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AN INFORMAL REPORT

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LAPHANO: A P_0 Multigroup Photon-Production Matrix and Source Code for ENDF

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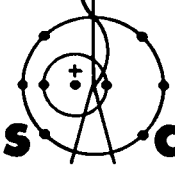

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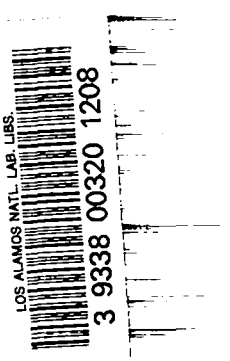

by

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

LAPHANO: A P_0 MULTIGROUP PHOTON-PRODUCTION MATRIX AND SOURCE CODE FOR ENDF

by

Donald J. Dudziak, Robert E. Seamon, and Dante V. Susco

ABSTRACT

The LAPHANO code is a revision of the LAPH code and is intended to be an interim P_0 version of a more general P_4 code, LAPHAN. Photon-production cross-section data are retrieved from the ENDF Files 12 through 15, processed into specified photon and neutron energy groups, and combined as necessary to produce photon-production matrices. These can be either microscopic or macroscopic matrices for mixtures of materials. Also, spatially dependent photon-production source vectors can optionally be calculated from the macroscopic matrices. Production cross sections are averaged over neutron fine groups and then collapsed into a given broad-group structure using input weighting functions. Multiple zones can be accommodated with separate weighting functions for each zone. A code package including the FORTRAN-IV source deck, a sample problem input and output, and an INDEX (cross reference) listing are available from the Radiation Shielding Information Center at the Oak Ridge National Laboratory. The code is presently operational on CDC 6600, CDC 7600, IBM 360, and UNIVAC 1108 computers.

I. INTRODUCTION AND SUMMARY

Photon-production data for several materials now exist in the revised ENDF format.[1] To process these data into multigroup form for transport calculations, the LAPH code[2] had to be updated to accommodate the revised formats and procedures. During this revision process, specifications were formulated[3] for a code, LAPHAN, which would process the photon-production angular distribution data in ENDF, with provision for matrices up to P_4. Before extending the basic LAPH code structure to higher-order Legendre moments, a P_0 capability was provided to satisfy immediate needs for processing ENDF data into photon-production matrices. Providing this capability resulted in the LAPHANO code, which not only operates on the revised format but also has many improvements in the calculational algorithms. These improvements decrease running time and provide greater accuracy.

This report is intended primarily to serve as a user's manual for LAPHANO. It relies on the LAPH code report[2] for detailed discussions of the theory and operation. Also, the reader must be familiar with the ENDF system formats and procedures[1] for photon-production data.

The LAPHANO code is currently operational on the CDC 6600 and 7600 computers at the Los Alamos Scientific Laboratory, the IBM 360 computer at the Oak Ridge National Laboratory (ORNL), and the UNIVAC 1108 computer at Gulf Radiation Technology Corporation.[4] It has been successfully used to process all photon data presently extant in the ENDF system (eleven materials as of September 1971). Appendix A is a sample problem input and output for aluminum. Test problems with the new code were run on nitrogen and oxygen, using an 18 by 22 photon-neutron multigroup energy structure devised by Straker at ORNL. Straker[5] compared the test problem results with his photon-production matrices derived previously from both ENDF and non-ENDF sources. Agreement was excellent between matrices produced by LAPHANO and other means. Additional comparisons have been made with

hand calculations at various laboratories, providing further confidence in the code theory and algorithms.

A code package identified as PSR-20B/LAPHANO is available from the Radiation Shielding Information Center. See the Code Abstract in Appendix B for details concerning requests for the code package.

Section II below lists the major modifications made to LAPH, excluding those pertaining solely to the changes in data format. Detailed input instructions for LAPHANO are given in Sec. III, although these differ very little from those in the LAPH report.

II. MODIFICATIONS TO LAPH ALGORITHMS

Major modifications in transforming from LAPH to LAPHANO, excluding changes due strictly to revisions of the data formats and procedures, include:

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. In anticipation of the completion of LAPHAN, a new input data format allows from P_0 to P_4 weighting functions for the neutron fine groups, as well as up to P_4 components of the neutron-flux vectors.

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 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 (see Appendix A).

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. This allows the code to continue operating within $133k_8$ in spite of expansion of array sizes necessitated by the current ENDF procedures. Labeled 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.

III. INPUT INSTRUCTIONS

A. Background

Input to LAPHANO is essentially the same as for LAPH, with two minor exceptions. For completeness, however, the instructions are repeated here in full.

Input is generally in the DTF-IV format system,[6] 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 LAPHANO 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 LAPHANO, the term material is used strictly in the sense of a MAT in the ENDF system.

Units for input should be as follows:

Energy:	eV
Number density:	atoms/b-cm
Flux:	n/cm^2-sec
Length:	cm

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 in the code package).

B. Input Data Format

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

C. Changes from LAPH Input

An attempt has been made to minimize the changes to the LAPH input yet make the input form consistent with that being used for the LAPHAN code, which is still under development. Only two changes have been required:

1. The first parameter, 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 4 of the integer parameters card is now a parameter IQA, the order of Legendre expansion. It is a provision for LAPHAN and must always be zero for LAPHANO. All integer parameters previously in Fields 4 through 12 in the LAPH input, i.e., IZM through I00, are simply shifted one field to the right. Thus, I00 now goes in the first field of a second integer parameter card.

For detailed discussions of the symbols and terminology used in Table I, especially the options on Tracks A, B, 1, and 2, refer to the LAPH report.[2]

D. Array Size Restrictions

To keep the code operable on computers with small-size memories, restrictions must be placed on array sizes. The restrictions are presently as follows:

$$\begin{aligned} NFG &\leq 99 \\ NBG &\leq 99 \\ NGG &\leq 49 \\ IZM &\leq 10 \\ IM &\leq 100 \\ MS &\leq 50 \\ IQA &= 0 \end{aligned}$$

E. Computer Requirements and Running Times

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

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	IQA	= 0 for LAPHANO. Order of the Legendre expansion of the photon-production matrices and source vectors.
5	IZM	Number of zones.
6	IM	Number of intervals.
7	MS	Number of mixture specifications (= length of mix tables).
8	MCR	Number of nuclides for which distinct fine-group cross sections and/or weighting functions are input.
9	MM	Number of reaction types, MT (= length of MTN table).
10	NPM	Total number of nuclides plus mixtures.
11	IRES	Special resonance weighting option to be used? 0/1 = no/yes. (0 = Track A, 1 = Track B.)
12	IWO	= 0, photon effective average energy for each group is input (Track 1).
		= 1, photon energy weighting function is yield function (Track 2).
13	IOO	= 0, print $[\sigma_{g,n}]_{i,j}$ for each nuclide i and zone j, and

$$\sum_i A_{i,j}[\sigma_{g,n}]_{i,j} \quad ,$$

the macroscopic matrices for each zone j. Punch the matrices in FIDO and DTF-IV format.

= 1, print all of Option 0 plus the source vector

$$C\sum_i A_{i,j}[\sigma_{g,n}]_{i,j}\,[\phi]_m \quad ,$$

at each spatial point m. Note that m determines j.

= 2, print all of Option 1, and punch the DTF-IV input source cards (cf. discussion of DTF-IV option in Ref. 2).

= 3, print only the matrix

$$\sum_i A_{i,j}[\sigma_{g,n}]_{i,j}$$

for each zone j, along with the source vector

$$C\sum_i A_{i,j}[\sigma_{g,n}]_{i,j}\,[\phi]_m \quad .$$

= 4, print all of Option 3 and punch the DTF input source cards.

TABLE I (continued)

= 5, same as output Option 0, but in standard interface file ISOTXS form.[a]

= 10, same as IOO = 0, substituting the energy-production matrices $[\tilde{\sigma}_{g,n}]_{i,j}$, etc.

= 11, same as IOO = 1, substituting the energy-production matrices $[\tilde{\sigma}_{g,n}]_{i,j}$, etc.

= 12, same as IOO = 2, substituting the energy-production matrices $[\tilde{\sigma}_{g,n}]_{i,j}$, etc.

= 13, same as IOO = 3, substituting the energy-production matrices $[\tilde{\sigma}_{g,n}]_{i,j}$, etc.

= 14, same as IOO = 4, substituting the energy-production matrices $[\tilde{\sigma}_{g,n}]_{i,j}$, etc.

= 15, same as IOO = 5, substituting the energy-production matrices $[\tilde{\sigma}_{g,n}]_{i,j}$, etc.[a]

= 20, do both Options 0 and 10 (i.e., print both photon-production and photon-energy-production matrices).

= 21, do both Options 1 and 11.

= 22, " " " 2 and 12.

= 23, " " " 3 and 13.

= 24, " " " 4 and 14.

= 25, " " " 5 and 15.[a]

(Note: The 2X series of output options requires an insignificant addition to the central processor time compared to the X or 1X series.)

C. Data Blocks (DTF-IV system): Dimension of variable is given if it is predetermined.

Name and Dimension	
C(1)	Renormalization constant for $[\phi]$.
NMAT(IZM)	Number of nuclides in each zone for which photon-production cross sections are desired.
NNM(2*MCR)	Nuclide sequence numbers (for mix table) and corresponding material (MAT) numbers, in successive pairs.
MZT(MCR)	For each MAT number in the NNM block, MZT is the number of values of MT to be entered in the next (MTN) block. A useful check is that $\sum_{I=1}^{MCR} MZT(I) = MM.$
MTN(MM)	MT numbers for each MAT number given in the NNM block. MT = -1 means use all MT numbers for which photon-production data exist in Files 12 and 13. MT = 0 means calculate no photon-production matrices for this material.

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

EG(NGG)	Effective average energy, $\bar{E}_g$, for each photon group. (Same for all materials and reaction types. Code checks that $E_g \leq \bar{E}_g \leq E_{g+1}$.)
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.
EMNG(NBG+1)	Neutron broad-group energy mesh, in decreasing magnitude of energy.

[a]This output option not yet available in the version of LAPHANO currently (1971) at the RSIC.

TABLE I (continued)

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

LOOP ON ZONES [IZM]	LOOP ON MAT's [NMAT(IZM)]	RXSC(NFG)[ab]	Fine-group resonance capture cross sections, $\bar{\sigma}_{\ell}^{102,r}$, starting at top group. First card is a title card in 12A6 format.
		RXSF(NFG)[ab]	Fine-group resonance fission cross sections, $\bar{\sigma}_{\ell}^{18,r}$, starting at top group. First card is a title card in 12A6 format.
		SXSC(NFG)[b]	Fine-group smooth (including unresolved resonance) capture cross sections, $\bar{\sigma}_{\ell}^{102,s}$, starting at top group. First card is a title card in 12A6 format.
		SXSF(NFG)[b]	Fine-group smooth (including unresolved resonance) fission cross sections, $\bar{\sigma}_{\ell}^{18,s}$, starting at top group. First card is a title card in 12A6 format.
		RW(NFG)[ab]	Fine-group resonance weighting functions for the zone, starting at top group. First card is a title card in 12A6 format.
		SW(NFG)	Fine-group smooth (flux) weighting functions for the zone, starting at top group. First card is a title card in 12A6 format.

The following six data blocks are identical to their homologous blocks in DTF-IV. In fact, for many LAPHANO problems, they will be identical to those for the DTF-IV problem used to compute the neutron flux vectors.

R(IM+1)	Radii of the spatial mesh points.
MA(IM)	Zone numbers for each interval.
MZ(IZM)	Mixture number in each zone.
MB(MS)	Mixture numbers for mix table.
MC(MS)	Mix command: Specification of nuclides in the mixtures.
XMD(MS)	Mix density of the nuclide in the mixtures.

Lastly, the data block for the neutron flux vectors appears in a format exactly like that used for DTF-IV flux dumps; it is deleted if IOO = 0, 5, 10, 15, 20, or 25.

PHI(IM,NBG)	Normalized neutron fluxes by columns (i.e., by mesh interval and then by neutron broad groups).

[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.

CDC 6600 central processor time required for a problem with three regions, six materials, ten mesh points, 11 photon groups, and 26 neutron groups, including calculation of both photon-production matrices and photon source vectors was approximately 3 min. A simple problem to produce a microscopic matrix for one material, using 18 photon groups and 22 neutron fine and broad groups, required approximately 1 min of CDC 6600 central processor time or 18 sec of CDC 7600 central processor time.

F. Sample Problem

Most of the usage of the LAPH and LAPHANO codes to date has involved calculation of microscopic matrices for a single material per run. Thus, the sample problem chosen for this document was such a case, using aluminum (ENDF MAT number 511). A simple group structure (three photon groups, four neutron fine groups, and two neutron broad groups), as well as simple fine-group weighting, was selected for illustrative purposes. The reaction types for which photon-production matrices were computed include MT = 28 (n,n'p), which has a continuum gamma-ray energy distribution, along with MT = 103 (n,p), which has only discrete gamma rays. Yield weighting of the gamma-ray energy (IWO = 1) was chosen for the energy-production matrices.

For a more complicated sample problem involving three regions and six nuclides, refer to Sec. III.E of the LAPH report.[2]

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. Donald J. Dudziak, Alan H. Marshall, and Robert E. Seamon, "LAPH, A Multigroup Photon Production Matrix and Source Vector Code for ENDF/B," LA-4337 (ENDF-132), Los Alamos Scientific Laboratory (1969).

   Computer Code Abstract, Nucl. Sci. Eng. 40, 352 (1970).

3. Donald J. Dudziak and Robert E. Seamon, "Generating Moments of the Photon Production Matrices and Sources from ENDF Data: The LAPHAN Code," Proc. National Topical Meeting on New Developments in Reactor Mathematics and Applications, CONF-710302, Vol. 2, 1016 (1971).

4. Martin P. Fricke, private communication (1971).

5. Edward A. Straker, private communication (1971).

6. K. D. Lathrop, "DTF-IV, A FORTRAN-IV Program for Solving the Multigroup Transport Equation with Anisotropic Scattering," LA-3373, Los Alamos Scientific Laboratory (1965).

APPENDIX A

SAMPLE PROBLEM INPUT

```
81271 SAMPLE PROBLEM-AL(MAT=511). MICRO MATRIX, 4 FINE GRPS.          DJD   TITLE
    3     4     2     0     1     1     2     1     2     2     0     1 PARAMS1
   20                                                                  PARAMS2
  1.0     3                                                            C
           13                                                          NMAT
           1          5113                                             NNM
           23                                                          MZT
           28         1033                                             MTN
  3.0   E+7   7.0   E+6   3.0   E+6   5.0   E+43                       EMG
  1.7   E+7   9.0   E+6   6.0   E+6   4.0   E+6   1.0   E+63          EMNF
  1.7   E+7   6.0   E+6   1.0   E+63                                   EMNB
FINE GROUP WEIGHTING FOR SAMPLE PROBLEM WITH 4 FINE GROUPS, 2 BROAD.
  1.0     102 0.5         1.0     3                                    SW
  0.0           1.0       3                                          R
           13                                                         MA
           23                                                         MZ
102        23                                                         MB
           0           13                                             MC
  0.0           1.0       3                                          XMD
```

SAMPLE PROBLEM OUTPUT

```
ENDF/B TAPE I. D. =   -0       ALUMINUM-27 ENDF/B TAPE   --  FOSTER,YOUNG  --  4/71

 81271 SAMPLE PROBLEM-AL(MAT=511), MICRO MATRIX, 4 FINE GRPS.          DJD   TITLE
INTEGER PARAMETERS  NGG     NFG     NBG     IQA     IZM     IM      MS     MCR     MM     NPM     IRES    IWO     IOO
                      3       4       2       0       1       1       2       1       2       2       0       1       20

RENORM CONST      1
  1.0000E+00

NO MATS/ZONE      1
          1
NUMBER OF NUCLIDES IN EACH ZONE
          ZONE  NUMBER  OF NUCLIDES
            1          1

NNM ARRAY         2
          1         511
NUCLIDE SEQUENCE NUMBER      NUCLIDE
            1---------------  511

MZT ARRAY         1
          2

MTN NUMBERS       2
         28         103
NUCLIDE SEQUENCE NUMBER         MT NUMBERS
                  1                  28 103

GAMMA BOUNDS      4
  3.0000E+07  7.0000E+06  3.0000E+06  5.0000E+04

NEUTRON FINE      5
  1.7000E+07  9.0000E+06  6.0000E+06  4.0000E+06  1.0000E+06

NEUTRON BRD       3
  1.7000E+07  6.0000E+06  1.0000E+06

  FINE GROUP WEIGHTING FOR SAMPLE PROBLEM WITH 4 FINE GROUPS, 2 BROAD.

SW                4
  1.0000E+00  5.0000E-01  5.0000E-01  1.0000E+00

RADII             2
  0.          1.0000E+00

ZONE NUMBERS      1
          1

MIXTURE NOS       1
          2

MIX TABLE         2
          2           2

MIX COMMAND       2
          0           1

MIX DENSITY       2
  0.          1.0000E+00
 ----- ZONE   1 ----- NUCLIDE   1  -----
```

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

657

.1000E+07	.1010E+07	.1012E+07	.1014E+07	.1016E+07	.1020E+07	.1024E+07	.1026E+07	.1028E+07	.1030E+07	.1032E+07	.1034E+07
.1036E+07	.1038E+07	.1040E+07	.1042E+07	.1044E+07	.1046E+07	.1048E+07	.1050E+07	.1051E+07	.1060E+07	.1070E+07	.1080E+07
.1082E+07	.1084E+07	.1086E+07	.1088E+07	.1090E+07	.1092E+07	.1094E+07	.1096E+07	.1098E+07	.1100E+07	.1104E+07	.1110E+07
.1120E+07	.1130E+07	.1140E+07	.1146E+07	.1148E+07	.1150E+07	.1152E+07	.1154E+07	.1156E+07	.1158E+07	.1160E+07	.1162E+07
.1164E+07	.1166E+07	.1168E+07	.1170E+07	.1172E+07	.1174E+07	.1176E+07	.1178E+07	.1180E+07	.1182E+07	.1188E+07	.1190E+07
.1191E+07	.1192E+07	.1193E+07	.1194E+07	.1195E+07	.1196E+07	.1197E+07	.1198E+07	.1200E+07	.1210E+07	.1220E+07	.1230E+07
.1240E+07	.1245E+07	.1246E+07	.1247E+07	.1248E+07	.1249E+07	.1250E+07	.1251E+07	.1252E+07	.1253E+07	.1254E+07	.1255E+07
.1256E+07	.1258E+07	.1260E+07	.1262E+07	.1264E+07	.1266E+07	.1268E+07	.1270E+07	.1275E+07	.1280E+07	.1281E+07	.1282E+07
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.1305E+07	.1310E+07	.1315E+07	.1317E+07	.1318E+07	.1319E+07	.1320E+07	.1321E+07	.1322E+07	.1325E+07	.1330E+07	.1335E+07
.1340E+07	.1341E+07	.1342E+07	.1343E+07	.1344E+07	.1345E+07	.1346E+07	.1347E+07	.1348E+07	.1349E+07	.1350E+07	.1351E+07
.1352E+07	.1354E+07	.1356E+07	.1358E+07	.1360E+07	.1362E+07	.1363E+07	.1364E+07	.1365E+07	.1370E+07	.1375E+07	.1380E+07
.1385E+07	.1390E+07	.1395E+07	.1400E+07	.1405E+07	.1410E+07	.1415E+07	.1420E+07	.1425E+07	.1427E+07	.1428E+07	.1430E+07
.1432E+07	.1434E+07	.1436E+07	.1438E+07	.1440E+07	.1442E+07	.1444E+07	.1446E+07	.1448E+07	.1449E+07	.1450E+07	.1455E+07
.1460E+07	.1470E+07	.1480E+07	.1490E+07	.1500E+07	.1510E+07	.1515E+07	.1520E+07	.1525E+07	.1530E+07	.1532E+07	.1534E+07
.1536E+07	.1538E+07	.1540E+07	.1542E+07	.1544E+07	.1546E+07	.1548E+07	.1550E+07	.1555E+07	.1560E+07	.1565E+07	.1570E+07
.1575E+07	.1580E+07	.1585E+07	.1590E+07	.1596E+07	.1598E+07	.1600E+07	.1602E+07	.1604E+07	.1606E+07	.1608E+07	.1610E+07
.1615E+07	.1620E+07	.1625E+07	.1630E+07	.1635E+07	.1640E+07	.1645E+07	.1650E+07	.1655E+07	.1660E+07	.1665E+07	.1670E+07
.1675E+07	.1680E+07	.1685E+07	.1690E+07	.1695E+07	.1700E+07	.1705E+07	.1710E+07	.1720E+07	.1725E+07	.1730E+07	.1735E+07
.1736E+07	.1737E+07	.1738E+07	.1740E+07	.1742E+07	.1744E+07	.1746E+07	.1748E+07	.1749E+07	.1750E+07	.1755E+07	.1760E+07
.1765E+07	.1770E+07	.1775E+07	.1780E+07	.1790E+07	.1800E+07	.1810E+07	.1820E+07	.1830E+07	.1840E+07	.1845E+07	.1846E+07
.1848E+07	.1850E+07	.1851E+07	.1852E+07	.1853E+07	.1854E+07	.1855E+07	.1856E+07	.1858E+07	.1860E+07	.1862E+07	.1863E+07
.1864E+07	.1865E+07	.1870E+07	.1875E+07	.1880E+07	.1885E+07	.1890E+07	.1892E+07	.1894E+07	.1896E+07	.1898E+07	.1899E+07
.1900E+07	.1902E+07	.1904E+07	.1906E+07	.1908E+07	.1910E+07	.1915E+07	.1920E+07	.1930E+07	.1935E+07	.1940E+07	.1945E+07
.1950E+07	.1955E+07	.1960E+07	.1965E+07	.1970E+07	.1975E+07	.1980E+07	.1985E+07	.1990E+07	.1995E+07	.2000E+07	.2005E+07
.2010E+07	.2015E+07	.2020E+07	.2025E+07	.2030E+07	.2035E+07	.2040E+07	.2045E+07	.2050E+07	.2055E+07	.2060E+07	.2065E+07
.2070E+07	.2075E+07	.2080E+07	.2085E+07	.2090E+07	.2095E+07	.2100E+07	.2105E+07	.2110E+07	.2115E+07	.2120E+07	.2125E+07
.2130E+07	.2140E+07	.2150E+07	.2155E+07	.2160E+07	.2165E+07	.2170E+07	.2175E+07	.2180E+07	.2185E+07	.2190E+07	.2195E+07
.2200E+07	.2205E+07	.2210E+07	.2215E+07	.2220E+07	.2225E+07	.2230E+07	.2235E+07	.2240E+07	.2245E+07	.2250E+07	.2255E+07
.2260E+07	.2265E+07	.2270E+07	.2275E+07	.2280E+07	.2285E+07	.2290E+07	.2293E+07	.2295E+07	.2300E+07.	.2305E+07	.2310E+07
.2315E+07	.2320E+07	.2325E+07	.2330E+07	.2335E+07	.2340E+07	.2345E+07	.2350E+07	.2355E+07	.2360E+07	.2365E+07	.2370E+07
.2375E+07	.2380E+07	.2385E+07	.2390E+07	.2395E+07	.2400E+07	.2405E+07	.2410E+07	.2415E+07	.2420E+07	.2425E+07	.2430E+07
.2440E+07	.2450E+07	.2455E+07	.2460E+07	.2465E+07	.2470E+07	.2475E+07	.2480E+07	.2490E+07	.2495E+07	.2500E+07	.2505E+07
.2510E+07	.2515E+07	.2520E+07	.2525E+07	.2530E+07	.2535E+07	.2540E+07	.2545E+07	.2550E+07	.2555E+07	.2560E+07	.2565E+07
.2570E+07	.2575E+07	.2580E+07	.2590E+07	.2600E+07	.2610E+07	.2620E+07	.2625E+07	.2630E+07	.2640E+07	.2650E+07	.2655E+07
.2660E+07	.2665E+07	.2670E+07	.2675E+07	.2680E+07	.2685E+07	.2690E+07	.2695E+07	.2700E+07	.2710E+07	.2720E+07	.2730E+07
.2740E+07	.2750E+07	.2760E+07	.2770E+07	.2775E+07	.2780E+07	.2785E+07	.2790E+07	.2800E+07	.2810E+07	.2820E+07	.2830E+07
.2834E+07	.2840E+07	.2850E+07	.2855E+07	.2860E+07	.2865E+07	.2870E+07	.2875E+07	.2880E+07	.2885E+07	.2890E+07	.2895E+07
.2900E+07	.2905E+07	.2910E+07	.2915E+07	.2920E+07	.2925E+07	.2930E+07	.2935E+07	.2940E+07	.2945E+07	.2950E+07	.2960E+07
.2970E+07	.2980E+07	.2985E+07	.2990E+07	.2995E+07	.3000E+07	.3020E+07	.3040E+07	.3060E+07	.3080E+07	.3091E+07	.3100E+07
.3113E+07	.3120E+07	.3140E+07	.3160E+07	.3180E+07	.3200E+07	.3220E+07	.3240E+07	.3248E+07	.3260E+07	.3280E+07	.3300E+07
.3320E+07	.3340E+07	.3360E+07	.3380E+07	.3400E+07	.3420E+07	.3440E+07	.3460E+07	.3480E+07	.3500E+07	.3520E+07	.3540E+07
.3560E+07	.3580E+07	.3600E+07	.3620E+07	.3640E+07	.3660E+07	.3680E+07	.3700E+07	.3720E+07	.3740E+07	.3760E+07	.3780E+07
.3800E+07	.3815E+07	.3820E+07	.3840E+07	.3860E+07	.3880E+07	.3900E+07	.3920E+07	.3940E+07	.3960E+07	.3980E+07	.4000E+07
.4050E+07	.4100E+07	.4104E+07	.4150E+07	.4200E+07	.4207E+07	.4250E+07	.4300E+07	.4350E+07	.4400E+07	.4450E+07	.4500E+07
.4550E+07	.4574E+07	.4600E+07	.4650E+07	.4677E+07	.4700E+07	.4750E+07	.4751E+07	.4800E+07	.4850E+07	.4900E+07	.4950E+07
.4991E+07	.5000E+07	.5100E+07	.5200E+07	.5300E+07	.5400E+07	.5446E+07	.5500E+07	.5600E+07	.5700E+07	.5800E+07	.5900E+07
.5965E+07	.6000E+07	.6100E+07	.6200E+07	.6272E+07	.6300E+07	.6400E+07	.6484E+07	.6500E+07	.6600E+07	.6700E+07	.6800E+07
.6900E+07	.7000E+07	.7002E+07	.7200E+07	.7400E+07	.7521E+07	.7600E+07	.7800E+07	.8000E+07	.8040E+07	.8200E+07	.8400E+07
.8558E+07	.8580E+07	.8600E+07	.8800E+07	.9000E+07	.9077E+07	.9200E+07	.9400E+07	.9500E+07	.9596E+07	.9600E+07	.9800E+07
.1000E+08	.1011E+08	.1020E+08	.1040E+08	.1048E+08	.1050E+08	.1060E+08	.1063E+08	.1080E+08	.1100E+08	.1115E+08	.1120E+08
.1129E+08	.1140E+08	.1150E+08	.1160E+08	.1167E+08	.1180E+08	.1200E+08	.1219E+08	.1220E+08	.1240E+08	.1250E+08	.1260E+08
.1271E+08	.1280E+08	.1300E+08	.1320E+08	.1323E+08	.1340E+08	.1350E+08	.1354E+08	.1360E+08	.1374E+08	.1380E+08	.1400E+08
.1420E+08	.1426E+08	.1440E+08	.1460E+08	.1478E+08	.1480E+08	.1500E+08	.1520E+08	.1530E+08	.1540E+08	.1560E+08	.1580E+08
.1582E+08	.1600E+08	.1620E+08	.1634E+08	.1640E+08	.1660E+08	.1680E+08	.1686E+08	.1700E+08			

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PRIS OUTPUT

ILOI	MT	NEUT ENERGY	GAMMA ENERGY RANGE		NUMERATOR	DENOMINATOR	EHAT
1	28	.1320E+08	.50000E+05	.30000E+07	.908811E+06	.596627E+00	.152325E+07
10	28	.1320E+08	.30000E+07	.70000E+07	.140792E+07	.343062E+00	.410398E+07
28	28	.1400E+08	.50000E+05	.30000E+07	.908811E+06	.596627E+00	.152325E+07
36	28	.1400E+08	.30000E+07	.70000E+07	.140792E+07	.343062E+00	.410398E+07
52	28	.1500E+08	.50000E+05	.30000E+07	.600863E+06	.365380E+00	.164449E+07
60	28	.1500E+08	.30000E+07	.70000E+07	.261025E+07	.616750E+00	.423227E+07
76	28	.1600E+08	.50000E+05	.30000E+07	.893818E+06	.543665E+00	.164406E+07
84	28	.1600E+08	.30000E+07	.70000E+07	.186288E+07	.440625E+00	.422780E+07
92	28	.1600E+08	.70000E+07	.30000E+08	.279173E-11	.413590E-18	.675000E+07
100	28	.1700E+08	.50000E+05	.30000E+07	.834311E+06	.505700E+00	.164981E+07
101	28	.1700E+08	.30000E+07	.70000E+07	.209878E+07	.485250E+00	.432515E+07
102	28	.1700E+08	.70000E+07	.30000E+08	.168750E+04	.250000E-03	.675000E+07

PHOTON PRODUCTION MATRIX FOR NUCLIDE (OR MIXTURE) 1

	GROUP 1	GROUP 2
1	5.87688E-07	0.
2	5.02468E-03	0.
3	1.57774E-01	5.71000E-03

PHOTON PRODUCTION MATRIX FOR NUCLIDE (OR MIXTURE) 2

	GROUP 1	GROUP 2
1	5.87688E-07	0.
2	5.02468E-03	0.
3	1.57774E-01	5.71000E-03

PHOTON ENERGY PRODUCTION MATRIX FOR NUCLIDE (OR MIXTURE) 1

	GROUP 1	GROUP 2
1	4.18728E+00	0.
2	2.30674E+04	0.
3	2.41352E+05	7.10994E+03

PHOTON ENERGY PRODUCTION MATRIX FOR NUCLIDE (OR MIXTURE) 2

	GROUP 1	GROUP 2
1	4.18728E+00	0.
2	2.30674E+04	0.
3	2.41352E+05	7.10994E+03

APPENDIX B

CODE ABSTRACT

1. NAME OF CODE

LAPHANO: A P_0 Multigroup Photon Production Matrix and Source Vector Code for ENDF Data. (This code replaces the LAPH code.[1])

AUXILIARY ROUTINES

Data should be preprocessed with the CHECKER code[2] and the VIXEN code[3] to eliminate errors in format syntax and physical consistency.

2. CONTRIBUTOR

University of California
Los Alamos Scientific Laboratory
Theoretical Division
Post Office Box 1663
Los Alamos, New Mexico 87544

3. CODING LANGUAGE AND COMPUTER

FORTRAN IV; CDC 6600 and CDC 7600. (IBM 360 and UNIVAC 1108 versions are also available.)

4. NATURE OF PROBLEM SOLVED

LAPHANO retrieves photon production cross sections or multiplicities and corresponding neutron interaction cross sections from the ENDF data file, applies suitable weighting functions over G specified photon groups and N specified neutron broad groups, and constructs a G x N photon production matrix (microscopic and/or macroscopic). As an option, it operates on this matrix with flux vectors from a neutronics code, as well as with scalar multipliers such as atom number densities and effective photon group energies, to directly provide spatially dependent photon source vectors (number or energy) for transport calculations. Multiple zones can be accommodated, with separate cross-section weighting functions for each zone. Input is in the DTF-IV format and source vector output is also in this format, allowing direct coupling to DTF-IV. Complete freedom is allowed to pick those materials and reaction types for which photon production matrices are desired.

5. METHOD OF SOLUTION

LAPHANO first constructs photon production cross sections, pointwise in neutron and photon energy, from the ENDF data. These cross sections are then integrated over photon energy groups with either constant or direct energy weighting. After integrating over neutron energy in all neutron fine groups, weighting in neutron broad groups is by input fine-group weighting functions, usually the scalar fluxes from a fine-group neutronics calculation. Macroscopic photon production matrices and photon energy production matrices are then computed by scalar multiplication. Photon source vectors are computed by operating on these matrices with spatially dependent neutron flux vectors.

6. RESTRICTIONS OR LIMITATIONS

The microscopic pointwise data must be in ENDF format. The code is presently restricted to 99 fine or broad groups, 49 photon groups, and 50 mixture specifications.

7. TYPICAL RUNNING TIME

The central processor time on the CDC 6600 for a sample problem to produce a microscopic matrix for one material (oxygen) using 18 photon groups and 22 neutron fine and broad groups is approximately one minute. The same problem on the CDC 7600 executes in approximately 18 seconds.

8. COMPUTER HARDWARE REQUIREMENTS

(a) CDC 6600 and 7600: 65 k_{10} words of memory; (b) one magnetic tape--the ENDF data tape is designated as Tape 20. All other tapes are virtual tapes on disk, extended core storage, or other peripheral storage device.

9. COMPUTER SOFTWARE REQUIREMENTS

The code runs under the CDC SCOPE 3.1.2 System (locally modified) for the CDC 6600 and under the LASL CROS System for the CDC 7600.

10. CONTENTS OF CODE PACKAGE

The package contains the following items:

a. the code user's manual

b. a reel of magnetic tape with the following files:
   (1) a card-image copy of the BCD source deck
   (2) the sample problem input in BCD card image
   (3) the sample problem output
   (4) an INDEX (cross reference) listing of the source deck.

c. a reel of magnetic tape with the ENDF data for the sample problem.

11. HOW TO OBTAIN PACKAGE

Inquiries or requests for the code package may be mailed to:

CODES COORDINATOR
Radiation Shielding Information Center
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37830,

or telephoned to:

Area Code 615, 485-8611, Extension 3-6944,

or

FTS 615-483-6944.

Persons requesting the package should send two reels of magnetic tape to the above address.

12. REFERENCES

(1) DONALD J. DUDZIAK, ALAN H. MARSHALL, and ROBERT E. SEAMON, "LAPH: A Multigroup Photon Production Matrix and Source Vector Code for ENDF/B," LA-4337 (ENDF-132), Los Alamos Scientific Laboratory (1969).

(2) HENRY C. HONECK, "Retrieval Subroutines for the ENDF/B System," BNL (ENDF-110), Brookhaven National Laboratory (1967). (Revised CHECKER code by Oak Ridge National Laboratory, 1970)

(3) DONALD J. DUDZIAK and JOHNNY M. ROMERO, "VIXEN: a Code to Check Physical Consistency of Photon-Production Data in Revised ENDF Format," LA-4739 (ENDF-155), Los Alamos Scientific Laboratory (1971).