and Transition Probability (TP) Arrays. The EG-ES pairs and the neutron energy ranges over which they are given are stored for both options. Only for option No. 1 (Multiplicities) is the total photon energy released at a particular neutron energy computed and printed on the output. If a reaction has some continuum photons, the average photon energy computed in File 15 is used in computing the total photon energy released. The EG-ES pairs are checked against those in File 14.

The EG-ES pairs of File 13 are checked against those from File 12 to determine whether there is redundancy in the data. They are also checked with the EG-ES pairs in File 14. The summed partial photon-production cross sections are checked against the tabulated total photon-production cross sections in the data, and any disagreements are flagged.

At the very end of the code, all the EG-ES pairs found in File 14 are checked against those found in Files 12 and 13, and any pairs not referenced in Files 12 or 13

are flagged. Successful completion of code processing is indicated by the printed comment *FINIS CORONAT OPUS*.

Two types of comments are printed on the output listing of a VIXEN run. One, signaled by asterisks (\*), indicates an error or possible error. The other, set off by dollar signs (\$), prints potentially valuable data and/or comments to help evaluators and reviewers. Note that an error comment may occasionally not be flagging a valid error. For example, for all exoergic reactions ( $Q > 0.0$ ), the neutron energies should span at least the range  $10^{-5}$  eV to 20 MeV. For MT = 91 (inelastic scattering to the continuum), the Q value is generally given as zero, not because the reaction is exoergic but because the Q value may not be meaningful. This leads to printing of an error flag (associated with the neutron energy ranges) on the output listing although there is really no error. There are very few possible invalid error flags, and the user is cautioned not to shrug off an error flag as a "code error."

Format syntax errors are the most damaging to a processing code like VIXEN. A seemingly simple error may mean that the code will be unable to continue processing. Consequently, VIXEN has been written so that incorrect control parameters are flagged (usually by the ERROR subroutine), and reasonable values are assumed. This does not automatically guarantee that processing can continue without consequence, even when a correct value for an incorrect control parameter is determined from other pertinent data read in. Therefore, we cannot urge too strongly that you preprocess all data with CHECKER to eliminate most format syntax errors.

The card-sequence numbers in the output listing correspond to those on a BCD data tape. This is a convenience when a particular incorrectly written card must be replaced. Binary tapes (Mode 1) have no card-sequence numbers, so all output listing card-sequence numbers are generated by VIXEN, and reflect only the relative order of the neutron and photon-production files.

### III. Checks and Processings

Most checks of the photon-production data (Files 12 through 15) are derived from the Procedures section of the respective file descriptions in Ref. 1. All of the theory behind the physics checks is derived from elementary nuclear physics. As noted, an error comment may occasionally be printed when no actual error exists. See the example and discussion in the previous section. Errors are flagged immediately following the record in which they are detected.

All the checking and processing done by VIXEN is given below in order of ENDF files. Checks or processes common to more than one file are given explicitly in the first file in which they apply and implicitly in later files. Definitions of symbols not included in the photon-production data format are given with the first use of each symbol. Unless explicitly covered in the checks to follow, the error is described in a comment printed on the output listing.

#### A. File 3 (Neutron Cross Sections)

1. Reaction (MT) numbers should be in ascending order.

2. All MT numbers are stored here for later reference in Files 12 through 15.

3. The NR and NP parameters are confined to the following ranges.

- a.  $1 \leq NR \leq 10$ ,
- b.  $2 \leq NP \leq 5000$ .

4. Q values should be reasonable.

- a. For  $51 \leq MT \leq 90$ ,  $721 \leq MT \leq 738$ ,  $761 \leq MT \leq 778$ ,

$$Q < 0.0,$$

and

$$10^4 \text{ eV} \leq |Q| \leq 2.0 \times 10^7 \text{ eV}.$$

- b. For MT = 91,  $Q \leq 0.0$ .

- c. For MT = 3, MT = 18, MT = 27, MT = 29, or MT = 101,

$$Q \geq 0.0.$$

- d. For MT = 102,  $Q \geq 0.0$ . If  $Q \neq 0.0$ ,

$$1.7 \times 10^6 \text{ eV} \leq Q \leq 1.2 \times 10^7 \text{ eV};$$

but, if  $Q = 0.0$ , then Q is set equal to  $8.0 \times 10^6$  for later checks.

- e. Store the Q value here for later reference in Files 12 through 15.

5. Threshold-energy checks. The threshold energy [E(1)] here means the energy that appears first in the tabulation of neutron cross sections. The theoretical threshold (ETHEO) is that computed from the Q and AWR values. For  $Q < 0.0$ ,

$$\text{ETHEO} = |Q| * \left( \frac{\text{AWR} + 1.0}{\text{AWR}} \right)$$

but ETHEO = 0.0 for  $Q \geq 0.0$ .

The effective threshold (ETH) is that threshold energy value [E(1) or ETHEO] stored in File 3 for later reference in Files 12 through 15.

- a. If  $Q \geq 0.0$ , the threshold energy should be such that  $E(1) \leq 10^{-5}$  eV.
- b. If  $Q \geq 0.0$ , the theoretical threshold is set equal to zero.
- c. Check to see that  $ETHEO \leq E(1) * 1.001$ .
- d. If  $ETHEO > E(1) * 1.001$ , set  $ETH = ETHEO$ ; otherwise, set  $ETH = E(1)$ .
- e. If the first energy, E(1), is greater than the theoretical threshold by a factor of 1.02, an error comment is written. (No comment is written if  $E_1 \leq 10^{-5}$  to allow for those values of ETHEO equal to zero.)
- f. The effective threshold value, ETH, is stored.

6. Calculate and print  $\sigma(2200 \text{ m/sec}) \equiv \sigma(0.0253 \text{ eV})$  for  $MT = 102$  (radiative capture).  $\sigma(0.0253 \text{ eV})$  is not printed if any of the following conditions exist.

- a.  $E_1 > 0.0253 \text{ eV}$ . A comment is printed explaining why the cross section is not printed.
- b.  $NP > 1000$ .
- c. Data tape is not in Mode 3 (BCD).

#### B. File 12 (Multiplicities and Transition Probability Arrays)

##### 1. MT number checks:

- a. Every MT number appears in File 3.
- b. Every MT numbers appears in File 14.
- c. Only the following MT numbers are allowed.

MT = 1, 3, or 4	MT = 120
$16 \leq MT \leq 30$	$701 \leq MT \leq 719$
$32 \leq MT \leq 38$	$721 \leq MT \leq 739$
MT = 46	$741 \leq MT \leq 759$
$51 \leq MT \leq 91$	$761 \leq MT \leq 779$
$101 \leq MT \leq 114$	$781 \leq MT \leq 799$

If a reaction is not given in File 3, checks against File 3 quantities (Q value, threshold energy, maximum neutron energy) cannot be made.

2.  $LO = 1$  or 2. If  $LO$  does not equal 1 (Multiplicities) or 2 (Transition Probability Arrays),  $LO$  is set equal to 1.

##### 3. $LO = 1$ checks:

- a. The L2 and N2 fields for the HEAD card should be blank.
- b. The NK parameter on the HEAD card must be reasonable for the MT number. The NK value is checked in subroutine TESTMT. First, if  $NK \leq 0$ , NK is set equal to 1. The NK value should be such that if

$51 \leq MT \leq 90$ ,	$NK \leq MT - 50$
$701 \leq MT \leq 718$ ,	$NK \leq MT - 700$
$721 \leq MT \leq 738$ ,	$NK \leq MT - 720$
$741 \leq MT \leq 758$ ,	$NK \leq MT - 740$
$761 \leq MT \leq 778$ ,	$NK \leq MT - 760$
$781 \leq MT \leq 799$ ,	$NK \leq MT - 780$

Unless  $NK \leq 0$ , its value is not altered by the code.  $51 \leq MT \leq 90$  are the inelastic scattering to discrete levels reactions.  $701 \leq MT \leq 718$ , etc., are the discrete excited states of the residual nucleus from (n,x) reactions. These 700-number series are hereafter referred to as the 700 series.

- c. If the total number of discrete photons and photon continua is one ( $NK = 1$ ) for a reaction, then the total photon yield TAB1 record is omitted.
- d. The neutron-energy range for the first TAB1 record ( $LF = 1$  or 2) should span at least the following ranges.

(1)  $10^{-5} \text{ eV} \leq E \leq 2 \times 10^7 \text{ eV}$  if  $Q \geq 0.0$

(2)  $(ETH(MT) * F) \leq E \leq 2 \times 10^7 \text{ eV}$  if  $Q < 0.0$ .  
 $F = 1.01$  for  $MT = 4, 18-21, 51-91, 701-719, 721-739, 741-759, 761-779, 781-799$ .  
 $F = 1.1$  for all other MT numbers.

This condition holds even if  $NK = 1$  (no total-photon-yield TAB1 record is given).

e. Checks common to both the total-photon-yield TAB1 records and the partial-yield TAB1 records are:

(1)  $1 \leq NR \leq 10$ . If  $NR < 1$ , NR is set equal to 1.

(2)  $2 \leq NP \leq 1000$ . If  $NP < 2$ , NP is set equal to 2.

Note that if the Procedures Manual is violated and  $NP > 1000$ , the arrays used for reading and storing photon yields will overflow and code errors may result.

(3)  $NP > NR$ . If  $NP \leq NR$ , NR is set equal to 1; then, if  $NP \leq 1$ , NP is set equal to 2.

(4)  $1 \leq INT(1) \leq 5$ . INT(1) is the interpolation scheme for the 1th region.

(5)  $INT(I) \neq INT(I+1)$ . No two consecutive regions should have the same interpolation scheme.

(6)  $E(1) * 1.001 \geq ETH(MT)$ . The first energy of each TAB1 should be greater than or equal to the effective threshold from File 3.

(7)  $E(NP) \leq EMAX(MT)$ . The last energy of each TAB1 should be less than or equal to the maximum neutron energy in File 3.

(8) All neutron energies should be in ascending order.

f. Checks common to the TAB1 records for subsections with  $LF = 1$  or  $LF = 2$  are:

$E(1) \geq ETAB(1)$ , and  $E(NP) \leq ETAB(NP)$ . Neutron energies of the partial-yield TAB1 records,  $E(I)$ , are within the energy range of the neutron energies of the total-photon-yield TAB1 record,  $ETAB(J)$ .

g. For  $LF = 2$  (discrete photon energy):

(1) Subsections are given in order of decreasing magnitude of EG.

(2)  $EG > 0.0$ . EG is a photon energy.

(3)  $ES \leq 2 \times 10^7$ . ES is a level energy.

(4) For inelastic scattering to discrete levels and the 700 series,

$$EG \geq 10^4 \text{ eV,}$$

$$ES = |Q|,$$

$$ES \geq 10^4 \text{ eV,}$$

$$EG \leq ES,$$

$$ES(K) = ES(1) \quad K = 2(1)NK.$$

(5) For those MT numbers not in (4) above,

$$ES \geq 0.0,$$

$$EG \geq 10^4 \text{ eV if } EG \neq 0.0,$$

$$EG \leq ES \text{ if } ES \neq 0.0.$$

h. For  $LF = 1$  (normalized tabulated function):

(1)  $EG = 0.0$ .

(2) The continuum TAB1 record is the last one for this MT.

(3) Only one continuum is allowed per MT.

(4) Photon-energy distributions must be given in File 15.

(5) The neutron energies in Files 12 and 15 should span exactly the same energy range.

i. The calculated sum of photon yields must be greater than zero at each neutron energy.

j. The difference between the tabulated total yield and the calculated sum of the partial yields at each tabulated total-yield neutron energy should be less than 0.1%.

k. The total photon energy released is computed at those neutron energies entered in the total-yield TAB1 record.

l. The total photon energy released must satisfy the following conditions.

(1) For  $51 \leq MT \leq 90$  and the 700 series, the total photon energy released at each neutron energy,  $YTIL(I)$ , must be equal to or less than the absolute value of Q.  $YTIL(I) \leq |Q|, I = 1(1)NE$ .

(2) For  $MT = 91$ ,  $YTIL(I) \leq ECM$ . Here ECM is the incident neutron energy in the center-of-mass system.

$$ECM = E * \left( \frac{AWR}{AWR + 1.0} \right)$$

(3) For all MT numbers not included in (1) and (2) above,  $YTIL(I) \leq Q + ECM$ . The total photon energy released at the Ith neutron energy must be equal to or less than Q plus ECM.

4. For  $LO = 2$ , TP Arrays:

a. The LG parameter on the HEAD card must be equal to 1 or 2. If LG does not equal 1 or 2, an attempt is made to determine the value of LG from the fifth and sixth fields of the first card of the following LIST record.

b. The NS parameter on the HEAD card must be correct for the reaction number being processed. The same process used to check the value of NK for multiplicities is used for the NS parameter. If the value of NS is too large for an MT number, NS is set equal to the largest allowable value for that MT. When  $NS = 0$ , it is also set equal to the largest allowable value.

c. Only the reaction-type numbers for inelastic scattering to discrete levels (reactions) and the 700 series are allowed to have TP array representation. (HEAD card check.)



d. The N2 field for the HEAD card should be blank.

e.  $NT \leq NS$ . If  $NT > NS$ , NT is set equal to NS.

f.  $LG = \frac{(LG + 1)(NT)}{NT} - 1$ . The ratio of fifth to sixth fields, minus one, should be equal to LG. This process is used to determine LG when  $LG \neq 1$  or 2.

g. Fifth field =  $(LG + 1) * NT$ . If the fifth field does not equal the quantity  $(LG + 1)$  times NT, it is so set.

h. Checks on the level energies for both  $LG = 1$  (Doublet Arrays) and  $LG = 2$  (Triplet Arrays):

(1)  $ES(1) < ES_{NS}$ . The first level energy given must be less than the level energy of the excited state being processed.

(2)  $ES_{NS} = |Q|$ . The energy of the level for which the TP arrays are given must be equal to the Q value. The level is uniquely defined by  $ES_{NS}$ , NS, or MT for TP arrays.

(3)  $10^4 \leq ES_{NS} \leq 2 \times 10^7$ .

(4)  $ES(1) > ES(I + 1)$ . The level energies are given in order of decreasing magnitude.

i. Checks on the transition probabilities (TP's) for both  $LG = 1$  and  $LG = 2$ :

(1)  $0.0 < TP(I) \leq 1.0$ ,  $I = 1(1)NT$ .

(2)  $0.999 < \sum_{I=1}^{NT} TP(I) < 1.001$ .

The sum of the transition probabilities should be equal to unity within three significant figures.

j.  $0.0 < GP(I) \leq 1.0$ ,  $I = 1(1)NT$ . GP(I) is the conditional probability of photon emission from level NS to level I.

5. Processings common to both  $LO = 1$  and  $LO = 2$  are:

a.  $\{EG-ES\}_{12} \subset \{EG-ES\}_{14}$ . Every EG-ES pair given in File 12 must appear in File 14.

b. Every EG-ES pair and its corresponding neutron energy is stored in File 12 for later reference in File 13.

### C. File 13 (Photon-Production Cross Sections)

1. The MT number checks made in File 12 are also made in File 13. See B.1. above.

2. The NK value checks made in File 12 are also made in File 13. See B.3.b. above.

3. The L1, L2, and N2 fields on the HEAD card should be blank.

4. The total photon-production cross section TAB1 record is omitted if  $NK = 1$ . No comment is written, but the code may stop processing because of an excess TAB1 record.

5. The neutron-energy range spans for endoergic and exoergic reactions are the same as in File 12. See Sec. B.3.d.

6. The checks common to all TAB1 records in File 13 are the same as those made in File 12. See B.3.e.

7. The neutron energies of the partial photon-production cross section TAB1 records must be within the energy range of the total photon-production cross section TAB1 record.  $E(1) \geq ETAB(1)$ , and  $E(NP) \leq ETAB(NP)$ .

8. The checks for  $LF = 2$  TAB1 records in File 13 are the same as those in File 12. See B.3.g.

9. The checks for the  $LF = 1$  TAB1 records in File 13 are the same as those in File 12. See B.3.h.

10.  $\{EG-ES\}_{13} \subset \{EG-ES\}_{14}$ . Every EG-ES pair found in File 13 must appear in File 14.

11.  $\{EG-ES\}_{13} \not\subset \{EG-ES\}_{12}$ . No EG-ES pair in File 13 should appear in File 12 under the same or overlapping neutron energy range.

12. The computed sums of the partial photon-production cross sections and the tabulated total photon-production cross sections differ by less than 0.1%.

13. Except for the first neutron energy, when the computed sum of the partial photon-production cross section, YCAL(1), can equal 0.0, YCAL(1) should be greater than zero.

### D. File 14 (Photon Angular Distributions)

1. MT number checks and processings:

a. Every MT number must appear in File 3.

b. All MT numbers are stored in File 14 for later reference in Files 12, 13, and 15.

c. Only the MT numbers given in Sec. B.1.c. are allowed.

2. The flag LI must be equal to 1 (Isotropic Angular Distribution) or 0 (Anisotropic Angular Distribution). If  $LI \neq 0$  or 1, the value of 0 is assumed.

3. The NK value is checked to be reasonable for the MT number as in Sec. B.3.b. The NK value is not altered unless  $NK = 0$ , in which case it is set equal to 1.

4. The checks made on the isotropic angular distributions ( $LI = 1$ ) are:

a. L2 and N2 fields on the HEAD card should be blank, and

b. The card immediately after the HEAD card should be a SEND card.

5. Checks for  $LI = 0$  (Anisotropic Angular Distribution) (Checks a and b are HEAD card checks.):

a.  $1 \leq LTT \leq 2$ . LTT must equal 1 (Legendre Coefficient Representation) or 2 (Tabulated Form). If  $LTT \neq 1$  or 2, it is set equal to 2.

b.  $NI < NK$ . The number of isotropic distributions must be less than the total number of photons entered for a reaction. If  $NI > NK$ , NI is set equal to zero; then if NK is still less than or equal to NI, NK is set equal to 1. Use of  $NI = NK$  instead of the isotropic distribution ( $LI = 1$ ) is strongly discouraged.

c. If  $NI \neq 0$  (isotropic and anisotropic distributions for this MT), then:

(1) The subsections within each isotropic and anisotropic block are given in order of decreasing magnitude of EG.

(2) All the level energies (ES) are the same within an MT for  $51 \leq MT \leq 90$  or the 700 series.

d. Checks common to TAB1 and TAB2 records:

(1)  $NR > 0$ . If  $NR \leq 0$ , NR is set equal to 1.

(2)  $NP \geq 2$ . If  $NP < 2$ , NP is set equal to 2.

(3)  $NP > NR$ . If  $NP \leq NR$ , NR is set equal to 1; then if  $NP \leq NR$ , NP is set equal to 2.

(4)  $1 \leq INT(I) \leq 3$ . The interpolation scheme should be linear in the ordinate.

(5)  $INT(M) \neq INT(M + 1)$ . No two consecutive regions should have the same interpolation scheme.

e. Checks common to TAB2 records of  $LTT = 1$  and  $LTT = 2$ :

(1) For  $51 \leq MT \leq 90$  and the 700 series,

$EG > 0.0$ ,

$EG > 10^4$  eV,

$10^4 \leq ES \leq 2 \times 10^7$  eV,

$EG \leq ES$ ,

$ES = |O|$ .

$ES(K) = ES(1)$ ,  $K = 2(1)NK$ ,

where  $ES(1)$  is the first level energy entered for the reaction.

(2) For all those MT's not in (1) above,

$EG \geq 0.0$ ,

If  $EG \neq 0.0$ , then  $EG \geq 10^4$  eV,

$0.0 \leq ES \leq 2 \times 10^7$  eV.

If  $ES \neq 0.0$ , then  $EG \leq ES$ .

(3) If  $EG = 0.0$ , then  $ES = 0.0$ .

(4) If  $EG = 0.0$ , then MT is not in the range covered by  $51 \leq MT \leq 90$  or the 700 series, and MT is not equal to 50, 700, 720, 740, 760, or 780.

(5) The TAB2 records are given in order of decreasing magnitude of EG.

(6) Only one continuum per MT is allowed.

f. Checks for  $LTT = 1$  (Legendre Coefficient Representation) LIST records:

(1)  $E(I) * 1.001 \geq ETH(MT)$ .

(2)  $E(I) \leq EMAX(MT)$ .

(3) The neutron energies should be entered in ascending order.

(4) NL, the number of Legendre coefficients used to represent the angular distribution, should be an even number in the range  $1 \leq NL \leq 20$ . (NL = 1 is an allowed exception to the even-number rule.)

(5) If all the Legendre coefficients for the kth photon are equal to zero, a comment is written suggesting that the kth photon be entered as an isotropic EG-ES pair.

g. Checks for the  $LTT = 2$  (Tabulated Angular Distribution) TAB1 records:

(1)  $E(I) * 1.001 \geq ETH(MT)$ .

(2)  $E(I) \leq EMAX(MT)$ .

(3) Neutron energies should be entered in

ascending order.

(4)  $1 \leq \text{INT}(I) \leq 2$ . Recommended interpolation scheme is linear-linear in  $\mu$ .

(5) If all the probabilities for the  $k$ th photon lie in the range

$$0.499 \leq p_k(\mu, E_i) \leq 0.501,$$

a comment is written suggesting that the  $k$ th photon be entered as an isotopic EG-ES pair.

6. Store EG-ES pairs in File 14 for later reference in Files 12 and 13. Dummy EG-ES pairs are stored for the isotropic distributions.

#### E. File 15 (Continuous Energy Distribution)

1. Reaction number checks in File 15 are the same as in File 12. See Sec. B.1.

2. The NC parameter on the HEAD card must be equal to 1. Only NC = 1 is presently allowed.

3. The numbers  $51 \leq \text{MT} \leq 90$ , 700 series, 700, 720, 740, 760, and 780 are not allowed. (HEAD card check.)

4. The L1, L2, and N2 fields on the HEAD card should be blank.

5. Checks common to all TAB1 and TAB2 records:

a.  $1 \leq \text{NR} \leq 10$ . NR is set equal to 1 if  $\text{NR} \leq 0$ .

b.  $2 \leq \text{NP} \leq 1000$ . NP is set equal to 2 if  $\text{NP} \leq 1$ . (TAB1 record.)

$2 \leq \text{NE} \leq 1000$ . NE is set equal to 2 if  $\text{NE} \leq 1$ . (TAB2 record.)

c.  $\text{NP}$  (or  $\text{NE}$ )  $>$   $\text{NR}$ : NR is set equal to 1 if  $\text{NP} \leq \text{NR}$ ; then if  $\text{NP} \leq 1$ , NP is set equal to 2.

d.  $\text{INT}(M) \neq \text{INT}(M + 1)$ . No two consecutive regions should have the same interpolation scheme.

e.  $1 \leq \text{INT}(M) \leq 3$ .

6. For the first TAB1 record only:

a. The C1, C2, and L1 fields should be blank.

b. LF = 1. Only this law number is presently defined.

c. The neutron energies should be in ascending order.

d.  $E(1) * 1.001 \geq \text{ETH}(\text{MT})$ . The first (lowest) neutron energy in File 15 must be greater than or equal to the effective threshold in File 3.

e.  $E(\text{NP}) \leq \text{EMAX}(\text{MT})$ . The last (highest) neutron energy in File 15 must be less than or equal to the maximum neutron energy in File 3.

f.  $p_1[E(I)] = 1.000$ ,  $I = 1(1)\text{NP}$ . The probability given to the first partial distribution must be equal to 1.0, because only one distribution law is presently defined.

7. Store the (TAB2 record) interpolation schemes of the neutron energy mesh in File 15 for later reference in File 12.

8. For all TAB1 records, except the first, check that:

a. The TAB1 records are given in order of increasing magnitude of neutron energy,

b. The photon energies are in ascending order within a subsection,

c. The neutron energy is in the range covered by the neutron energies in the first TAB1 record,

d.  $E(1) * 1.001 \geq \text{ETH}(\text{MT})$ , and  $E(I) \leq \text{EMAX}(\text{MT})$ ,

e. The maximum photon energy does not exceed (1) the absolute value of Q for  $51 < \text{MT} < 90$  (these forbidden MT numbers are flagged),

(2) the value of ECM (incident neutron energy in center-of-mass system) for  $\text{MT} = 4$  and  $\text{MT} = 91$ , or

(3) the value of Q + ECM for all MT numbers not included in (1) or (2) above.

f. The probability distributions are normalized to one

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

9. For all TAB1 records, except the first, compute the average photon energy at each neutron energy. The average photon energy is printed on the output listing.

#### IV. Functional Description of Main Program and Subroutines

VIXEN. The main calling program, VIXEN, provides

initializing and executive functions. It reads the two input BCD control cards and then calls the ENDF input-output routines to search and read appropriate files. Processing begins with File 3 and proceeds through the photon-production files (12 through 15). VIXEN calls appropriate subroutines to check HEAD cards, the range of MT numbers, EG-ES pairs, etc. Various options (in File 14, for example, tabulated angular distributions or Legendre coefficients) are sensed, and loops are set up for reading the data. Checks made explicitly by the main program are as follows.

1. Verification that the code is given two input control cards.
2. Use of the SEARCH subroutine to determine whether a file is on the data tape for the MAT number given in the first control card read in.
3. A check that Files 12 or 13 and File 14 exist before processing is continued.
4. Determination that no angular distribution is given explicitly when LI = 1 (isotropic distribution). If it is, the flag is changed to LI = 0, and processing continues on this assumption.
5. Setting of the LF value to 2 for Files 12 and 13 if  $LF \neq 1$  and  $LF \neq 2$ .
6. Verification that the continuum photon energy distribution, if present, appears in the last subsection.
7. Setting of the card-sequence numbers generated by the code to those values given in the data tape.

**Input-Output Subroutines (SEARCH, RREC, WREC, and CXFP).** The input-output subroutines are derived from the standard ENDF retrieval subroutines, but have been extensively altered for this code. Most alterations were made because of the need to process Modes 1 and 3 only and because of the great amount of tape manipulation needed to print the files in order on the output listing. The changes in SEARCH require that the files and MT numbers be in ascending order. The subroutines PRCONT, PRTAB1, etc., are considered to be part of the WREC subroutine.

**CKHD.** This subroutine checks the HEAD-card parameters of Files 12 through 15 to determine if all are consistent and in an allowable range. Appropriate comments are printed, and reasonable values are assumed to attempt continued processing. The MT numbers of Files 12 through 15 are checked to determine if they are proper for the photon-production files.

**FIL3.** Checks on reasonableness of the Q values, threshold energies, and the maximum neutron energies are made for File 3. The Q values, effective thresholds, and maximum neutron energies are stored here for later reference in Files 12 through 15. The 2200-m/sec cross section

for  $MT = 102$  is calculated if the data tape is in BCD, less than 1001 neutron energy points are given, and the first neutron energy is less than or equal to 0.0253 eV.

**FIL12.** MT numbers are checked to see that they appear in both Files 3 and 14. This MT number check is also done in FIL13 and FIL15. The neutron energies for which EG-ES pairs are given are checked against the threshold and maximum neutron energies given in File 3. The EG-ES pair energies are checked against the corresponding Q value for the MT being processed. All EG-ES pairs and the neutron energy ranges over which they are given are stored in File 12 for later reference in File 13. By use of the TESTMT subroutine, the MT numbers are checked to be appropriate. All EG-ES pairs are checked against those in File 14, using the EGESPR subroutine. For  $LO = 2$ , the level energies in a cascade are checked against previous level-energy data, using the subroutine STATE. The total photon energy released is computed for multiplicities at every neutron energy entered in the total-photon-yield table, or in the first yield table if  $NK = 1$ . Every MT number for which a continuum is given is checked to see that it appears in File 15.

**FIL13.** The neutron energies for which EG-ES pairs are given are checked as in FIL12. The EG-ES pair energies are checked against the corresponding Q value for the MT being processed. All EG-ES pairs and the neutron energy ranges over which they are given are checked against the EG-ES pairs in File 12 to ensure that no EG-ES pair is given over the same neutron energy range in both files. The MT numbers are checked as in FIL12. All EG-ES pairs are checked against those in File 14 as in FIL12. Every MT for which a continuum is given is checked to see that it appears in File 15.

**FIL14.** The MT numbers in File 14 are checked against those in File 3 to see that every MT number in File 14 appears in File 3. Every MT number in File 14 is stored there for later reference in Files 12, 13, and 15. The neutron energies over which EG-ES pairs are given are checked against the threshold and maximum neutron energies in File 3. Every EG-ES pair given is stored in File 14 for later reference in Files 12 and 13. The EG-ES pair energies are checked against the corresponding Q value for the MT being processed. All anisotropic distributions for both  $LTT = 1$  and  $LTT = 2$  are checked to be truly anisotropic.

**FIL15.** The neutron energies are checked against the threshold and maximum neutron energies in File 3. The maximum neutron energy entered in every subsection is checked to be less than that value allowed by the Q value and/or the incident neutron energy associated with that section. The probability distributions are checked to be normalized to 1.0. A comment giving the average photon energy is given for each subsection.

**TESTMT.** This subroutine checks that MT numbers are correct for certain files, for example,  $MT = 51$  cannot appear in File 15. It also checks the NK and NS parameters of Files 12 through 14. If an NS value is too large, a correct value is computed, and NS is set equal to it.

**EGESPR.** Besides storing all the EG-ES pairs of Files 12 through 14, this subroutine checks to see which EG-ES pairs are:

entered redundantly (cross-reference of File 13 to File 12),

not entered at all (cross-reference of Files 12 and 13 to File 14), or

entered under a different MT (cross-reference of Files 12 and 13 to File 14).

A final check of EG-ES pairs gives those entered in File 14 but not entered in Files 12 or 13.

**STATE.** The level energies given in TP arrays (Doublets and Triplets) in File 12 are stored and checked to be equal to some previous level energies.

**ERROR.** Errors detected in the RREC subroutine are flagged by the ERROR subroutine. Errors related to the interpolating and integrating subroutines (TERP1 and INTG, respectively) are also flagged by ERROR. Those errors referred to ERROR are usually basic and could force the code to stop processing.

**TERP1.** This subroutine performs the interpolation needed in FIL3, FIL12, and FIL13. TERP1 can interpolate with any of the five interpolation schemes.

**INTG.** The check for normalization of the probability distributions and the computation of the average photon energies in File 15 require a subroutine capable of integrating with any of three interpolation schemes (1, 2, or 3).

## V. Hardware and Software Requirements

VIXEN is written in USA Standard FORTRAN IV, with only the IF(EOF)ij statement being nonstandard.<sup>5</sup>

Although the code was first written for the CDC 6600, it was written so as to be easily convertible to other machines, notably the IBM 360. A 41,472<sub>10</sub> (121,000<sub>8</sub>) core memory, a magnetic tape unit, two scratch files (disk or extended core storage), a card reader, and an output line printer are required to run the code. The central processor time for the silicon data is slightly less than 1 min. on a CDC 6600.

A test problem input and output is given in Appendix A. A discussion of some of the code logic and of the importance of the INDEX listing available in the code package is given in Appendix B.

## REFERENCES

1. Donald J. Dudziak (Ed.), "ENDF Formats and Procedures for Photon Production and Interaction Data," LA-4549 (ENDF-102, Rev., Vol. II), Los Alamos Scientific Laboratory (1971).
2. M. K. Drake (Ed.), "Data Formats and Procedures for the ENDF Neutron Cross Section Library," BNL-50274 (ENDF-102, Vol. I), Brookhaven National Laboratory (1971).
3. Donald J. Dudziak, "PHOXE: A FORTRAN-IV Code to check Format Syntax, Consistency, and Physical Realism of ENDF/B Photon Production Data," LA-4506-MS (ENDF-140), Los Alamos Scientific Laboratory (1970).
4. J. L. Lucius, R. Q. Wright, and S. K. Penny, "Extension of the Program CHECKER," ORNL-TM-3395, Oak Ridge National Laboratory (1971).
5. USA Standard FORTRAN, USAS X3.9-1966, Business Equipment Manufacturers Association (sponsor) (1966).

APPENDIX A

TEST PROBLEM INPUT AND OUTPUT

Although the code package sample problem uses the ENDF material, silicon, we have used INUTIL, a material created especially to help debug the code, here. INUTIL is an imaginary material with an arbitrarily assigned MAT number of 2001. The advantage of using INUTIL rather than any other material is that one can in good conscience create as many errors in the data as one desires. Many errors have been introduced in the INUTIL problem data so that the user can fully appreciate the many checks performed by the code and the comments associated with these checks. The typical VIXEN run time for an INUTIL evaluation is 1/2 min.

Only two BCD cards and an ENDF data tape are required for the VIXEN code input. The first card, read in 3I11 format, specifies the input/output unit number of the ENDF data tape, the Mode (1 or 3) of the tape, and

the ENDF material number of the material being processed. Use of 3, 5, 6, or 8 for the I/O unit number of the ENDF data tape is strictly prohibited, because these numbers are assigned to other units in the code. The code will process only that data written in Mode 1 (Standard Binary Arrangement) or 3 (BCD). The second card, read in 20A4 format, allows the user to place whatever heading he wants on the output listing.

Test Problem Input

Column	11	22	30	31	32	33	80
	2	3	2	0	0	1	

Test Problem Output

THIS RUN IS LOOKING FOR FILES 3,12,13,14, AND 15 OF INUTIL.

THIS DATA FILE IS A CREATION OF JOHN ROMERO AND IS CALLED INUTIL. 0 0 0 0

```
1.00000 + 4 2.27860 + 1 -0 -0 -0 -0 2001 3 3 1
                2001 3 0 6
1.00000 + 4 2.27860 + 1 -0 -0 -0 -0 2001 3 51 7
                2001 3 0 12
1.00000 + 4 2.27860 + 1 -0 -0 -0 -0 2001 3 52 13
                2001 3 0 18
1.00000 + 4 2.27860 + 1 -0 -0 -0 -0 2001 3 91 19
***** EFFECTIVE THRESHOLD VALUE BELOW THEORETICAL ALLOWED BY Q VALUE. *****
***** EFFECTIVE THRESHOLD= 0. THEORETICAL= 7.30721E+05 Q= 7.00000E+05 *****
***** EFFECTIVE THRESHOLD VALUE HAS BEEN SET EQUAL TO THE THEORETICAL VALUE. *****
1.00000 + 4 2.27860 + 1 -0 -0 -0 -0 2001 3 0 24
                2001 3102 25
SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS SIGMA(2200M/S) = 5.36000E-01 B
                2001 3 0 30
                2001 0 0 31
```

ERROR STOP 103
MAT=2001 MF=13 MT= 3
THIS MAY PROVE TO BE A FATAL ERROR.

```
1.00000 + 4 2.27860 + 1 2 1 1 -0 200112 51 32
4.39200 + 5 0.00000 + 0 -0 -0 2 1 200112 51 33
0.00000 + 0 1.00000 + 1 200112 51 34
***** TPI GREATER THAN 1.0 AT ESI = 0. 0. *****
***** TOTAL TP GREATER THAN 1.001. TOTAL= 1.00000E+01 *****
1.00000 + 4 2.27860 + 1 2 3 2 -0 200112 0 35
                200112 52 36
***** LG NOT IN DEFINED RANGE. VALUE FOR LG WILL BE DETERMINED FROM RATIO OF N1 TO N2. *****
2.08100 + 6 0.00000 + 0 -0 -0 4 2 200112 52 37
4.39200 + 5 9.10000 - 1 0.00000 + 0 9.00000 -2 200112 52 38
***** ES(NS) SHOULD BE EQUAL TO THE ABS(Q). Q = 2.08000E+06 *****
```

\$\$\$\$\$\$\$\$\$\$\$\$\$ THE FOLLOWING EG-ES PAIR IS ASSUMED TO BE ONE OF THE ISOTROPIC ONES IN FILE 14. \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ EG= 1.6418E+06 ES= 2.0810E+06 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ THE FOLLOWING EG-ES PAIR IS ASSUMED TO BE ONE OF THE ISOTROPIC ONES IN FILE 14. \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ EG= 2.0810E+06 ES= 2.0810E+06 \$\$\$\$\$\$\$\$\$\$\$\$\$

1.00000 + 4 2.27860 + 1 2 -0 5 200112 0 39  
 \*\*\*\*\* NS IS LARGER THAN LEVEL NUMBER WILL ALLOW. NS SET EQUAL TO LEVEL NUMBER. \*\*\*\*\*  
 \*\*\*\*\* THIS REACTION (MT) DID NOT APPEAR IN FILE 3. CHECKS AGAINST FILE 3 QUANTITIES \*\*\*\*\*  
 \*\*\*\*\* (Q VALUE, THRESHOLD ENERGY, AND MAXIMUM NEUTRON ENERGY) WILL NOT BE MADE. \*\*\*\*\*

2.39100 + 6 0.00000 + 0 -0 -0 4 2 200112 53 41  
 4.39200 + 5 3.30000 - 1 0.00000 + 0 6.70000 - 1 200112 53 42

\$\$\$\$\$\$\$\$\$\$\$\$\$ THE FOLLOWING EG-ES PAIR IS ASSUMED TO BE ONE OF THE ISOTROPIC ONES IN FILE 14. \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ EG= 1.9518E+06 ES= 2.3910E+06 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \*\*\*\*\* THE FOLLOWING EG-ES PAIR IS NOT FOUND IN FILE 14. EG= 2.3910E+06 ES= 2.3910E+06 \*\*\*\*\*

1.00000 + 4 2.27860 + 1 1 -0 1 -0 200112 0 43  
 1.00000 + 0 0.00000 + 0 -0 1 1 4 200112 91 44  
 4 2 200112 91 45  
 200112 91 46

9.05000 + 6 9.63170 - 1 1.20000 + 7 1.00500 + 0 1.60000 + 7 1.18000 + 0 200112 91 47  
 1.80000 + 7 1.40390 + 0 200112 91 48

\*\*\*\*\* IF REACTION IS ENDOERGIC, NEUTRON ENERGIES SHOULD SPAN RANGE FROM THRESHOLD TO 2.0E+7. \*\*\*\*\*  
 \*\*\*\*\* EG MUST EQUAL 0.0 FOR LAW LF=1. \*\*\*\*\*

\$\$\$\$\$\$\$\$\$\$\$\$\$ THE FOLLOWING EG-ES PAIR IS ASSUMED TO BE ONE OF THE ISOTROPIC ONES IN FILE 14. \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ EG= 1.0000E+00 ES= 0. \$\$\$\$\$\$\$\$\$\$\$\$\$

\*\*\*\*\* THE NEUTRON ENERGIES IN FILES 12 AND 15 DO NOT SPAN THE SAME ENERGY RANGE. \*\*\*\*\*

\$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 1.9517E+06 EV AT INCIDENT NEUTRON ENERGY = 9.0500E+06 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 2.3624E+06 EV AT INCIDENT NEUTRON ENERGY = 1.2000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 2.3911E+06 EV AT INCIDENT NEUTRON ENERGY = 1.6000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 2.8448E+06 EV AT INCIDENT NEUTRON ENERGY = 1.8000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$

1.00000 + 4 2.27860 + 1 1 -0 3 -0 200112 0 49  
 0.00000 + 0 0.00000 + 0 -0 -0 1 3 200112102 50  
 3 2 200112102 51  
 200112102 52  
 1.00000 - 4 3.00000 + 0 1.00000 + 0 2.00000 + 0 2.00000 + 7 3.00000 + 0 200112102 53

\*\*\*\*\* IF REACTION IS EXOERGIC, NEUTRON ENERGIES SHOULD SPAN THE RANGE 1.0E-5 TO 2.0E+7. \*\*\*\*\*

2.00000 + 2 0.00000 + 0 -0 2 1 3 200112102 54  
 3 2 200112102 55  
 1.00000 - 4 1.00000 + 0 1.00000 + 0 2.00000 + 7 1.00000 + 0 200112102 56

\*\*\*\*\* THE FOLLOWING EG-ES PAIR IS NOT FOUND IN FILE 14. EG= 2.0000E+02 ES= 0. \*\*\*\*\*

\*\*\*\*\* EG IS LESS THAN 10 KEV. POSSIBLE ERROR. \*\*\*\*\*

7.00000 + 6 0.00000 + 0 -0 2 2 3 200112102 57  
 2 2 200112102 58

8.00000 + 0 1.00000 - 1 1.00000 + 0 0.00000 + 0 2.00000 + 7 1.00000 + 0 200112102 59

\*\*\*\*\* NO TWO CONSECUTIVE REGIONS SHOULD HAVE THE SAME INTERPOLATION SCHEME. \*\*\*\*\*

\*\*\*\*\* NEUTRON ENERGIES ARE NOT IN ASCENDING ORDER. \*\*\*\*\*

\*\*\*\*\* EG MUST BE IN DESCENDING ORDER WITHIN AN MT. \*\*\*\*\*

0.00000 + 0 0.00000 + 0 -0 1 1 3 200112102 60  
 2 2 200112102 61  
 1.00000 - 4 1.90000 + 0 1.00000 + 0 1.00000 + 0 2.00000 + 7 1.00000 + 0 200112102 62

\*\*\*\*\* PHOTON ENERGY DISTRIBUTIONS FOR THIS MT NUMBER ARE NOT GIVEN IN FILE 15. \*\*\*\*\*

\*\*\*\*\* TOTAL PHOTON ENERGY RELEASED CANNOT INCLUDE ANY CONTRIBUITION FROM FILE 15. \*\*\*\*\*

\*\*\*\*\* TABULATED TOTAL YIELD NOT EQUAL TO TOTAL OF THE SUBSECTION YIELDS. \*\*\*\*\*

\*\*\*\*\* TABULATED TOTAL YIELD = 3.00000E+00 \*\*\*\*\*

\*\*\*\*\* CALCULATED TOTAL YIELD = 2.90000E+00 \*\*\*\*\*

\*\*\*\*\* AT NEUTRON ENERGY = 1.00000E-04 \*\*\*\*\*

\$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 2.0000E+02 EV AT INCIDENT NEUTRON ENERGY = 1.0000E-04 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 2.0000E+02 EV AT INCIDENT NEUTRON ENERGY = 1.0000E+00 \$\$\$\$\$\$\$\$\$\$\$\$\$  
 \$\$\$\$\$\$\$\$\$\$\$\$\$ TOTAL PHOTON ENERGY RELEASED = 7.0002E+06 EV AT INCIDENT NEUTRON ENERGY = 2.0000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$

1.00000 + 4 2.27860 + 1 -0 -0 1 -0 200112 0 63  
 2001 0 0 64  
 200113 3 65

ERROR STOP 103  
 MAT=2001 MF=13 MT= 3  
 THIS MAY PROVE TO BE A FATAL ERROR.

7.00000 + 6 7.00000 + 6 -0 2 -1 4 200113 3 66  
 4 2 200113 3 67

1.00000	- 5	1.00000	- 2	3.00000	+ 4	1.00000	- 3	5.00000	+ 6	1.00000	+ 0	200113	3	68
2.00000	+ 7	1.00000	- 20									200113	3	69
***** NR MUST BE GREATER THAN 0. NR SET EQUAL TO 1. *****														
\$\$\$\$\$\$\$\$\$\$\$\$ THE FOLLOWING EG-ES PAIR IS ASSUMED TO BE ONE OF THE ISOTROPIC ONES IN FILE 14. \$\$\$\$\$\$\$\$\$\$\$\$\$														
\$\$\$\$\$\$\$\$\$\$\$\$ EG= 7.0000E+06 ES= 7.0000E+06 \$\$\$\$\$\$\$\$\$\$\$\$\$														
												200113	0	70
												2001	0	71
1.00000	+ 4	2.27860	+ 1		1		- 0		1		- 0	200114	3	720
												200114	0	721
1.00000	+ 4	2.27860	+ 1		0		2		1		0	200114	51	73
4.39200	+ 5	4.39200	+ 5		- 0		- 0		1		2	200114	51	74
	2		2									200114	51	75
0.00000	+ 0	4.60000	+ 5		- 0		- 0		1		2	200114	51	76
	2		2									200114	51	77
1.00000	+ 0	4.99900	- 1	0.00000	+ 0	5.00000	- 1					200114	51	78
0.00000	+ 0	6.00000	+ 6		- 0		- 0		1		2	200114	51	79
	2		2									200114	51	80
1.00000	+ 0	5.00000	- 1	0.00000	+ 0	5.00000	- 1					200114	51	81
***** DISTRIBUTION SHOULD BE ENTERED AS ISOTROPIC EITHER *****														
***** AS LI=1 OR AS LI=0 WITH NI GREATER THAN 0. *****														
												200114	0	82
1.30000	+ 4	2.27860	+ 1		1		- 0		3		- 0	200114	52	83
***** ARE SO MANY DISCRETE PHOTONS NECESSARY. WILL CONTINUE PROCESSING WITH NK AS GIVEN. *****														
												200114	0	84
1.00000	+ 4	2.27860	+ 1		1		- 0		1		- 0	200114	53	85
***** THIS REACTION (MT) DID NOT APPEAR IN FILE 3. CHECKS AGAINST FILE 3 QUANTITIES *****														
***** (Q VALUE, THRESHOLD ENERGY, AND MAXIMUM NEUTRON ENERGY) WILL NOT BE MADE. *****														
												200114	0	86
1.00000	+ 4	2.27860	+ 1		1		- 0		1		- 0	200114	91	860
												200114	0	861
1.00000	+ 4	2.27860	+ 1		0		2		3		2	200114102		87
7.00000	+ 6	0.00000	+ 0		- 0		- 0		- 0		- 0	200114102		89
2.00000	+ 4	0.00000	+ 0		- 0		- 0		- 0		- 0	200114102		88
0.00000	+ 0	0.00000	+ 0		- 0		- 0		1		2	200114102		89
	2		2									200114102		90
0.00000	+ 0	4.00000	+ 6		- 0		- 0		1		3	200114102		91
	3		2									200114102		92
1.00000	+ 0	5.00000	- 1	0.00000	+ 0	4.99900	- 1	1.00000	+ 0	5.00000	- 1	200114102		93
0.00000	+ 0	5.00000	+ 6		- 0		- 0		1		3	200114102		94
	3		2									200114102		95
1.00000	+ 0	5.10000	- 1	0.00000	+ 0	4.80000	- 1	1.00000	+ 0	5.00000	- 1	200114102		96
												200114	0	96
												2001	0	97
1.00000	+ 4	2.27860	+ 1		- 0		- 0		1		- 0	200115	91	98
0.00000	+ 0	0.00000	+ 0		- 0		1		1		4	200115	91	99
	4		2									200115	91	100
9.05000	+ 6	1.00000	+ 0	1.20000	+ 7	1.00000	+ 0	1.60000	+ 7	1.00000	+ 0	200115	91	101
2.00000	+ 7	1.00000	+ 0									200115	91	102
0.00000	+ 0	0.00000	+ 0		- 0		- 0		1		4	200115	91	103
	4		2									200115	91	104
0.00000	+ 0	9.05000	+ 6		- 0		- 0		1		3	200115	91	105
	3		2									200115	91	106
1.00000	+ 4	1.20000	- 26	1.00000	+ 6	3.30000	- 7	4.00000	+ 6	2.28000	- 7	200115	91	107
\$\$\$\$\$\$\$\$\$\$\$\$ AVERAGE PHOTON ENERGY= 2.02635E+06 AT INCIDENT NEUTRON ENERGY= 9.05000E+06 \$\$\$\$\$\$\$\$\$\$\$\$\$														
0.00000	+ 0	1.20000	+ 7		- 0		- 0		1		4	200115	91	108
	4		2									200115	91	109
1.00000	+ 4	1.30000	- 26	1.00000	+ 6	2.76000	- 7	4.00000	+ 6	1.00000	- 7	200115	91	110
1.00000	+ 7	1.30000	- 26									200115	91	111
\$\$\$\$\$\$\$\$\$\$\$\$ AVERAGE PHOTON ENERGY= 2.35062E+06 AT INCIDENT NEUTRON ENERGY= 1.20000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$														
0.00000	+ 0	1.60000	+ 7		- 0		- 0		1		3	200115	91	112
	3		2									200115	91	113
1.00000	+ 4	1.40000	- 26	1.00000	+ 6	3.30000	- 7	4.00000	+ 6	2.28000	- 7	200115	91	114
\$\$\$\$\$\$\$\$\$\$\$\$ AVERAGE PHOTON ENERGY= 2.02635E+06 AT INCIDENT NEUTRON ENERGY= 1.60000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$														
0.00000	+ 0	2.00000	+ 7		- 0		- 0		1		4	200115	91	115
	4		2									200115	91	116
1.00000	+ 4	1.30000	- 26	1.00000	+ 6	2.76000	- 7	4.00000	+ 6	1.00000	- 7	200115	91	117
1.00000	+ 8	1.30000	- 26									200115	91	118
***** MAXIMUM PHOTON ENERGY EXCEEDS THAT ALLOWED BY ECM. ECM= 1.91592E+07 *****														
***** PROBABILITY DISTRIBUTION IS NOT NORMALIZED TO 1.0. INTEGRAL EQUAL TO 5.50062E+00 *****														
\$\$\$\$\$\$\$\$\$\$\$\$ AVERAGE PHOTON ENERGY= 2.03506E+07 AT INCIDENT NEUTRON ENERGY= 2.00000E+07 \$\$\$\$\$\$\$\$\$\$\$\$\$														
												200115	0	114
												2001	0	115



```

***** THE FOLLOWING EG-ES PAIR IN FILE 14, MT= 52 WAS NOT REFERENCED IN FILE 12 OR FILE 13. *****
*****                                     EG= 3.00000E+00                               ES= 3.00000E+00 *****

***** THE FOLLOWING EG-ES PAIR IN FILE 14, MT=102 WAS NOT REFERENCED IN FILE 12 OR FILE 13. *****
*****                                     EG= 2.00000E+04                               ES= 0. *****
+++++ ALL EG-ES PAIRS ACCOUNTED FOR. FINIS CORONAT OPUS. +++++

```

## APPENDIX B

### PROGRAMMING PROCEDURES

No code is ever complete, because changes in the data format or untested logic paths will undoubtedly force its revision. VIXEN, unfortunately, is no exception, so the user may find that he must change it. To modify a code and yet have it function properly, the user must understand, at least partially, its logic. This appendix points out and explains the code logic that we feel merits discussion.

Fortunately, only a few areas may cause the user trouble. These areas are outlined below, and the discussion is organized in the same manner so that the user may read only the pertinent sections.

- I. Tape handling in VIXEN.
  - A. Binary records, ENDFILE, and REWIND of Tape JD.
  - B. BCD 110-character records, ENDFILE, and REWIND of Tape JY.
- II. Writing error comments on dummy files.
- III. Storing and retrieving the EG-ES pairs.
- IV. Assignment of the output tape.

I. The vast amount of cross-referencing among files in VIXEN, along with the printing of the files in order of increasing file number, necessitates much tape handling in the code.

A. Tape JD is used to store the data from Files 12 and 13 for processing after Files 14 and 15. The File 12 and 13 data are written in binary (Mode 1) to economize on the time needed for writing and later reading. No end-of-file mark is written on tape JD to signal the end of information in Files 12 and 13. There are only two situations in which an end-of-file mark might be used, and they are taken care of in another fashion. The first is when neither File 12 nor 13 appears. Then, the code stops processing at the onset of file reading, and a comment is written on the output listing explaining why processing stopped. The second situation in which an end-of-file mark might be used on Tape JD is when File 12 is present but File 13 is not. The SEARCH and RREC subroutines

are such that the code continues to search for File 13 until it encounters an end-of-tape mark on Tape JY or until the system discovers that reading cannot continue. Although the code would probably continue processing after not finding File 13, the search for File 13 would consume peripheral processor time unnecessarily. This situation is avoided by using the flag parameter L13 to signal the absence of File 13 on the ENDF data tape. When File 13 is to be read from Tape JD, a test on the flag L13 indicates whether or not File 13 is present. If File 13 is absent, a comment signaling the absence is written on the output listing, and no reading or processing is attempted. When File 12 is absent but File 13 is not, there is no problem whatsoever. When Tape JD is read (by SEARCH and RREC) for File 12, a File 13 HEAD card is encountered. Because the MF numbers must appear in ascending order for the SEARCH subroutine, control is transferred back to the VIXEN program, where a comment signaling the absence of File 12 is printed on the output listing.

Tape JD is not rewound until Files 14 and 15 have been processed and processing of Files 12 and 13 is to begin. The code reads data (Files 12 and 13) until it encounters two FEND (end-of-ENDF-file) cards or until reading is stopped in some other fashion (L13 flag).

B. The processed output of Files 14 and 15 is written on Tape JY. The output is written in BCD with 110 characters per record, even though BCD requires more time than binary to write and read. BCD records, rather than binary records, were chosen because BCD records are easier to read when the number of words in a record is not known. The processed output has ENDF records of various lengths (HEAD, TAB1, etc.) which, by themselves, would not be difficult to read in binary, as is done from Tape JD. However, processed output has informative comments flagging errors or giving computed quantities interspersed in a random fashion. Moreover, the comments are 110 characters (BCD) long, whereas the data are only 80 characters long. Owing to the ease with which BCD records of up to 136 characters can be read, we decided to use BCD records for writing the processed output. We chose 110- rather than 136-character records, because BCD records shorter than 136 characters can be written on the CDC 6600 disk (on which Tape JY

actually exists). This allows the records to be closer together to conserve disk space. If Tape JY is an actual magnetic tape, no harm is done. Magnetic-tape BCD records are 136 characters long (maximum), but only 110 characters of each record are read.

An ENDFILE mark is placed on Tape JY immediately after processing of Files 14 and 15, and the tape is not rewound until after processing of Files 12 and 13. By using an ENDFILE mark on Tape JY, one can copy the tape onto the output listing later with a simple read statement and a test on the ENDFILE mark. Furthermore, if the ENDFILE mark is written immediately after processing of Files 14 and 15 and the tape is not rewound until after processing of Files 12 and 13, Tape JY can be used to write irrelevant information without fear that it will appear on the output. An example of this use of Tape JY is given in the next section.

II. Although the VIXEN code in its present form utilizes the advantages derived from the ENDFILE mark and REWIND of Tape JY only once, changes to the data format or to the code may make the opportunity of writing on the tape more attractive.

The subroutine CKHD contains a test on the NS value used for TP arrays in File 12. If the NS value is larger than the MT number will allow, as determined by the TESTMT subroutine, NS is set equal to the largest NS value allowed for the MT. However, if the NS value is less than the largest allowed for that MT, the NS values are not corrected. This leaves room for a gross error in the sense that no lower bound is established. What if  $NS < 0$ ? The code would not detect the error, and code errors might result. To correct this situation, the NS value is checked to be greater than or equal to zero. Probably the most convenient method for determining a correct NS value is to use the TESTMT subroutine, but a way must be found that allows one to use the upper-bound test in TESTMT. This has been accomplished by setting NS equal to 1000 when  $NS < 0$ , then changing the output tape assignment from 6 to 8 (output listing to Tape JY, respectively). Because 1000 is much higher than any NS value allowed, the TESTMT upper-bound test is failed, the comment associated with the test failure is written on Tape JY, a new NS value is computed, and NS is set equal to a new (proper) value. Immediately afterward, the output tape assignment is changed back from 8 to 6, ensuring that all other error comments written by the code will appear on the output listing.

III. The scheme used for storing and retrieving the neutron energies of Files 12 and 15 is the same as that used for storing the EG-ES pairs of Files 12 and 14. This scheme was first used in PHOXE to store and retrieve EG-ES pairs. Provisions have been made in the code to store up to 500 EG-ES pairs, and a method is needed to allow the retrieval of any of these pairs by MT number. One obvious solution is to store the EG-ES pairs in two two-dimensional arrays. One subscript would be the MT number, and the other number would indicate the relative position of that photon energy (EG) or corresponding level energy (ES). This method, however, requires excessive storage and, thus, is not very efficient. An alternative method (that used in VIXEN) is to store the EG-ES pairs in two one-dimensional arrays without concern for which pairs go with which MT number. Referencing EG-ES pairs in a particular MT is then a sticky problem, but a solution is apparent with the realization that the number of pairs for each MT is given in the data. If the number of EG-ES pairs for each MT is stored, one can get at the pairs in a particular MT number by summing the number of EG-ES pairs in all the preceding MT numbers and indexing the sum by one. This locates the first EG-ES pair of the MT number under study. The rest is trivial. Any tests to be made on the EG-ES pairs of that MT are done by indexing by one until the total number of pairs in that MT number is reached. This method is used throughout the code.

IV. Serious format syntax errors are usually detected by the RREC subroutine and flagged by the ERROR subroutine. While Files 12 and 13 are first read and written on Tape JD, errors detected by the RREC subroutine are flagged on the output listing. These same errors are flagged again while the data are read from Tape JD for processing. By changing the tape assignment of Tape JY, one can easily prevent multiple flagging of the same error. However, without multiple flagging, the user may have difficulty in finding the error. The first flagging of the error gives the MF and MT number where the error occurred, plus the comment, "This may prove to be a fatal error." If, indeed, the error proves fatal, the user at least has the location of the error narrowed down to a section (MT). However, if the error is not fatal (the writing of Tape JD could be completed), its location can be found exactly from the processed output listing.