LA-4963
(ENDF-182)

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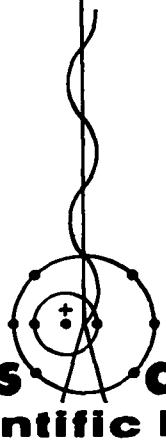
LAPHAN: A Code to Compute the P_0 to P_4 Multigroup Photon-Production Matrices



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UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

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-4963
(ENDF-182)
UC-32 & 80
ISSUED: January 1973

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Gerald E. Bosler

This work supported by Reactor Physics Branch, Division of Reactor Development and Technology, United States Atomic Energy Commission.

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ABSTRACT

The LAPHAN code is a revision and extension of previous codes in the LAPH series -- LAPH and LAPHANO. Photon-production cross-section and angular distribution data are retrieved from the ENDF Files 12 through 15, processed into specified photon and neutron energy groups, and combined as necessary to produce up to P_4 photon-production matrices and photon-energy-production matrices. Production cross sections are averaged over neutron fine groups and then collapsed into a given broad-group structure using specified weighting functions. Input is in DTF-IV format, and output matrices are in either DTF-IV or FIDO format. The code is written in ANS standard FORTRAN for computers with a $65K_{10}$ memory.

I. INTRODUCTION AND SUMMARY

With the emergence of photon-production data in the Evaluated Nuclear Data File (ENDF),[1,2] a set of codes known as the LAPH series[3,4] has been developed to process these data into multigroup form for transport calculations.[5] Originally, the LAPH code was provided to produce zero-order Legendre moments of photon-production matrices. However, when ENDF photon-production formats[6] were modified, revisions in LAPH became necessary. Specifications[7] were formulated for a new code which would accommodate the revised formats and also process the photon-production angular distribution data with provisions for matrices up to P_4. Interim P_0 capability from the new ENDF formats was provided by the LAPHANO code. The LAPHAN code now provides the higher-order Legendre photon-production matrices. During the genesis of these LAPH codes improvements in the calculational algorithms have been continually incorporated. These improvements have decreased running times and provided greater accuracy, as well as allowing new options.

In summary, the LAPHAN code retrieves photon-production cross sections or multiplicities, photon angular distributions, and corresponding neutron interaction cross sections from the ENDF data file, applies suitable weighting functions over G specified photon groups and N specified neutron groups, and constructs G × N photon-production matrices. The number of matrices is L + 1, where L is the order of the Legendre expansion requested. LAPHAN has been used to process all photon-production data currently extant in the latest version (III) of the ENDF which include either angular distributions or Legendre coefficient representations (four materials as of June 1972). The P_0 moments, as required, were identical to previously verified LAPHANO results. The higher-order moments compared favorably with hand calculations, providing confidence in the code theory and algorithms.

Throughout this report frequent reference is made to the ENDF. Some pertinent ENDF format information will be reviewed as required. Detailed descriptions of the ENDF and the data formats are given in Refs. 1 and 2.

II. THEORY

A. Photon-Production Data Format in ENDF

To understand the process of computing photon-production matrices from the current ENDF (the process is loosely called "theory") it is helpful to review briefly the form in which data are received into LAPHAN, i.e., the form in which they are stored in the ENDF. Photon-production data are divided into five distinct files.[2]

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

With the exception of File 12, all of the files are closely analogous to the corresponding neutron data files with the same number (modulo 10). The purpose of File 12 is to provide additional methods for representing the energy dependence of photon-production cross sections. The parallel structure between neutron and photon data files facilitates the use of existing neutron data retrieval routines for the photon data. The units for data stored in the ENDF file are:

Quantity	Units
energy	eV
angle	dimensionless cosine
cross section	barns
photon yields	photons

The LAPHAN code processes all of the photon files with the exception of File 16 which is not currently used in the ENDF. If all the photon-production data are stored in Files 13-15, reference to the neutron data files is unnecessary. However, when the photon-production data are represented by either multiplicities or transition probability arrays in File 12 the LAPHAN code uses File 3, neutron interaction cross sections, to construct the photon-production matrices. Higher-order Legendre moments may be constructed if anisotropic distribution data are present in File 14.

Transition probability (TP) arrays are processed to produce the higher-order Legendre moments even though current ENDF conventions call for a phase-out of TP arrays. The TP arrays have limitations such as the inability to predict accurately the photon production by neutrons at energies appreciably above that of the highest level for which the decay scheme is well known. The reason for this is that, at higher energies, levels above the one for which the decay scheme is well known may be excited and cascade through lower levels. Because current data in the ENDF still rely heavily on the TP arrays, the LAPHAN code processes them by constructing the cascades. It will not use the TP arrays to calculate photon production at neutron (center-of-mass) energies above the highest level in the arrays; i.e., if ES_{max} is the highest level energy for which a transition probability array is given, no photon production will be calculated from the arrays for incident-neutron energies above $ES_{max} \times \frac{AWR + 1}{AWR}$, where AWR is the atomic weight ratio.

B. Photon Yields and Photon-Production Cross Sections

As they are stored in the ENDF data file, photon-production data can be considered to represent a pointwise differential photon-production cross section

$$\sigma_\gamma(E_\gamma \leftarrow E) = \sigma(E)\, y(E_\gamma \leftarrow E) , \qquad (1)$$

where $\sigma(E)$ is the neutron interaction cross section and $y(E_\gamma \leftarrow E)$ is the differential yield of photons at energy E_γ from a neutron interaction at energy E. Regardless of the option used to store the data in ENDF, such a cross section is implicitly reconstructed by LAPHAN. Before proceeding to compute the photon-production matrix, it is convenient to define the subscripts and superscripts to be used.

- g = photon energy group, g = 1(1)G
- h = neutron fine group, h = 1(1)H
- k = parital yield (subsection) index within a reaction type p, k = 1(1)NK
- ℓ = Legendre expansion index, ℓ = 0(1)L
- n = neutron broad group, n = 1(1)N
- p = reaction type (section or MT) number
- r = resolved-resonance component
- s = smooth plus unresolved-resonance components.

The lower energy limit of a group is denoted by E_g, E_h, or E_n, where $E_{g+1} > E_g$, $E_{h+1} > E_h$, and $E_{n+1} > E_n$. Photon-number-production cross sections will be denoted by σ, τ, and ρ, while energy-production cross sections will use the same symbols with the diacritical mark ~ (tilde).

Two weighting options, called tracks, are available to compute the photon-energy-production

cross section in group g. On either track, the group photon-(number) production cross section is calculated without weighting, i.e.,

$$\sigma_g^k(E) = \int_{E_g}^{E_{g+1}} dE_\gamma \, \sigma_\gamma^k(E_\gamma \leftarrow E) \qquad (2\text{-a})$$

or

$$\sigma_g^k(E) = \sigma^p(E) \int_{E_g}^{E_{g+1}} dE_\gamma \, y^k(E_\gamma \leftarrow E), = \sigma^p(E) \, y_g^k(E) \, , \qquad (2\text{-b})$$

where the photon energy dependence of $\sigma_\gamma^k(E_\gamma \leftarrow E)$ may be a Dirac delta function. Here, $\sigma^p(E)$ is the neutron interaction cross section for reaction type p in File 3, and $y^k(E_\gamma \leftarrow E)$ and $y_g^k(E)$ are, respectively, the photon yield function and integrated yield function for subsection k of reaction type p.

Track 1:

On Track 1, the group photon-energy-production cross section, $\tilde{\sigma}_g^k(E)$, is computed using an arbitrary group-effective photon energy, $\bar{E}_g$, which is an input quantity.* In effect, on Track 1, the photon-energy-production cross section is

$$\tilde{\sigma}_g^k(E) = \sigma_g^k(E) \, \bar{E}_g \, . \qquad (3)$$

If a value of $\bar{E}_g$ is not in the interval $[E_g, E_{g+1}]$, the code will assume the median group energy,

$$\tilde{E}_g = \tfrac{1}{2}(E_g + E_{g+1}) \, ,$$

and proceed with this calculated value vice the input value.

Track 2:

On Track 2, the group photon-energy-production cross section is computed as follows:

$$\tilde{\sigma}_g^k(E) = \int_{E_g}^{E_{g+1}} dE_\gamma \, \sigma_\gamma^k(E_\gamma \leftarrow E) \, E_\gamma \, . \qquad (4)$$

*However, for (sectionally) continuous photon spectra, the code still calculates the energy-weighted yield on Track 2 (see below) and provides the user with a listing of the cross-section-weighted average photon energy, $\hat{E}_g^k(E)$, in each photon group and at several representative neutron energies.

For a "continuous" spectrum in File 15, the calculation in Eq. (4) is also performed on Track 1, and the average energy in each group is then determined from

$$\hat{E}_g^k(E) = \frac{\int_{E_g}^{E_{g+1}} dE_\gamma \, \sigma_\gamma^k(E_\gamma \leftarrow E) \, E_\gamma}{\int_{E_g}^{E_{g+1}} dE_\gamma \, \sigma_\gamma^k(E_\gamma \leftarrow E)} \, . \qquad (5)$$

The photon energy group structure is arbitrary, and is specified by an input energy mesh, starting at the highest energy. Likewise, the neutron energy group structures are arbitrary, except that the fine-group energy mesh points must have the broad-group mesh points as a subset. In practice, the neutron group structures are usually the corresponding structures in a spectrum-averaging code such as MC^2. In fact, a version of the MC^2 code[8] has been modified to output pertinent portions of the LAPHAN input. The photon energy mesh for the integrations on either Track 1 or 2 is the overlay of the photon group energy mesh and the E_γ mesh for the $y_k(E_\gamma \leftarrow E)$ in File 15. The simple trapezoidal rule is used for the integration. The $\sigma_g^k(E)$ and $\tilde{\sigma}_g^k(E)$ are evaluated at every tabulated neutron energy in Files 3, 12, 13, and 15 for the reaction being considered.

There is one approximation inherent in using data for a continuous photon spectrum. For any incident-neutron energy E, between two neutron energies E_1 and E_2 at which photon energy distributions are tabulated, there may be a component of the photon distribution up to energy $E_2 + Q$. Here Q has its usual meaning -- the reaction energy. Thus, photons can be constructed at energies greater than E + Q (the theoretical maximum) from this interpolated energy distribution. This problem occurs for any interpolation scheme between incident-neutron energies, and minimizing the induced error depends upon the evaluator having entered the data in the ENDF file with a fine enough incident-neutron energy mesh. (The same problem occurs for secondary neutron distributions in ENDF File 5.)

Having averaged the cross sections over each photon group, the averaging over each neutron fine group proceeds along one of two tracks.

For all MT numbers except 18 and 102 (fission and radiative capture, respectively), Track A is used; for fission and capture, either Track A or B may be used as specified by an input option. Briefly, the cross-section averaging over a neutron fine group may be performed in the resonance region by a spectrum-averaging code (Track B), or the resonance parameters may be ignored (or be nonexistent) and all cross-section averaging will be done internally by LAPHAN (Track A). Track B cannot be used when photon-production cross sections for fission or radiative capture are given in File 13.

Track A:

In calculating the ℓ^{th} Legendre component of the photon-production cross section on Track A, a choice of weighting functions over a neutron fine group can be used. Define

$$\tau_{g,h}^{p,\ell} = \frac{\sum_{k=1}^{NK} \int_{E_h}^{E_{h+1}} dE\ \sigma_g^k(E)\ a_\ell^k(E)\ S_h(E)}{\int_{E_h}^{E_{h+1}} S_h(E)\ dE}, \qquad \ell = 0(1)L \tag{6}$$

where $S_h(E)$ is the optional weighting function, $\sigma_g^k(E)$ is given by Eq. (2), and $a_\ell^k(E)$ is the ℓ^{th} Legendre moment of the photon angular distribution,

$$a_\ell^k(E) = \int_{-1}^{1} d\mu\ P_\ell(\mu)\ p_k(E,\mu), \qquad \ell = 0(1)L, \tag{7}$$

where $p_k(E,\mu)$ is the tabulated photon angular distribution (normalized).

If no angular distribution is given in File 14 for the corresponding reaction type p, an isotropic distribution is assumed by LAPHAN and an error comment is printed; i.e., it is assumed that

$$a_o^k(E) \equiv 1.0, \quad \text{all } k \in p,$$

$$a_\ell^k(E) \equiv 0.0, \quad \ell \geq 1, \text{ all } k \in p.$$

For the option where the $p_k(E,\mu)$ are tabulated in File 14, the $a_\ell^k(E)$ are calculated by LAPHAN.

$S_h(E)$ is specified for each group at the user's option and has one of the following six forms:

(a) $S_h(E) = 1.0$, constant weighting

(b) $S_h(E) = 1/E$, inverse energy weighting

(c) $S_h(E) = \sqrt{E}e^{-0.776E}$ (E in MeV), fission spectrum weighting

(d) $S_h(E) = e^{-0.776E}$ (E in MeV), asymptotic fission spectrum weighting

(e) $S_h(E) = E$, energy weighting

(f) $S_h(E) = Ee^{-E/kT^*}$ (E in eV), Maxwellian weighting.

Legendre components of the photon-energy-production cross section are

$$\tilde{\tau}_{g,h}^{p,\ell} = \frac{\sum_{k=1}^{NK} \int_{E_h}^{E_{h+1}} dE\ \tilde{\sigma}_g^k(E)\ a_\ell^k(E)\ S_h(E)}{\int_{E_h}^{E_{h+1}} S_h(E)\ dE}, \qquad \ell = 0(1)L. \tag{8}$$

Track B:

This track is used only for fission and capture reactions, and then only if chosen by the input option. It uses input values of the neutron interaction cross sections which have been independently averaged over the neutron fine groups. Define

$$\rho_{g,h}^{p,\ell,r} = (\Delta E_h)^{-1}\ \bar{\sigma}_h^{p,r} \sum_{k=1}^{NK} \int_{E_h}^{E_{h+1}} dE\ y_g^k(E)\ a_\ell^k(E), \tag{9}$$

and

$$\rho_{g,h}^{p,\ell,s} = (\Delta E_h)^{-1}\ \bar{\sigma}_h^{p,s} \sum_{k=1}^{NK} \int_{E_h}^{E_{h+1}} dE\ y_g^k(E)\ a_\ell^k(E), \tag{10}$$

where p = 18 or 102 and

$$(\Delta E_h) = E_{h+1} - E_h. \tag{11}$$

Here $\bar{\sigma}_h^{p,}$— is the neutron interaction cross section (resonance, or smooth plus unresolved resonance) averaged over fine group h by a spectrum-averaging code, while $\tilde{\rho}_{g,h}^{p,\ell,}$— is the ℓ^{th} Legendre component of the corresponding photon-production cross section. Similarly, the Legendre components of the photon-energy-production cross section are

*For the Maxwellian distribution, a temperature of 300°K was assumed.

$$\tilde{\rho}_{g,h}^{p,\ell,r} = (\Delta E_h)^{-1} \overline{\sigma}_h^{p,r} \sum_{k=1}^{NK} \int_{E_h}^{E_{h+1}} dE\ \tilde{y}_g^k(E)\ a_\ell^k(E)\ , \tag{12}$$

and

$$\tilde{\rho}_{g,h}^{p,\ell,s} = (\Delta E_h)^{-1} \overline{\sigma}_h^{p,s} \sum_{k=1}^{NK} \int_{E_h}^{E_{h+1}} dE\ \tilde{y}_g^k(E)\ a_\ell^k(E)\ , \tag{13}$$

where the $\tilde{y}_g^k(E)$ have a definition entirely analogous to the $\tilde{\sigma}_g^k(E)$ in Eqs. (3) and (4). This track normally would not be used, for example, if resonance data were not given in ENDF File 2 for the materials considered. If it is used, it must be used over the entire neutron energy range, i.e., both tracks cannot be used for a given reaction. Also, the same track must be used for both fission and capture.

Having computed the photon-production cross-section elements for the neutron fine-group structure, it remains to find a weighted average over the broad groups. These broad groups would normally correspond to the groups used in a neutron transport calculation from which the fluxes are obtained for use in determining the photon source. Weighting of the fine-group photon-production cross sections is done with arbitrary sets of input weights, one set for the smooth (plus unresolved resonance) cross sections and one for the resonance cross sections. The latter set, of course, is used only if Track B is chosen. In practice, the smooth cross-section weights are usually the fine-group flux moments from an infinite medium (zero-dimensional), one-dimensional, or other appropriate spectrum. Also, the resonance weights are usually those from the same spectrum-averaging code. At LASL, both sets of weights for $\ell = 0$ are output by the modified MC^2 code referred to above. Denoting the smooth weights by $w_h^{\ell,s}$ and the resonance weights by w_h^r, the elements of the ℓ^{th} Legendre component of the G × N microscopic photon-production matrix for reaction type p are

$$\sigma_{g,n}^{p,\ell} = \left[\sum_{h\epsilon n} \tau_{g,h}^{p,\ell}\ w_h^{\ell,s}\right] \left[\sum_{h\epsilon n} w_h^{\ell,s}\right]^{-1} + \left[\sum_{h\epsilon n} \rho_{g,h}^{p,\ell,r}\ w_h^r\right] \left[\sum_{h\epsilon n} w_h^r\right]^{-1} + \left[\sum_{h\epsilon n} \rho_{g,h}^{p,\ell,s}\ w_h^{\ell,s}\right] \left[\sum_{h\epsilon n} w_h^{\ell,s}\right]^{-1}\ , \tag{14}$$

and analogous elements $\tilde{\sigma}_{g,n}^{p,\ell}$ for the energy-production matrix. For any specific p, either the τ's or the ρ's will be nonexistent.

Given the set of reaction types, {MT}, for which photon-production cross sections are desired, the ℓ^{th} Legendre component of the total microscopic photon-production cross-section matrix is given by

$$\left[\sigma_{g,n}\right]^\ell = \left[\sum_{p\epsilon\{MT\}} \sigma_{g,n}^{p,\ell}\right]\ . \tag{15}$$

The energy-production matrix $[\tilde{\sigma}_{g,n}]^\ell$ has an analogous definition.

III. MODIFICATIONS TO THE LAPH CODE

A. Major Modifications to Fundamental Code Operation

Major modifications in transforming from LAPH to LAPHAN include:

(a) removal of the geometry and mixing routines,
(b) dynamic storage allocation, and
(c) optional flux weighting within the fine neutron groups.

The geometry and mixing routines were deleted in favor of similar routines in the transport codes. It is more efficient to process single isotopes with LAPHAN and then use the geometry and mixing routines of the transport codes to process complete cross-section sets. Dynamic storage allocation reduces the required central processor storage. The optional weighting in the fine neutron group integration provides flexibility in selecting weighting spectra for the various energy regions.

B. Modifications to LAPH Algorithms

Other modifications, excluding the changes due strictly to revisions of the data formats and procedures, are described below:

(a) The PR15 subroutine was extensively revised to process the new ENDF Files 12 through 15 and to renormalize to unity all interpolated continuous photon energy distributions from File 15. Also, integration routines were modified to allow any interpolation scheme between tabulated points that is allowed by ENDF procedures.

(b) A new input data format allows from P_0 to P_4 weighting functions for the neutron fine groups.

(c) The mesh for all numerical integrations over neutron energy has been changed to the neutron mesh in File 3 for the total cross section (MT = 1). This has considerably simplified the MESH subroutine. Requirements in the new Format and Procedures Manual[9] that the energy mesh of any partial cross section must be a subset of the total cross-section energy mesh has made this simplification possible. Also, the procedures for photon-production files require that the data for photon yields, production cross sections, and angular and energy distributions have no more structure in neutron energy than the cross sections in File 3. Both the size and contents of the array containing the neutron energy mesh are printed on the output listing.

(d) Under the option to compute photon production for all reaction types which have photon-production data given (the flag MT = -1), a new algorithm has been added to the PHOTON subroutine. The set of MT numbers is obtained by the PHOTON subroutine from the index in File 1, thereby saving significant central processor and peripheral processor time. The set is then written on the output listing.

(e) Additional secondary overlays have been constructed by dividing the subroutines called by the LAPH subroutine into two separate overlays, thereby saving central memory locations. Labelled COMMON was of necessity shuffled to accommodate the new overlay structure. Also, buffer lengths have been reduced to gain needed storage.

(f) The sign of the input parameter NGG is sensed in subroutine PR15. If NGG > 0, the card count information in File 1 is used to skip rapidly to Files 12 through 14. This avoids using excessive peripheral processor time while searching for the photon-production data files. If the index in File 1 is incorrect, as would be the case if one had an abridged tape with Files 2 through 7 removed, then NGG < 0, and the tape is searched until the photon-production data are located.

IV. INPUT INSTRUCTIONS

A. Background

Because of the elimination of the geometry and mixing routines, the input to LAPHAN is much simpler than the input to LAPHANO or LAPH. Input is generally in the DTF-IV format system,[10] with the exception of the title and parameter cards at the beginning of the data. The DTF-IV system consists of a basic 12-column field, but the first three columns are reserved for a control flag, and the remaining nine columns are a data field. There are seven possible controls in the first column of the three-column subfield as follows:

0 or blank = normal input; the nine columns for data are read in normal FORTRAN E, F, or I format.

1 = repeat; the number in the data field is repeated the number of times specified by the integer NN in the second and third columns of the control field.

2 = interpolate; the number of interpolates, NN, specified in the second and third columns of the control field are placed between the number in the data field and the number in the succeeding data field.

3 = terminate; ends the data block -- each data block must have this flag at the end.

4 = fill remainder of data block with the number in the data field.

5 = repeat the number in the data field 10*NN times, where NN is the number in the second and third columns of the control field.

9 = skip to next card.

Whether the data in the data field are integer or real is indicated by the first letter of the block name in the usual FORTRAN tradition.

A problem regarding terminology arises for LAPHAN when using DTF-IV input along with ENDF input because the term material has a different meaning in each case. No completely satisfactory resolution was found, and the term material in DTF-IV has been replaced by the term nuclide. Also

departing from DTF usage, "nuclide" does not include a mixture of nuclides. In LAPHAN, the term material is used strictly in the sense of a MAT in the ENDF system.

The code has many error triggers that will lead to a call to the subroutine ERROR. The type of error encountered will be identified on the output listing by an error number. A brief description of this error can then be found in the comment card in ERROR for the corresponding error number (see listing of the code). Errors in array sizes or input format are detected by the LOAD subroutine, which prints informative comments at the place the offending array is printed. Some warning comments are printed by other subroutines also.

B. Input Data Format

Data blocks are given in Table I in order of input, preceded by the corresponding variable name in LAPHAN. For the parameter table, the location (order) of the parameter is given first.

C. Change From LAPH Input

Since LAPHAN processes individual isotopes, all of the LAPH input parameters pertaining to mixing of isotopes and geometric zones have been deleted. In addition to these deletions, three other changes have been made to the LAPH input. These are:

1. The first paramter, NGG, has been used as the flag for a new option to read an abridged ENDF data set, i.e., one with Files 2 through 7 removed. The use of an abridged tape is specified by placing a minus sign before the value of NGG.

2. Field 5 of the integer parameter card is now a parameter IQA, the order of Legendre expansion. IQA is zero for isotropic emission.

3. Addition of the IWT parameters, the within-fine-group weighting function parameters, which must be specified for each fine neutron group. The options for IWT(h) are shown in Sec. II.B. The recommended upper energy limit for the fission spectrum weighting (Option 3) is 4 MeV. Above this limit the asymptotic fission spectrum (Option 4) should be used. Comment statements are printed by LAPHAN if the usage of a particular option appears to be out-of-range. For instance, it will question the use of the Maxwellian distribution at energies above 100 eV. The code, however, will continue despite apparent errors in the weighting option usage.

D. Computer Requirements and Running Times

The code requires no special hardware or software but does use one input file, viz., Tape 20, which contains the ENDF data in Mode 3 (BCD card-image format in standard arrangement). Several scratch files on disk, large core memory, or other peripheral storage device are also used.

The CDC 6600 central processor time required for a sodium P_4 problem with 12 photon groups, 75 neutron fine groups, and 30 neutron broad groups was approximately four minutes. A simple problem to produce chlorine P_4 matrices for 8 photon groups, 10 neutron fine groups, and 5 neutron broad groups required three minutes of CDC 6600 central processor time. ENDF MT numbers which have photon-production data in File 13 will be processed quickly by LAPHAN. However, MT numbers for which LAPHAN must construct the cross sections, i.e., File 12 data, require appreciably more processing time.

E. Sample Problem

A P_4 sample problem using chlorine (ENDF MAT Number 1149) is shown in App. A. A simple group structure (8 photon groups, 10 neutron groups, and 5 neutron broad groups) was selected for illustrative purposes. Various flux weighting options (IWT) were used and direct weighting of the gamma-ray energy (IWO=1) was chosen for the energy-production matrices.

F. Code Description

Comments concerning code operation and subroutines are given in App. B.

IV. ACKNOWLEDGMENTS

The authors are indebted to Robert E. Seamon, Dante V. Susco, and Alan H. Marshall for their contributions to the programming of predecessor codes in the LAPH series. Also, we gratefully acknowledge Johnny M. Romero for variably dimensioning the LAPHAN code.

TABLE I

INPUT DATA FORMAT

A. Title Card (I6,11A6): Any integer for problem identification, and any BCD information for identification of output.

B. Integer Parameters (12I6):

Location	Name	
1	±NGG	Number of gamma groups is |NGG|. A minus sign before the NGG parameter is a flag indicating that an abridged ENDF tape is being used.
2	NFG	Number of neutron fine groups.
3	NBG	Number of neutron broad groups.
4	NKP	Ultrafine - group integration parameter. Each fine group is divided into NKP equal subgroups.
5	IQA	Order of the Legendre expansion of the photon-production matrices. ($0 \leq IQA \leq 4$)
6	MAT	ENDF material number.
7	MM	Number of reaction types, MT (= length of MTN table).
8	IRES	Special resonance weighting option to be used? 0/1 = no/yes. (0 = Track A, 1 = Track B.)
9	IWO	= 0, photon effective average energy for each group is input (Track 1). = 1, direct photon energy weighting (Track 2).
10	IOO	= 0, print $[\sigma_{g,n}]$. = 1, print Option 0 and punch the matrices in DTF and FIDO format. = 10, same as IOO = 0, substituting the energy production matrices $[\tilde{\sigma}_{g,n}]$, etc. = 20, do both Options 0 and 10 (i.e., print both photon-production and photon energy production matrices). = 21, do both Options 1 and 20.

C. Data Blocks (DTF-IV System): Dimension of variable is given in parentheses.

Name and Dimension	
C(1)	Renormalization constant.
MTN(MM)	MT numbers. MT = -1 means use all MT numbers for which photon-production data exist in Files 12 and 13.

If, and only if, IWO = 0, the following data block appears:

EG(NGG)	Effective average energy, $\overline{E}_g$, for each photon group. (Same for all materials and reaction types.)
EMG(NGG+1)	Photon group energy mesh, in decreasing magnitude of energy.
EMNF(NFG+1)	Neutron fine-group energy mesh, in decreasing magnitude of energy.
EMNB(NBG+1)	Neutron broad-group energy mesh, in decreasing magnitude of energy.
IWT(NFG)	Weighting function type within fine groups. IWT(h) = 1 constant weighting = 2 inverse energy weighting = 3 fission spectrum weighting = 4 asymptotic fission spectrum weighting = 5 energy weighting = 6 Maxwellian weighting

One set of the following six data blocks. Each block is preceded by a title card in 12A6 format.

RXSC(NFG)[a,b]	Fine-group resonance capture cross sections, $\overline{\sigma}_\ell^{102,r}$, starting at top group.
RXSF(NFG)[a,b]	Fine-group resonance fission cross sections, $\overline{\sigma}_\ell^{18,r}$, starting at top group.
SXSC(NFG)[b]	Fine-group smooth (including unresolved resonance) capture cross sections, $\overline{\sigma}_\ell^{102,s}$, starting at top group.
SXSF(NFG)[b]	Fine-group smooth (including unresolved resonance) fission cross sections, $\overline{\sigma}_\ell^{18,s}$, starting at top group.
RW(NFG)[a,b]	Fine-group resonance weighting functions starting at top group.
SW(LXNFG)[c]	Fine-group smooth (flux) weighting functions for each Legendre order starting at top group.

[a] If IRES = 1, these should be entered even for nonresonance materials. In such case, any numbers may be used to fill the fields.

[b] Delete this data block if IRES = 0.

[c] LXNFG = NFG*(IQA+1)

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APPENDIX A

SAMPLE PROBLEM INPUT AND OUTPUT

```
072172 LAPHAN P-4 SAMPLE PROBLEM. CHLORINE(MAT=1149),MT=-1                TITLE
     8    10     5     1     4  1149     1     0     1    21          CL PARAM
   1.0     3                                                             C
          -13                                                           MTN
   3.0  E+7   1.0  E+7   9.0  E+6   6.0  E+6   5.0  E+6   4.0  E+6     EMG
   3.0  E+6   1.0  E+6   5.0  E+43                                      EMG
   1.7  E+7   1.0  E+7   8.0  E+6   7.0  E+6   6.0  E+6   5.0  E+6     EMNF
   4.0  E+6   3.0  E+6   2.0  E+6   1.0  E+6   1.0  E+53                EMNF
   1.7  E+7   8.0  E+6   6.0  E+6   4.0  E+6   2.0  E+6   1.0  E+5     EMNB
3                                                                       EMNB
106        4103        3           23                                   IWT
SMOOTH WTS FOR P-4 PROBL WITH 10 FINE GROUPS AND 5 BROAD GROUPS.
150      1.03                                                          P-4 SW
```

```
ENDF TAPE I.D. =  302       ENDF/B-III TAPE 302  (1-26-72)


LAPHS PROBLEM ID =  72172 LAPHAN P-4 SAMPLE PROBLEM. CHLORINE(MAT=1149),MT=-1

INTEGER PARAMETERS        NGG      NFG      NBG      NKP      IOA      MAT      MM      IRES      IWO      IOO
                            8       10        5        1        4     1149       1       0         1       21

RENORM CONST      1
  1.0000E+00

MT NUMBERS        1
         -1

GAMMA BOUNDS      9
  3.0000E+07  1.0000E+07  9.0000E+06  6.0000E+06  5.0000E+06  4.0000E+06  3.0000E+06  1.0000E+06  5.0000E+04

NEUTRON FINE     11
  1.7000E+07  1.0000E+07  8.0000E+06  7.0000E+06  6.0000E+06  5.0000E+06  4.0000E+06  3.0000E+06  2.0000E+06  1.0000E+06
  1.0000E+05

NEUTRON BRD       6
  1.7000E+07  8.0000E+06  6.0000E+06  4.0000E+06  2.0000E+06  1.0000E+05

IWT              10
          4         4         4         4         4         4         3         3         3         2

 SMOOTH WTS FOR P-4 PROBL WITH 10 FINE GROUPS AND 5 BROAD GROUPS.

SW               50                                                                                       
  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00

 CP TIME AT END OF INPUT PROCESSING IS  20.053
   UNDER THE OPTION PROVIDED WHEN INPUT MT=-1 IS USED, THERE WILL BE   14 REACTION TYPES USED AS FOLLOWS -
     MTAC(I)=   3  51  52  53  54  55  56  57  58  59  60  61  91 102

 CP TIME AT CALL TO MESH IS    53.383

 SIZE AND CONTENTS OF NEUTRON ENERGY MESH FOR INTEGRATIONS OVER FINE GROUPS

        706
1.0000E+05 1.0500E+05 1.0700E+05 1.0750E+05 1.0800E+05 1.0900E+05 1.1000E+05 1.1100E+05 1.1200E+05 1.1300E+05 1.1400E+05 1.1500E+05
1.1550E+05 1.1600E+05 1.1700E+05 1.1800E+05 1.1900E+05 1.2000E+05 1.2100E+05 1.2200E+05 1.2300E+05 1.2400E+05 1.2500E+05 1.2600E+05
1.2700E+05 1.2800E+05 1.2900E+05 1.3000E+05 1.3100E+05 1.3500E+05 1.3800E+05 1.3900E+05 1.4000E+05 1.4100E+05 1.4500E+05 1.4800E+05
1.5000E+05 1.5500E+05 1.6000E+05 1.6500E+05 1.7000E+05 1.7500E+05 1.8000E+05 1.8100E+05 1.8200E+05 1.8400E+05 1.8500E+05 1.8550E+05
1.8600E+05 1.8650E+05 1.8700E+05 1.8800E+05 1.8850E+05 1.8900E+05 1.9000E+05 1.9100E+05 1.9200E+05 1.9300E+05 1.9400E+05 1.9500E+05
1.9600E+05 1.9700E+05 1.9800E+05 1.9900E+05 2.0000E+05 2.0100E+05 2.0300E+05 2.0500E+05 2.0600E+05 2.0700E+05 2.0800E+05 2.0900E+05
2.1000E+05 2.1200E+05 2.1500E+05 2.1700E+05 2.1800E+05 2.2000E+05 2.2100E+05 2.2200E+05 2.2300E+05 2.2400E+05 2.2500E+05 2.2700E+05
2.2800E+05 2.2900E+05 2.3000E+05 2.3200E+05 2.3500E+05 2.3600E+05 2.3800E+05 2.3900E+05 2.4000E+05 2.4100E+05 2.4200E+05 2.4400E+05
2.4500E+05 2.4600E+05 2.4700E+05 2.4800E+05 2.4900E+05 2.5000E+05 2.5100E+05 2.5200E+05 2.5300E+05 2.5400E+05 2.5500E+05 2.5600E+05
2.5700E+05 2.5800E+05 2.5900E+05 2.6000E+05 2.6100E+05 2.6200E+05 2.6300E+05 2.6400E+05 2.6500E+05 2.6600E+05 2.6700E+05 2.6800E+05
2.6900E+05 2.7000E+05 2.7100E+05 2.7200E+05 2.7300E+05 2.7400E+05 2.7500E+05 2.7600E+05 2.7700E+05 2.7800E+05 2.7900E+05 2.8000E+05
2.8100E+05 2.8300E+05 2.8500E+05 2.8700E+05 2.8800E+05 2.8900E+05 2.9000E+05 2.9200E+05 2.9300E+05 2.9500E+05 2.9600E+05 2.9700E+05
2.9800E+05 2.9900E+05 3.0000E+05 3.0100E+05 3.0200E+05 3.0300E+05 3.0500E+05 3.0700E+05 3.0900E+05 3.1000E+05 3.1100E+05 3.1200E+05
3.1300E+05 3.1400E+05 3.1500E+05 3.1600E+05 3.1650E+05 3.1700E+05 3.1800E+05 3.1900E+05 3.2000E+05 3.2200E+05 3.2400E+05 3.2500E+05
3.2600E+05 3.2700E+05 3.2800E+05 3.2900E+05 3.3100E+05 3.3200E+05 3.3300E+05 3.3400E+05 3.3500E+05 3.3750E+05 3.3900E+05 3.4000E+05
3.4050E+05 3.4100E+05 3.4130E+05 3.4150E+05 3.4200E+05 3.4250E+05 3.4300E+05 3.4350E+05 3.4400E+05 3.4450E+05 3.4500E+05 3.4600E+05
3.4700E+05 3.4800E+05 3.4900E+05 3.5000E+05 3.5250E+05 3.5500E+05 3.5750E+05 3.6000E+05 3.6200E+05 3.6250E+05 3.6300E+05 3.6350E+05
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3.6400E+05 3.6500E+05 3.6600E+05 3.6750E+05 3.6800E+05 3.6900E+05 3.6950E+05 3.7000E+05 3.7100E+05 3.7200E+05 3.7300E+05 3.7400E+05
3.7500E+05 3.7600E+05 3.7700E+05 3.7800E+05 3.7900E+05 3.8000E+05 3.8200E+05 3.8300E+05 3.8400E+05 3.8500E+05 3.8750E+05 3.9000E+05
3.9100E+05 3.9150E+05 3.9200E+05 3.9250E+05 3.9300E+05 3.9400E+05 3.9500E+05 3.9600E+05 3.9700E+05 3.9800E+05 3.9900E+05 4.0000E+05
4.0100E+05 4.0200E+05 4.0300E+05 4.0400E+05 4.0500E+05 4.0600E+05 4.0650E+05 4.0700E+05 4.0800E+05 4.0900E+05 4.1000E+05 4.1250E+05
4.1500E+05 4.1750E+05 4.2000E+05 4.2100E+05 4.2150E+05 4.2200E+05 4.2250E+05 4.2300E+05 4.2400E+05 4.2500E+05 4.2750E+05 4.3000E+05
4.3100E+05 4.3200E+05 4.3400E+05 4.3600E+05 4.3800E+05 4.4000E+05 4.4100E+05 4.4200E+05 4.4300E+05 4.4400E+05 4.4500E+05 4.4600E+05
4.4700E+05 4.4800E+05 4.4900E+05 4.5000E+05 4.5100E+05 4.5200E+05 4.5300E+05 4.5350E+05 4.5400E+05 4.5500E+05 4.5600E+05 4.5700E+05
4.5800E+05 4.5900E+05 4.6000E+05 4.6100E+05 4.6200E+05 4.6300E+05 4.6400E+05 4.6500E+05 4.6600E+05 4.6700E+05 4.6800E+05 4.6900E+05
4.7000E+05 4.7100E+05 4.7150E+05 4.7200E+05 4.7300E+05 4.7400E+05 4.7500E+05 4.7600E+05 4.7700E+05 4.7800E+05 4.7900E+05 4.7950E+05
4.8000E+05 4.8100E+05 4.8200E+05 4.8300E+05 4.8400E+05 4.8500E+05 4.8600E+05 4.8700E+05 4.8800E+05 4.8900E+05 4.9000E+05 4.9100E+05
4.9200E+05 4.9250E+05 4.9300E+05 4.9400E+05 4.9500E+05 4.9600E+05 4.9700E+05 4.9800E+05 4.9900E+05 5.0000E+05 5.0100E+05 5.0200E+05
5.0300E+05 5.0400E+05 5.0500E+05 5.0600E+05 5.0700E+05 5.0800E+05 5.0900E+05 5.1000E+05 5.1100E+05 5.1200E+05 5.1300E+05 5.1400E+05
5.1500E+05 5.1600E+05 5.1700E+05 5.1800E+05 5.1850E+05 5.1900E+05 5.1950E+05 5.2000E+05 5.2100E+05 5.2200E+05 5.2300E+05 5.2400E+05
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5.5900E+05 5.6000E+05 5.6100E+05 5.6200E+05 5.6300E+05 5.6350E+05 5.6400E+05 5.6500E+05 5.6600E+05 5.6700E+05 5.6800E+05 5.6900E+05
5.7000E+05 5.7100E+05 5.7200E+05 5.7300E+05 5.7400E+05 5.7500E+05 5.7600E+05 5.7700E+05 5.7800E+05 5.7850E+05 5.7900E+05 5.8000E+05
5.8100E+05 5.8200E+05 5.8300E+05 5.8400E+05 5.8500E+05 5.8600E+05 5.8700E+05 5.8800E+05 5.8900E+05 5.9000E+05 5.9100E+05 5.9200E+05
5.9300E+05 5.9400E+05 5.9500E+05 5.9600E+05 5.9700E+05 5.9800E+05 5.9900E+05 6.0000E+05 6.0100E+05 6.0200E+05 6.0300E+05 6.0400E+05
6.0500E+05 6.0600E+05 6.0700E+05 6.0800E+05 6.0900E+05 6.1000E+05 6.1100E+05 6.1200E+05 6.1300E+05 6.1400E+05 6.1500E+05 6.1600E+05
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6.4000E+05 6.4100E+05 6.4200E+05 6.4300E+05 6.4400E+05 6.4500E+05 6.4600E+05 6.4700E+05 6.4800E+05 6.4900E+05 6.5000E+05 6.5100E+05
6.5200E+05 6.5300E+05 6.5400E+05 6.5500E+05 6.5600E+05 6.5700E+05 6.5800E+05 6.5900E+05 6.6000E+05 6.6100E+05 6.6200E+05 6.6300E+05
6.6400E+05 6.6500E+05 6.6600E+05 6.6700E+05 6.6800E+05 6.6900E+05 6.7000E+05 6.7100E+05 6.7200E+05 6.7300E+05 6.7400E+05 6.7500E+05
6.7600E+05 6.7700E+05 6.7800E+05 6.7900E+05 6.8000E+05 6.8100E+05 6.8200E+05 6.8300E+05 6.8400E+05 6.8500E+05 6.8600E+05 6.8700E+05
6.8800E+05 6.8900E+05 6.9000E+05 6.9100E+05 6.9200E+05 6.9300E+05 6.9400E+05 6.9500E+05 6.9600E+05 6.9700E+05 6.9800E+05 6.9900E+05
7.0000E+05 7.0100E+05 7.0200E+05 7.0300E+05 7.0400E+05 7.0500E+05 7.0600E+05 7.0700E+05 7.0800E+05 7.0900E+05 7.1000E+05 7.1100E+05
7.1200E+05 7.1300E+05 7.1400E+05 7.1500E+05 7.1600E+05 7.1700E+05 7.1800E+05 7.1900E+05 7.2000E+05 7.2100E+05 7.2200E+05 7.2300E+05
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7.3600E+05 7.3700E+05 7.3800E+05 7.3900E+05 7.4000E+05 7.4100E+05 7.4200E+05 7.4300E+05 7.4400E+05 7.4500E+05 7.4600E+05 7.4700E+05
7.4800E+05 7.4900E+05 7.5000E+05 7.5100E+05 7.5200E+05 7.5300E+05 7.5400E+05 7.5500E+05 7.5750E+05 7.6000E+05 7.6250E+05 7.6500E+05
7.6750E+05 7.7000E+05 7.7500E+05 7.8000E+05 7.8500E+05 7.9000E+05 7.9500E+05 8.0000E+05 8.0500E+05 8.1000E+05 8.1500E+05 8.2000E+05
8.2500E+05 8.3000E+05 8.3500E+05 8.4000E+05 8.4500E+05 8.5000E+05 8.5500E+05 8.6000E+05 8.6500E+05 8.7000E+05 8.7500E+05 8.8000E+05
8.8500E+05 8.9000E+05 8.9500E+05 9.0000E+05 9.0500E+05 9.1000E+05 9.1250E+05 9.1500E+05 9.2000E+05 9.2500E+05 9.2750E+05 9.3000E+05
9.3500E+05 9.4000E+05 9.4500E+05 9.5000E+05 9.6000E+05 9.7000E+05 9.8000E+05 9.9000E+05 1.0000E+06 1.2000E+06 1.2550E+06 1.3000E+06
1.4000E+06 1.5000E+06 1.6000E+06 1.7000E+06 1.8000E+06 1.9000E+06 2.0000E+06 2.1000E+06 2.2000E+06 2.3000E+06 2.4000E+06 2.5000E+06
2.6000E+06 2.7000E+06 2.8000E+06 2.9000E+06 3.0000E+06 3.2000E+06 3.4000E+06 3.6000E+06 3.8000E+06 4.0000E+06 4.2000E+06 4.4000E+06
4.6000E+06 4.8000E+06 5.0000E+06 5.2500E+06 5.5000E+06 5.7500E+06 6.0000E+06 6.2500E+06 6.5000E+06 6.5513E+06 6.7500E+06 7.0000E+06
7.1900E+06 7.5000E+06 8.0000E+06 8.5000E+06 9.0000E+06 9.5000E+06 1.0000E+07 1.0500E+07 1.1000E+07 1.1500E+07 1.2000E+07 1.2500E+07
1.3000E+07 1.3010E+07 1.3500E+07 1.4000E+07 1.4500E+07 1.5000E+07 1.5500E+07 1.6000E+07 1.6500E+07 1.7000E+07

CP TIME AT RETURN FROM MESH (CALL TO PR15) IS 54.741

PR15 OUTPUT

ILC1	MT	NEUT ENERGY	GAMMA ENERGY RANGE		NUMERATOR	DENOMINATOR	EHAT
1	91	6.0000E+06	5.0000E+04	1.0000E+06	9.60849E+04	1.47986E-01	6.49283E+05
10	91	6.0000E+06	1.0000E+06	3.0000E+06	1.13925E+06	5.66193E-01	2.01212E+06
19	91	6.0000E+06	3.0000E+06	4.0000E+06	6.56277E+05	1.92667E-01	3.40627E+06
28	91	6.0000E+06	4.0000E+06	5.0000E+06	3.37069E+05	7.75292E-02	4.34763E+06
37	91	6.0000E+06	5.0000E+06	6.0000E+06	7.73925E+04	1.54785E-02	5.00000E+06
46	91	6.2500E+06	6.0000E+06	9.0000E+06	2.90824E+03	4.84706E-04	6.00000E+06
54	91	8.0000E+06	5.0000E+04	1.0000E+06	9.16153E+04	1.41110E-01	6.49246E+05
59	91	8.0000E+06	1.0000E+06	3.0000E+06	1.08472E+06	5.38869E-01	2.01296E+06
64	91	8.0000E+06	3.0000E+06	4.0000E+06	6.41015E+05	1.87605E-01	3.41683E+06
69	91	8.0000E+06	4.0000E+06	5.0000E+06	4.18023E+05	9.49330E-02	4.40335E+06
74	91	8.0000E+06	5.0000E+06	6.0000E+06	1.71216E+05	3.34677E-02	5.11586E+06
79	91	8.0000E+06	6.0000E+06	9.0000E+06	2.32659E+04	3.87765E-03	6.00000E+06
84	91	1.0000E+07	5.0000E+04	1.0000E+06	8.85119E+04	1.36319E-01	6.49302E+05
89	91	1.0000E+07	1.0000E+06	3.0000E+06	1.04801E+06	5.20645E-01	2.01291E+06
94	91	1.0000E+07	3.0000E+06	4.0000E+06	6.26357E+05	1.83090E-01	3.42104E+06

99	91	1.0000E+07	4.00000E+06	5.0C000E+06	4.33924E+05	9.82217E-02	4.41780E+06
104	91	1.0000E+07	5.00000E+06	6.0C00CE+06	2.53201E+05	4.79030E-02	5.28571E+06
109	91	1.0000E+07	6.0000CE+06	9.0CC00E+06	8.21190E+04	1.36865E-02	6.00000E+06
114	91	1.2000E+07	5.0000CE+04	1.0C000E+06	8.41955E+04	1.29674E-01	6.49286E+05
120	91	1.2000E+07	1.00000E+06	3.0C000E+06	9.96906E+05	4.95248E-01	2.01294E+06
126	91	1.2000E+07	3.00000E+06	4.0C00CE+06	6.02652E+05	1.75947E-01	3.42518E+06
132	91	1.2000E+07	4.00000E+06	5.0C00CE+06	4.62966E+05	1.04360E-01	4.43623E+06
138	91	1.2000E+07	5.0000CE+06	6.0C000E+06	3.19322E+05	5.97230E-02	5.34673E+06
144	91	1.2000E+07	6.00000E+06	9.0C000E+06	2.23785E+05	3.49275E-02	6.40713E+06
150	91	1.4000E+07	5.0000CE+04	1.0C00CE+06	8.07505E+04	1.24365E-01	6.49301E+05
155	91	1.4000E+07	1.0000CE+06	3.0C000E+06	9.56033E+05	4.74941E-01	2.01295E+06
160	91	1.4000E+07	3.00000E+06	4.0C00CE+06	5.85630E+05	1.70727E-01	3.43020E+06
165	91	1.4000E+07	4.0000CE+06	5.0C000E+06	4.76532E+05	1.07217E-01	4.44454E+06
170	91	1.4000E+07	5.0000CE+06	6.0000CE+06	3.63223E+05	6.75355E-02	5.37825E+06
175	91	1.4000E+07	6.0000CE+06	9.0C000E+06	3.63528E+05	5.50920E-02	6.59856E+06
180	91	1.4500E+07	9.00000E+06	1.0C000E+07	7.31531E+03	8.12812E-04	9.00000E+06
184	91	1.6000E+07	5.0000CE+04	1.0C00CE+06	7.70356E+04	1.18652E-01	6.49258E+05
187	91	1.6000E+07	1.00000E+06	3.0C00CE+06	9.10045E+05	4.51375E-01	2.01616E+06
190	91	1.6000E+07	3.0000CE+06	4.0CC00E+06	5.62857E+05	1.63985E-01	3.43237E+06
193	91	1.6000E+07	4.00000E+06	5.0C00CE+06	4.69691E+05	1.05576E-01	4.44886E+06
196	91	1.6000E+07	5.0000CE+06	6.0C000E+06	3.80220E+05	7.04145E-02	5.39975E+06
199	91	1.6000E+07	6.00000E+06	9.0C000E+06	6.04246E+05	8.66262E-02	6.97533E+06
202	91	1.6000E+07	9.00000E+06	1.0C00CE+07	2.92612E+04	3.25125E-03	9.00000E+06
205	91	1.6500E+07	1.00000E+07	3.0C00CE+07	1.01922E+04	1.01922E-03	1.00000E+07

CP TIME AT RETURN FROM PR15 (CALL TO TRC2 AND XSEC IN OVERLAY(2,2)) IS 76.457

CP TIME AT RETURN FROM TRC2 (CALL TO XSEC) IS 103.441

CP TIME AT RETURN FROM XSEC (CALL TO MATRIX) IS 329.845

PHOTON-PRODUCTION MATRIX FOR NUCLIDE (MAT) 1149, TABLE 1 (P-0 COMPONENT)

	NEUT GRP 1	NEUT GRP 2	NEUT GRP 3	NEUT GRP 4	NEUT GRP 5
PHOTON GRP 1	8.48981E-07	0.	0.	0.	0.
PHOTON GRP 2	3.19284E-05	0.	0.	0.	0.
PHOTON GRP 3	1.62704E-02	1.59330E-03	6.31453E-06	8.37951E-06	1.05401E-04
PHOTON GRP 4	5.03768E-02	5.39115E-02	9.84188E-03	1.26225E-06	1.56770E-05
PHOTON GRP 5	1.09173E-01	9.54098E-02	2.16791E-02	7.12924E-07	8.96743E-06
PHOTON GRP 6	2.00495E-01	2.09667E-01	2.35723E-01	7.30596E-02	3.61374E-06
PHOTON GRP 7	5.87215E-01	7.22425E-01	6.63130E-01	7.04104E-01	3.97782E-02
PHOTON GRP 8	1.88940E-01	1.56271E-01	1.87016E-03	6.36046E-04	7.47844E-05

PHOTON-PRODUCTION MATRIX FOR NUCLIDE (MAT) 1149, TABLE 2 (P-1 COMPONENT)

	NEUT GRP 1	NEUT GRP 2	NEUT GRP 3	NEUT GRP 4	NEUT GRP 5
PHOTON GRP 1	0.	0.	0.	0.	0.
PHOTON GRP 2	0.	0.	0.	0.	0.
PHOTON GRP 3	0.	0.	0.	0.	0.
PHOTON GRP 4	0.	0.	0.	0.	0.
PHOTON GRP 5	0.	0.	0.	0.	0.
PHOTON GRP 6	0.	0.	-7.22351E-06	-3.69131E-06	0.
PHOTON GRP 7	0.	0.	0.	0.	0.
PHOTON GRP 8	0.	0.	0.	0.	0.

PHOTON-PRODUCTION MATRIX FOR NUCLIDE (MAT) 1149, TABLE 3 (P-2 COMPONENT)

	NEUT GRP 1	NEUT GRP 2	NEUT GRP 3	NEUT GRP 4	NEUT GRP 5
PHOTON GRP 1	0.	0.	0.	0.	0.
PHOTON GRP 2	0.	0.	0.	0.	0.
PHOTON GRP 3	0.	0.	0.	0.	0.
PHOTON GRP 4	0.	-7.19029E-04	-3.23391E-04	0.	0.
PHOTON GRP 5	0.	9.42627E-04	1.01166E-03	0.	0.
PHOTON GRP 6	0.	-5.95666E-04	-1.40062E-03	-8.44363E-04	0.
PHOTON GRP 7	0.	-3.85827E-04	-3.38756E-04	-6.44697E-03	-2.11886E-04
PHOTON GRP 8	0.	5.73783E-05	1.17318E-04	4.76113E-05	0.

PHOTON-PRODUCTION MATRIX FOR NUCLIDE (MAT) 1149, TABLE 4 (P-3 COMPONENT)

	NEUT GRP 1	NEUT GRP 2	NEUT GRP 3	NEUT GRP 4	NEUT GRP 5
PHOTON GRP 1	0.	0.	0.	0.	0.
PHOTON GRP 2	0.	0.	0.	0.	0.
PHOTON GRP 3	0.	0.	0.	0.	0.
PHOTON GRP 4	0.	0.	0.	0.	0.
PHOTON GRP 5	0.	0.	0.	0.	0.
PHOTON GRP 6	0.	0.	1.86866E-06	9.25065E-07	0.
PHOTON GRP 7	0.	0.	0.	0.	0.
PHOTON GRP 8	0.	0.	0.	0.	0.

PHOTON-PRODUCTION MATRIX FOR NUCLIDE (MAT) 1149, TABLE 5 (P-4 COMPONENT)

	NEUT GRP 1	NEUT GRP 2	NEUT GRP 3	NEUT GRP 4	NEUT GRP 5
PHOTON GRP 1	0.	0.	0.	0.	0.
PHOTON GRP 2	0.	0.	0.	0.	0.
PHOTON GRP 3	0.	0.	0.	0.	0.
PHOTON GRP 4	0.	5.21017E-04	1.55592E-04	0.	0.
PHOTON GRP 5	0.	-8.54548E-05	-8.41848E-05	0.	0.
PHOTON GRP 6	0.	-3.09092E-07	-1.24495E-05	-4.88333E-06	0.
PHOTON GRP 7	0.	3.64275E-06	4.18461E-05	1.21544E-04	-1.36296E-07
PHOTON GRP 8	0.	1.23568E-07	-4.49598E-07	-4.25412E-07	0.

APPENDIX B

COMMENTS CONCERNING CODE OPERATION AND SUBROUTINES

As shown in Fig. B-1, the LAPHAN code has been divided into two primary overlays, namely, OVERLAY (1,0) and (2,0). The main overlay, OVERLAY (0,0) is very short and serves principally to define unlabelled COMMON and labelled COMMON/TAPES/ and to call the two primary overlays. In OVERLAY (1,0) the input is read in DTF-IV format and examined for possible errors. In OVERLAY (2,0), the photon-production matrices are calculated. OVERLAY's (2,1) and (2,2) are subsections of OVERLAY (2,0).

A brief description of each of the subroutines follows:

OVERLAY (0,0)

PROGRAM DON serves to define unlabelled COMMON and labelled COMMON/TAPES/ and to call the two primary overlays.

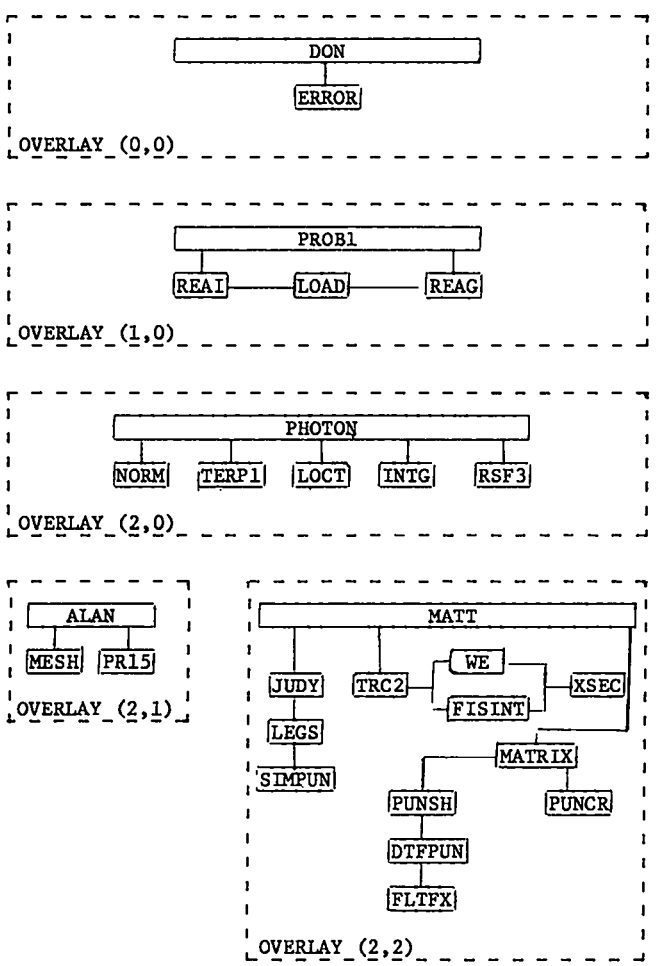

Fig. B-1. Arrangement of overlays and subroutines.

SUBROUTINE ERROR is called if there is an error in the input data or if any core storage allotments have been exceeded. An error stop number is printed, and execution is terminated. A complete catalog of the possible fatal error returns is included as a part of this subroutine. Other, nonfatal, errors are noted by printing within the various subroutines.

OVERLAY (1,0)

PROGRAM PROB1 reads all of the input data for the problem and does preliminary checking thereon.

SUBROUTINE REAI and SUBROUTINE REAG are DTF-IV routines. They are called by PROB1 to read integer and floating-point data, respectively, when these data are given in the DTF-IV format.

SUBROUTINE LOAD is another DTF-IV routine and is called by the two subroutines mentioned immediately above. This routine interprets the DTF-IV control flags and fills out the integer and floating-point arrays accordingly.

OVERLAY (2,0)

PROGRAM PHOTON reads the input data from Tape 20 and calls OVERLAYS (2,1) and (2,2). This routine interprets the "MT = -1" command in the input specification and determines which MT numbers are to be used.

SUBROUTINE INTG computes the integral of $y(x)$ between two points x_1 and x_2, where values of $y(x)$ are given at x_3 and x_4 such that $x_3 \leq x_1 \leq x_2 \leq x_4$. The dependence of $y(x)$ on x between the two tabulated points (e.g., linear-linear or log-log) must be specified.

FUNCTION LOCT locates the mesh interval in which a given variable lies.

SUBROUTINE TERP1 interpolates between two specified points of $y(x)$ vs x, assuming a dependence (e.g., linear-linear or log-log) which must be specified.

SUBROUTINE NORM normalizes the fine-group weighting functions over each broad group.

SUBROUTINE RSF3 reads tabulated arrays from the ENDF data tape.

OVERLAY (2,1)

PROGRAM ALAN supervises the formation of the integration energy mesh and calculation of the yield functions.

SUBROUTINE MESH forms the energy mesh to be used in the numerical integration over neutron energy. The fine-group energy mesh is augmented with the energies at which the total neutron cross sections are tabulated in File 3.

SUBROUTINE PR15 reads the photon production data from File 12 through 15 of the ENDF tape, and writes Files 14 and 15 on Tapes 14 and 19, respectively. For a continuous energy distribution under Option 1, the photon group yields, $Y_g(E)$ and $\tilde{Y}_g(E)$, are calculated on either Track 1 or 2 and written onto Tape 15. For distributions under Option 1 at discrete gamma energies, the yields are written directly onto Tape 17. The appropriate transition and conditional probabilities under Option 2 are read from the ENDF tape and are written onto Tape 16 for later use in SUBROUTINE TRC2.

OVERLAY (2,2)

PROGRAM MATT supervises the calculation of the photon-production matrices.

SUBROUTINE JUDY reads the data on Tape 14 (ENDF File 14) and supervises the production of the higher-order Legendre coefficients. The results are written on Tape 19.

SUBROUTINE LEGS, called by subroutine JUDY, determines the Legendre coefficients from the angular distribution data in File 14 of the ENDF.

SUBROUTINE SIMPUN is a Simpson's rule, non-constant mesh, integration routine used in subroutine LEGS.

SUBROUTINE TRC2 reconstructs the microscopic photon-production cross-section moments from the transition arrays (read from Tape 16), the appropriate cross sections (read from the ENDF tape File 3), and the Legendre coefficients (read from Tape 19), integrates over the neutron fine groups, and writes the results on Tape 16.

SUBROUTINE XSEC reconstructs the microscopic photon-production cross-section moments from the multiplicity arrays, the photon-production cross-sections (from Tapes 15 and 17), and the Legendre coefficients (read from Tape 19), integrates over the neutron fine groups, and writes the results on Tape 16.

FUNCTION WE determines the weighting functions within fine neutron groups as prescribed by the input options. These weighting functions are used in the fine-neutron-group integrations in subroutines TRC2 and XSEC.

SUBROUTINE FISINT determines the integral of the fission spectrum weighting function over the fine neutron groups.

SUBROUTINE MATRIX reads the microscopic fine-group photon- and energy-production matrix elements (τ's and ρ's) from Tape 16. It then performs the weighted sum over fine groups which results in the photon-production and energy-production matrices for each reaction type. Finally, the sum over reaction types is taken to produce the G × N matrices.

SUBROUTINE PUNCR punches both integer and floating-point arrays in DTF-IV format.

SUBROUTINE PUNSH sets up cards to be punched in FIDO format.

SUBROUTINE DTFPUN punches cards in FIDO format.

SUBROUTINE FLTFX converts floating-point numbers into integers.