LA-CP-03-0245

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Title: **MCNP — A General Monte Carlo N-Particle Transport Code, Version 5**

Volume II: User's Guide

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April 24, 2003 (Revised 10/3/05, 2/1/2008)

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FOREWORD

This manual is a practical guide for the use of the general-purpose Monte Carlo code MCNP. The previous version of the manual (LA-13709-M, March 2000) has been corrected and updated to include the new features found in MCNP Version 5 (MCNP5). The manual has also been split into 3 volumes:

Volume I:	MCNP Overview and Theory	Chapters 1, 2 and Appendices G, H
Volume II:	MCNP User's Guide	Chapters 1, 3, 4, 5 and Appendices A, B, I, J, K
Volume III:	MCNP Developer's Guide	Appendices C, D, E, F

Volume I (LA-UR-03-1987) provides an overview of the capabilities of MCNP5 and a detailed discussion of the theoretical basis for the code. The first chapter provides introductory information about MCNP5. The second chapter describes the mathematics, data, physics, and Monte Carlo simulation techniques which form the basis for MCNP5. This discussion is not meant to be exhaustive — details of some techniques and of the Monte Carlo method itself are covered by references to the literature.

Volume II (LA-CP-03-0245) provides detailed specifications for MCNP5 input and options, numerous example problems, and a discussion of the output generated by MCNP5. The first chapter is a primer on basic MCNP5 use. The third chapter shows the user how to prepare input for the code. The fourth chapter contains several examples, and the fifth chapter explains the output. The appendices provide information on the available data libraries for MCNP, the format for several input/output files, and plotting the geometry, tallies, and cross-sections.

Volume III (LA-CP-03-0284) provides details on how to install MCNP on various computer systems, how to modify the code, the meaning of some of the code variables, and data layouts for certain arrays.

The Monte Carlo method for solving transport problems emerged from work done at Los Alamos during World War II. The method is generally attributed to Fermi, von Neumann, Ulam, Metropolis, and Richtmyer. MCNP, first released in 1977, is the successor to their work and has been under continuous development for the past 25 years. Neither the code nor the manual is static. The code is changed as needs arise, and the manual is changed to reflect the latest version of the code. This particular manual refers to Version 5.

MCNP5 and this manual are the product of the combined effort of many people in the Monte Carlo Codes (X-3-MCC, formerly part of the X-5 group) section in the Applied Physics Division (X Division) at the Los Alamos National Laboratory:

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MCNP – A General Monte Carlo N-Particle Transport Code
Version 5

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ABSTRACT

MCNP is a general-purpose Monte Carlo N–Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori.

Pointwise cross-section data are used. For neutrons, all reactions given in a particular cross-section evaluation (such as ENDF/B-VI) are accounted for. Thermal neutrons are described by both the free gas and S(α,β) models. For photons, the code accounts for incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, and absorption in electron-positron pair production. Electron/positron transport processes account for angular deflection through multiple Coulomb scattering, collisional energy loss with optional straggling, and the production of secondary particles including K x-rays, knock-on and Auger electrons, bremsstrahlung, and annihilation gamma rays from positron annihilation at rest. Electron transport does not include the effects of external or self-induced electromagnetic fields. Photonuclear physics is available for a limited number of isotopes.

Important standard features that make MCNP very versatile and easy to use include a powerful general source, criticality source, and surface source; both geometry and output tally plotters; a rich collection of variance reduction techniques; a flexible tally structure; and an extensive collection of cross-section data.

Volume I: Overview and Theory

Volume II: User's Guide

Volume III: Developer's Guide

CHAPTER 1 - PRIMER

WHAT IS COVERED IN CHAPTER 1

Description of MCNP data input illustrated by a sample problem
How to run MCNP
Tips on problem setup

Chapter 1 provides a general description of an input deck followed by a sample problem and a brief introductory description of the input cards used in the sample problem. Section II tells how to run MCNP, and Section III lists tips for setting up correct problems and running them efficiently. The word "card" is used throughout this document to describe a single line of input up to 80 characters.

I. MCNP INPUT FOR SAMPLE PROBLEM

The main input file for the user is the INP (the default name) file that contains the input information to describe the problem. We will present here only the subset of cards required to run the simple fixed source demonstration problem. All input cards are discussed in Chapter 3 and summarized in Table 3.9 starting on page 3–155.

MCNP does extensive input checking but is not foolproof. A geometry should be checked by looking at several different views with the geometry plotting option. You should also surround the entire geometry with a sphere and flood the geometry with particles from a source with an inward cosine distribution on the spherical surface, using a VOID card to remove all materials specified in the problem. If there are any incorrectly specified places in your geometry, this procedure will usually find them. Make sure the importance of the cell just inside the source sphere is not zero. Then run a short job and study the output to see if you are calculating what you think you are calculating.

The basic constants used in MCNP are printed in optional print table 98 in the output file. The units used are:

1. lengths in centimeters,
2. energies in MeV,
3. times in shakes (10^{-8} sec),
4. temperatures in MeV (kT),
5. atomic densities in units of atoms/barn-cm,
6. mass densities in g/cm^3,
7. cross sections in barns (10^{-24} cm^2),
8. heating numbers in MeV/collision, and
9. atomic weight ratio based on a neutron mass of 1.008664967 amu. In these units, Avogadro's number is 0.59703109 x 10^{+24}.

A simple sample problem illustrated in Figure 1-1 is referred to throughout the remainder of this chapter. We wish to start 14-MeV neutrons at a point isotropic source in the center of a small sphere of oxygen that is embedded in a cube of carbon. A small sphere of iron is also embedded in the carbon. The carbon is a cube 10 cm on each side; the spheres have a 0.5-cm radius and are centered between the front and back faces of the cube. We wish to calculate the total and energy-dependent flux in increments of 1 MeV from 1 to 14 MeV, where bin 1 will be the tally from 0 to 1 MeV

1. on the surface of the iron sphere, and
2. averaged in the iron sphere volume.

This geometry has four cells, indicated by circled numbers, and eight surfaces—six planes and two spheres. Surface numbers are written next to the appropriate surfaces. Surface 5 comes out from the page in the $+x$ direction and surface 6 goes back into the page in the $-x$ direction.

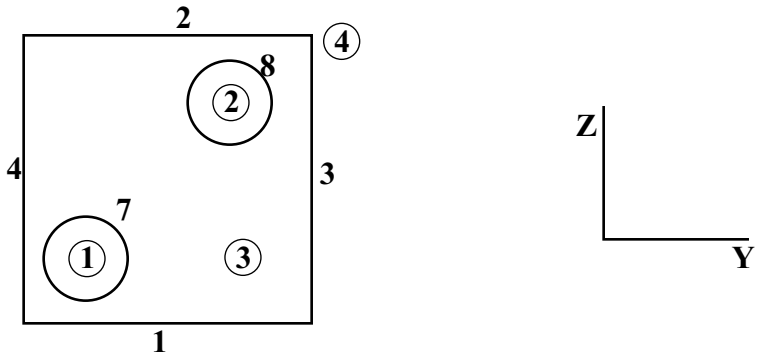

Figure 1-1.

With knowledge of the cell card format, the sense of a surface, and the union and intersection operators, we can set up the cell cards for the geometry of our example problem. To simplify this step, assume the cells are void, for now. Cells 1 and 2 are described by the following cards:

```
1   0   –7
2   0   –8
```

where the negative signs denote the regions inside (negative sense) surfaces 7 and 8. Cell 3 is everything in the universe above surface 1 intersected with everything below surface 2, intersected with everything to the left of surface 3, and so forth for the remaining three surfaces. The region in common to all six surfaces is the cube, but we need to exclude the two spheres by intersecting everything outside surface 7 and outside surface 8. The card for cell 3 is

```
3   0    1 –2 –3 4 –5 6 7 8
```

Cell 4 requires the use of the union operator. Cell 4 is the outside world, has zero importance, and is defined as everything in the universe below surface 1, plus everything above surface 2, plus everything to the right of surface 3, and so forth. The cell card for cell 4 is

```
4   0   –1 : 2 : 3 : –4 : 5 : –6
```

A. INP File

An input file has the following form:

Message Block } Optional
Blank Line Delimiter } Optional
One-line Problem Title Card
Cell Cards
•
•
Blank Line Delimiter
Surface Cards
•
•
Blank Line Delimiter
Data Cards
•
•
Blank Line Terminator (optional)

All input lines are limited to 80 columns. Alphabetic characters can be upper, lower, or mixed case. Unprintable characters found in an input line are converted to blank spaces. A $ (dollar sign) terminates data entry on a line. Anything on the line that follows the $ is interpreted as a comment. Blank lines are used as delimiters and as an optional terminator. Data entries are separated by one or more blanks.

Tab characters in the input file are converted to one or more blanks, such that the character following the tab will be positioned at the next tab stop. Tab stops are set every 8 characters, i.e., 9, 17, 25, etc. The limit of input lines to 80 columns applies after tabs are expanded into blank spaces.

Comment cards can be used anywhere in the INP file after the problem title card and before the optional blank terminator card. Comment lines must have a C somewhere in columns 1-5 followed by at least one blank and can be a total of 80 columns long.

Cell, surface, and data cards must all begin within the first five columns. Entries are separated by one or more blanks. Numbers can be integer or floating point. MCNP makes the appropriate conversion. A few entries on some cards are allowed to be 8 byte integers, i.e., integers larger than 2.147 billion but less than ~1E19. These entries are noted in their respective card description in Chapter 3. A data entry item, e.g., IMP:N or 1.1e2, must be completed on one line.

Blanks filling the first five columns indicate a continuation of the data from the last named card. An & (ampersand) ending a line indicates data will continue on the following card, where data on the continuation card can be in columns 1-80.

The optional message block, discussed in detail on page 3–1, is used to change file names and specify running options such as a continuation run. On most systems these options and files may alternatively be specified with an execution line message (see page 1–12). Message block entries supersede execution line entries. The blank line delimiter signals the end of the message block.

The first card in the file after the optional message block is the required problem title card. If there is no message block, this must be the first card in the INP file. It is limited to one 80-column line and is used as a title in various places in the MCNP output. It can contain any information you desire but usually contains information describing the particular problem.

MCNP makes extensive checks of the input file for user errors. A FATAL error occurs if a basic constraint of the input specification is violated, and MCNP will terminate before running any particles. The first fatal error is real; subsequent error messages may or may not be real because of the nature of the first fatal message.

B. Cell Cards

The cell number is the first entry and must begin in the first five columns.

The next entry is the cell material number, which is arbitrarily assigned by the user. The material is described on a material card (Mn) that has the same material number (see page 1–9). If the cell is a void, a zero is entered for the material number. The cell and material numbers cannot exceed 5 digits each.

Next is the cell material density. A positive entry is interpreted as atom density in units of 10^{24} atoms/cm^3. A negative entry is interpreted as mass density in units of g/cm^3. No density is entered for a void cell.

A complete specification of the geometry of the cell follows. This specification includes a list of the signed surfaces bounding the cell where the sign denotes the sense of the regions defined by the surfaces. The regions are combined with the Boolean intersection and union operators. A space indicates an intersection and a colon indicates a union.

Optionally, after the geometry description, cell parameters can be entered. The form is keyword=value. The following line illustrates the cell card format:

```
1    1    –0.0014    –7    IMP:N=1
```

Cell 1 contains material 1 with density 0.0014 g/cm^3, is bounded by only one surface (7), and has an importance of 1. If cell 1 were a void, the cell card would be

```
1    0    –7    IMP:N=1
```

The complete cell card input for this problem (with 2 comment cards) is

```
c  cell cards for sample problem
```

```
1   1  –0.0014   –7
2   2  –7.86     –8
3   3   –1.60   1 –2 –3  4 –5  6  7  8
4   0            –1:2:3:–4:5:–6
c  end of cell cards for sample problem
blank line delimiter
```

The blank line terminates the cell card section of the INP file. It is strongly suggested that the cells be numbered sequentially starting with one. A complete explanation of the cell card input is found in Chapter 3, page 3–9.

C. Surface Cards

The surface number is the first entry. It must begin in columns 1-5 and not exceed 5 digits. The next entry is an alphabetic mnemonic indicating the surface type. Following the surface mnemonic are the numerical coefficients of the equation of the surface in the proper order. This simplified description enables us to proceed with the sample problem. For a full description of the surface card see page 3–11.

Our problem uses planes normal to the *x*, *y*, and *z* axes and two general spheres. The respective mnemonics are PX, PY, PZ, and S. Table 1.1 shows the equations that determine the sense of the surface for the cell cards and the entries required for the surface cards. A complete list of available surface equations is contained in Table 3.1 on page 3–13.

Table 1.1
Surface Equations

Mnemonic	Equation	Card Entries
PX	x - D = 0	D
PY	y - D = 0	D
PZ	x - D = 0	D
S	$(x-\bar{x})^2+(x-\bar{y})^2+(z-\bar{z})^2-R^2 = 0$	$\bar{x}\,\bar{y}\,\bar{z}\,R$

For the planes, D is the point where the plane intersects the axis. If we place the origin in the center of the 10-cm cube shown in Figure 1-1, the planes will be at $x = -5$, $x = 5$, etc. The two spheres are not centered at the origin or on an axis, so we must give the *x*,*y*,*z* of their center as well as their radii. The complete surface card input for this problem is shown below. A blank line terminates the surface card portion of the input.

```
C  Beginning of surfaces for cube
   1  PZ    –5
   2  PZ     5
   3  PY     5
   4  PY    –5
```

```
     5   PX      5
     6   PX      –5
C    End of cube surfaces
     7    S  0    -4    -2.5     .5  $ oxygen sphere
     8    S  0     4     4       .5  $ iron sphere
     blank line delimiter
```

D. Data Cards

The remaining data input for MCNP follows the second blank card delimiter, or third blank card if there is a message block. The card name is the first entry and must begin in the first five columns. The required entries follow, separated by one or more blanks.

Several of the data cards require a particle designator to distinguish between input data for neutrons, data for photons, and data for electrons. The particle designator consists of the symbol : (colon) and the letter N or P or E immediately following the name of the card. For example, to enter neutron importances, use an IMP:N card; enter photon importances on an IMP:P card; enter electron importances on an IMP:E card. No data card can be used more than once with the same mnemonic, that is, M1 and M2 are acceptable, but two M1 cards are not allowed. Defaults have been set for cards in some categories. A summary starting on page 3–161 shows which cards are required, which are optional, and whether defaults exist and if so, what they are. The sample problem will use cards in the following categories:

	MCNP card name
1. mode,	MODE
2. cell and surface parameters,	IMP:N
3. source specification,	SDEF
4. tally specification,	Fn, En
5. material specification, and	Mn
6. problem cutoffs.	NPS

A complete description of the data cards is found on page 3–23 in Chapter 3.

1. MODE Card

MCNP can be run in several different modes:

MODE	N	— neutron transport only (default)
	N P	— neutron and neutron-induced photon transport
	P	— photon transport only
	E	— electron transport only
	P E	— photon and electron transport
	N P E	— neutron, neutron-induced photon, and electron transport

The MODE card consists of the mnemonic MODE followed by the choices shown above. If the MODE card is omitted, mode N is assumed.

MODE N P does not account for photo-neutrons but only neutron-induced photons. Photon-production cross sections do not exist for all nuclides. If they are not available for a MODE N P problem, MCNP will print out warning messages. To find out whether a particular table for a nuclide has photon-production cross sections available, check the Appendix G cross-section list.

MODE P or MODE N P problems generate bremsstrahlung photons with a computationally expensive thick-target bremsstrahlung approximation. This approximation can be turned off with the PHYS:E card.

The sample problem is a neutron-only problem, so the MODE card can be omitted because MODE N is the default.

2. Cell and Surface Parameter Cards

Most of these cards define values of cell parameters. Entries correspond in order to the cell or surface cards that appear earlier in the INP file. A listing of all available cell and surface parameter cards is found on page 3–33. A few examples are neutron and photon importance cards (IMP:N,IMP:P), weight window cards (WWE:N, WWE:P, WWNi:N, WWNi:P), etc. Some method of specifying relative cell importances is required; the majority of the other cell parameter cards are for optional variance reduction techniques. The number of entries on a cell or surface parameter card must equal the number of cells or surfaces in the problem or MCNP prints out a WARNING or FATAL error message. In the case of a WARNING, MCNP assumes zeros.

The IMP:N card is used to specify relative cell importances in the sample problem. There are four cells in the problem, so the IMP:N card will have four entries. The IMP:N card is used (a) for terminating the particle's history if the importance is zero and (b) for geometry splitting and Russian roulette to help particles move more easily to important regions of the geometry. An IMP:N card for the sample problem is

```
IMP:N  1  1  1  0
```

Cell parameters also can be defined on cell cards using the keyword=value format. If a cell parameter is specified on **any** cell card, it must be specified **only** on cell cards and **not at all** in the data card section.

3. Source Specification Cards

A source definition card SDEF is one of four available methods of defining starting particles. Chapter 3 has a complete discussion of source specification. The SDEF card defines the basic source parameters, some of which are

POS = x y z	default is 0 0 0;
CEL = starting cell number	
ERG = starting energy	default is 14 MeV;
WGT = starting weight	default is 1;
TME = time	default is 0;
PAR = source particle type	1 for N, N P, N P E; 2 for P, P E; 3 for E.

MCNP will determine the starting cell number for a point isotropic source, so the CEL entry is not always required. The default starting direction for source particles is isotropic.

For the example problem, a fully specified source card is

SDEF POS = 0 –4 –2.5 CEL = 1 ERG = 14 WGT = 1 TME = 0 PAR = 1

Neutron particles will start at the center of the oxygen sphere (0 –4 –2.5), in cell 1, with an energy of 14 MeV, and with weight 1 at time 0. All these source parameters except the starting position are the default values, so the most concise source card is

SDEF POS = 0 –4 –2.5

If all the default conditions applied to the problem, only the mnemonic SDEF would be required.

4. Tally Specification Cards

The tally cards are used to specify what you want to learn from the Monte Carlo calculation, perhaps current across a surface, flux at a point, etc. You request this information with one or more tally cards. Tally specification cards are not required, but if none is supplied, no tallies will be printed when the problem is run and a warning message is issued. Many of the tally specification cards describe tally "bins." A few examples are energy (En), time (Tn), and cosine (Cn) cards.

MCNP provides six standard neutron, six standard photon, and four standard electron tallies, all normalized to be per starting particle. Some tallies in criticality calculations are normalized differently. Chapter 2, page 2–80, discusses tallies more completely, and Chapter 3, page 3–80, lists all the tally cards and fully describes each one.

Tally Mnemonic	**Description**
F1:N or F1:P or F1:E	Surface current
F2:N or F2:P or F2:E	Surface flux
F4:N or F4:P or F4:E	Track length estimate of cell flux
F5a:N or F5a:P	Flux at a point (point detector)
F6:N or F6:P or F6:N,P	Track length estimate of energy deposition
F7:N	Track length estimate of fission energy deposition
F8:P or F8:E or F8:P,E	Energy distribution of pulses created in a detector

The tallies are identified by tally type and particle type. Tallies are given the numbers 1, 2, 4, 5, 6, 7, 8, or increments of 10 thereof, and are given the particle designator :N or :P or :E (or :N,P only in the case of tally type 6 or P,E only for tally type 8). Thus you may have as many of any basic tally as you need, each with different energy bins or flagging or anything else. F4:N, F14:N, F104:N, and F234:N are all legitimate neutron cell flux tallies; they could all be for the same cell(s) but with different energy or multiplier bins, for example. Similarly F5:P, F15:P, and F305:P are all photon point detector tallies. Having both an F1:N card and an F1:P card in the same INP file is not allowed. The tally number may not exceed three digits.

For our sample problem we will use Fn cards (Tally type) and En cards (Tally energy).

a. Tally (Fn) Cards: The sample problem has a surface flux tally and a track length cell flux tally. Thus, the tally cards for the sample problem shown in Figure 1-1 are

```
F2:N    8    $  flux across surface 8
F4:N    2    $  track length in cell 2
```

Printed out with each tally bin is the relative error of the tally corresponding to one estimated standard deviation. Results are not reliable until they become stable as a function of the number of histories run. Much information is provided for one bin of each tally in the tally fluctuation charts at the end of the output file to help determine tally stability. The user is strongly encouraged to look at this information carefully.

b. Tally Energy (En) Card: We wish to calculate flux in increments of 1 MeV from 14 to 1 MeV. Another tally specification card in the sample input deck establishes these energy bins.

The entries on the En card are the upper bounds in MeV of the energy bins for tally n. The entries must be given in order of increasing magnitude. If a particle has an energy greater than the last entry, it will not be tallied, and a warning is issued. MCNP automatically provides the total over all specified energy bins unless inhibited by putting the symbol NT as the last entry on the selected En card.

The following cards will create energy bins for the sample problem:

```
E2      1  2  3  4  5  6  7  8  9  10  11  12  13  14
E4      1  12I  14
```

If no En card exists for tally n, a single bin over all energy will be used. To change this default, an E0 (zero) card can be used to set up a default energy bin structure for all tallies. A specific En card will override the default structure for tally n. We could replace the E2 and E4 cards with one E0 card for the sample problem, thus setting up identical bins for both tallies.

5. Materials Specification

The cards in this section specify both the isotopic composition of the materials and the cross-section evaluations to be used in the cells. For a comprehensive discussion of materials specification, see page 3–121.

a. Material (Mm) Card: The following card is used to specify a material for all cells containing material m, where m cannot exceed 5 digits:

Mm $ZAID_1$ $fraction_1$ $ZAID_2$ $fraction_2$ ...

The m on a material card corresponds to the material number on the cell card (see page 1–4). The consecutive pairs of entries on the material card consist of the identification number (ZAID) of the constituent element or nuclide followed by the atomic fraction (or weight fraction if entered as a

negative number) of that element or nuclide, until all the elements and nuclides needed to define the material have been listed.

(1) Nuclide Identification Number (ZAID). This number is used to identify the element or nuclide desired. The form of the number is ZZZAAA.nnX, where

ZZZ	is the atomic number of the element or nuclide,
AAA	is the mass number of the nuclide, ignored for photons and electrons,
nn	is the cross-section evaluation identifier; if blank or zero, a default cross-section evaluation will be used, and
X	is the class of data: C is continuous energy; D is discrete reaction;
T	is thermal; Y is dosimetry; P is photon; E is electron; and
M	is multigroup.

For naturally occurring elements, AAA=000. Thus ZAID=74182 represents the isotope $^{182}_{74}$W, and ZAID=74000 represents the element tungsten.

(2) Nuclide Fraction. The nuclide fractions may be normalized to 1 or left unnormalized. For example, if the material is H_2O, the fractions can be entered as .667 and .333, or as 2 and 1 for H and O respectively. If the fractions are entered with negative signs, they are weight fractions; otherwise they are atomic fractions. Weight fractions and atomic fractions cannot be mixed on the same Mm card.

The material cards for the sample problem are

```
M1      8016    1     $ oxygen 16
M2      26000   1     $ natural iron
M3      6000    1     $ carbon
```

b. VOID Card: The VOID card removes all materials and cross sections in a problem and sets all nonzero importances to unity. It is very effective for finding errors in the geometry description because many particles can be run in a short time. Flooding the geometry with many particles increases the chance of particles going to most parts of the geometry—in particular, to an incorrectly specified part of the geometry—and getting lost. The history of a lost particle often helps locate the geometry error. The other actions of and uses for the VOID card are discussed on page 3–128.

The sample input deck could have a VOID card while testing the geometry for errors. When you are satisfied that the geometry is error-free, remove the VOID card.

6. Problem Cutoffs

Problem cutoff cards are used to specify parameters for some of the ways to terminate execution of MCNP. The full list of available cards and a complete discussion of problem cutoffs is found on page 3–139. For our problem we will use only the history cutoff (NPS) card. The mnemonic NPS is followed by a single entry that specifies the number of histories to transport. MCNP will terminate after NPS histories unless it has terminated earlier for some other reason.

7. Sample Problem Summary

The entire input deck for the sample problem follows. Recall that the input can be upper, lower, or mixed case.

```
Sample Problem Input Deck
c      cell cards for sample problem
1      1 -0.0014   -7
2      2 -7.86     -8
3      3 -1.60      1 -2 -3 4 -5 6 7 8
4      0           -1:2:3:-4:5:-6
c      end of cell cards for sample problem
                [blank line delimiter]
C      Beginning of surfaces for cube
1      PZ  -5
2      PZ   5
3      PY   5
4      PY  -5
5      PX   5
6      PX  -5
C      End of cube surfaces
7      S  0  -4  -2.5  .5  $  oxygen sphere
8      S  0   4   4.5  .5  $  iron sphere
                [blank line delimiter]
IMP:N  1  1  1  0
SDEF POS=0 -4 -2.5
F2:N   8        $  flux across surface 8
F4:N   2        $  track length in cell 2
E0     1  12I  14
M1     8016   1 $  oxygen 16
M2     26000  1 $  natural iron
M3     6000   1 $  carbon
NPS    100000
                [blank line delimiter   (optional)]
```

II. HOW TO RUN MCNP

This section assumes a basic knowledge of UNIX. Lines the user will type are shown in `lower case typewriter style` type. Press the ENTER key after each input line. MCNP is the executable binary file and **xsdir** is the cross-section directory. If **xsdir** is not in your current directory, you may need to set the DATAPATH environmental variable. The csh syntax for this is

```
setenv DATAPATH /ab/cd
```

where `/ab/cd` is the directory containing both **xsdir** and the data libraries.

A. Execution Line

The MCNP execution line has the following form:

```
mcnp5 Files Options
```

Files and *Options* are described below. Their order on the execution line is irrelevant. If there are no changes in default file names and options, nothing needs to be entered for *Files* and *Options*.

1. Files

MCNP uses several files for input and output. The file names can include full paths to the files (e.g., `/mydir/problem-x/jobs/problem_1a.inp`), but cannot be longer than 256 characters. The files pertinent to the sample problem are shown in Table 1.2. File INP must be present as a local file. MCNP will create OUTP and RUNTPE.

Table 1.2
MCNP Files

Default File Name	Description
INP	Problem input specification
OUTP	BCD output for printing
RUNTPE	Binary start-restart data
XSDIR	Cross-section directory

The default name of any of the files in Table 1.2 can be changed on the MCNP execution line by entering

```
default_file_name=newname
```

For example, if you have an input file called MCIN and want the output file to be MCOUT and the runtpe to be MCRUNTPE, the execution line is

```
mcnp5 inp=mcin outp=mcout runtpe=mcruntpe
```

Only enough letters of the default name are required to uniquely identify it. For example,

```
mcnp5 i=mcin o=mcout ru=mcrntpe
```

also works. If a file in your local file space has the same name as a file MCNP needs to create, the file is created with a different unique name by changing the last letter of the name of the new file to the next letter in the alphabet. For example, if you already have an OUTP, MCNP will create OUTQ. However, if the file includes an extension, such as "`.txt`" or "`.inp`", the last character before the extension will be checked and changed if necessary.

Sometimes it is useful for all files from one run to have similar names. If your input file is called JOB1, the following line

```
mcnp5 name=job1
```

will create an OUTP file called JOB1O and a RUNTPE file called JOB1R. If these files already exist, MCNP will NOT overwrite them or modify the last letter, but will issue a message that JOB1O already exists and then will terminate.

2. Options

There are two kinds of options: program module execution options and other options. Execution options are discussed next.

MCNP consists of five distinct execution operations, each given a module name. These operations, their corresponding module names, and a one-letter mnemonic for each operation are listed in Table 1.3.

Table 1.3
Execution Options

Mnemonic	Module	Operation
i	IMCN	Process problem input file
p	PLOT	Plot geometry
x	XACT	Process cross sections
r	MCRUN	Particle transport
z	MCPLOT	Plot tally results or cross section data

When *Options* are omitted, the default is **ixr**. The execution of the modules is controlled by entering the proper mnemonic on the execution line. If more than one operation is desired, combine the single characters (in any order) to form a string. Examples of use are as follows: **i** to look for input errors, **ip** to debug a geometry by plotting, **ixz** to plot cross-section data, and **z** to plot tally results from the RUNTPE or MCTAL files.

After a job has been run, the print file OUTP can be examined with an editor on the computer and/or sent to a printer. Numerous messages about the problem execution and statistical quality of the results are displayed at the terminal. These are repeated in the OUTP file.

The "other" options add more flexibility when running MCNP and are shown in Table 1.4.

Table 1.4
Other Options

Mnemonic	Operation
C m	Continues a run starting with m^{th} dump. If *m* is omitted, the last dump is used. See page 3–2.
CN	Like C, but dumps are written immediately after the fixed part of the RUNTPE, rather than at the end. See page 3–2.
DBUG n	Writes debug information every *n* particles. See DBCN card, page 3–146.
NOTEK	Indicates that your terminal has no graphics capability. PLOT output is in PLOTM.PS. Equivalent to TERM=0. See Appendix B for details.
FATAL	Transports particles and calculates volumes even if fatal errors are found.

Table 1.4
Other Options

PRINT	Creates the full output file; equivalent to PRINT card. See page 3–149.
TASKS n	Invokes OpenMP threading on shared memory systems. n=number of threads to be used. May be used in conjunction with MPI on a hybrid system.
BALANCE	Provides load balancing when used with MPI.
EOL	Add after all other MCNP keywords to distinguish MCNP keywords from directives added by MPICH. Only needed if the MPICH implementation of MPI is used.

MCNP may be compiled for either MPI or PVM and then executed in the same fashion as other parallel programs on a given system. The parallel operation is a master-slave algorithm with one master process accumulating total statistics and a group of slave processes tracking particles. When shared memory processors are used, MCNP may also be compiled for OpenMP threading, either independently or in combination with MPI or PVM. To use MCNP with PVM, see Appendix C, Execution in Parallel Modes, on page C–31. Under PVM, the tasks option is used to spawn both subtasks and threads.

Generally, the MPI execution line will look like this example from an SGI Origin 2000 system:

```
mpirun  -np <m> mcnp5.mpi  i=input ...
```

where <m> is the total number of MPI processes, including the master, and <m>-1 slave processes will track the particles. On other systems, the syntax of the MPI command may differ. Note that the minimum number of slaves accepted by MCNP is two, so at least three MPI processes must be initiated. That is, <m> can equal 1 or be greater than or equal to 3.

If MCNP is compiled with OpenMP on a multiprocessor SMP machine, then it is possible to optionally thread each slave by setting the TASKS option

```
mpirun –np <m> mcnp5.mpi i=input   tasks <n>
```

making (m-1) x n processors available to track particles. The syntax required to allocate enough resources for the threading varies by system. For instance, on alpha Tru64 System 5.1 you would use

```
prun –n <m> -c <n> mcnp5.mpi i=input  tasks <n>
```

to reserve <n> processors for each of <m> MPI processes.

An MCNP executable built with combined MPI and OpenMP options can be utilized as follows: sequentially, all MPI, threads only, or hybrid. To perform the combined executable in sequential or threads-only mode (for example, in early testing of a problem or plotting geometry), the system will likely require `mpirun -np 1`.

The simplest parallel run would be to build one shared memory node and run OpenMP threading. Then, use build option “omp” and execute with just the TASKS option on the command line:

```
mcnp5 i=input  tasks <n>
```

B. Interrupts

For non-MPI versions, MCNP allows four interactive interrupts while it is running:

`(ctrl c)<cr>` (default)	MCNP status
`(ctrl c)s`	MCNP status
`(ctrl c)m`	Make interactive plots of tallies
`(ctrl c)q`	Terminate MCNP normally after current history
`(ctrl c)k`	Kill MCNP immediately

The `(ctrl c)s` interrupt prints the computer time used so far, the number of particles run so far, and the number of collisions. In the IMCN module, it prints the input line being processed. In the XACT module, it prints the cross section being processed.

The `(ctrl c)q` interrupt has no effect until MCRUN is executed. `(Ctrl c)q` causes the code to stop after the current particle history, to terminate "gracefully," and to produce a final print output file and RUNTPE file.

The `(ctrl c)k` interrupt kills MCNP immediately, without normal termination. If `(ctrl c)k` fails, enter `(ctrl c)` three or more times in a row.

On some computer systems (e.g., SGI), MPI versions, even when run sequentially, do not allow the interactive interrupts because the MPI daemon catches the signal and aborts the MCNP run.

C. Running MCNP

To run the example problem, have the input file in your current directory. For illustration, assume the file is called SAMPLE. Type

```
mcnp5   n=sample
```

where `n` is an abbreviation for NAME. MCNP will produce an output file SAMPLEO that you can examine at your terminal, send to a printer, or both. To look at the geometry with the PLOT module using an interactive graphics terminal, type in

```
mcnp5   ip   n=sample
```

After the plot window appears, click anywhere in the picture to get the default plot. This plot will show an intersection of the surfaces of the problem by the plane $X = 0$ with an extent in the x-direction of 100 cm on either side of the origin. If you want to do more with PLOT, see the instructions on page B–1. Otherwise click "end" to terminate the session.

III. TIPS FOR CORRECT AND EFFICIENT PROBLEMS

This section has a brief checklist of helpful hints that apply to three phases of your calculation: defining and setting up the problem, preparing for the long computer runs that you may require, and making the runs that will give you results. Not everything mentioned in the checklist has been covered in this chapter, but the list can serve as a springboard for further reading in preparation for tackling more difficult problems.

A. Problem Setup

1. **Always plot the geometry to see if it is correctly defined and what was intended**.
2. Model the geometry and source distribution in enough detail as needed for accuracy.
3. Use simple cells.
4. Use the simplest surfaces.
5. Do not set up all geometry at once
6. Know and compare calculated mass and volumes/surf areas.
7. Use the VOID card when checking geometry.
8. Look at print tables 10, 110, and 170 to check the source.
9. Be aware of physics approximations, problem cutoffs, and default cross-sections.
10. Cross-section sets matter. Check the listing of datasets in the output file.
11. Use separate tallies for the fluctuation chart.
12. Use the most conservative variance reduction techniques.
13. Do not use too many variance reduction techniques.
14. Balance user time with computer time.
15. Study all warning messages.
16. Generate the best output (consider PRINT card).
17. Recheck the INP file (materials, densities, masses, sources, etc.)
18. GARBAGE into code = GARBAGE out of code.

B. Preproduction

1. Do not use MCNP as a “black box” - become familiar with the theory and methods.
2. Run some short jobs.
3. Examine the outputs carefully.
4. Study the summary tables.
5. Study the statistical checks on tally quality and the sources of variance.
6. Compare the figures of merit and variance of the variance.
7. Consider the collisions per source particle.
8. Examine the track populations by cell.
9. Scan the mean free path column.
10. Check detector diagnostic tables.
11. Understand large tally contributions (with event logs).
12. Strive to eliminate unimportant tracks.
13. Check secondary particle production.
14. Do a back-of-the-envelope check of the results.

C. Production

1. Save RUNTPE for expanded output printing, continue run, tally plotting.
2. Look at figure of merit stability.
3. Make sure answers seem reasonable.
4. Examine statistical checks.
5. Form valid confidence intervals.
6. Make continue runs if necessary.
7. See if stable errors decrease by $1/\sqrt{N}$.
8. Remember, accuracy is only as good as the nuclear data, modeling, MCNP sampling approximations, etc.
9. Adequately sample all cells.

D. Criticality

1. Use the MCNP plotter to examine the behavior of k_{eff} and the Shannon entropy of the source distribution with cycle number, to determine how many inactive (settle) cycles are needed.
2. For production runs, use at least 5000 or 10000 neutrons per cycle. More is better.
3. Continue calculations if trends are noticed.
4. Use at least 100 cycles after source convergence.
5. After a production run, use the MCNP plotter again to examine the behavior of k_{eff} and the Shannon entropy of the source distribution with cycle number, to ensure that a sufficient number of inactive cycles was used so that k_{eff} and the source distribution are both properly converged .

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CHAPTER 3 - DESCRIPTION OF MCNP INPUT

Input to MCNP consists of several files, but the main one supplied by the user is the INP (the default name) file, which contains the input information necessary to describe the problem. Only a small subset of all available input cards will be needed in any particular problem. The input cards are summarized by card type on page 3–161 and in Appendix A. The word "card" is used throughout this manual to describe a single line of input up to 80 characters.

Maximum dimensions exist for some MCNP input items; they are summarized on page 3–164. The user can increase any of these maximum values by altering the code and recompiling.

All features of MCNP should be used with caution and knowledge. This is especially true of detectors and variance reduction schemes; you are encouraged to read the appropriate sections of Chapter 2 before using them.

The units used throughout MCNP are given in Chapter 1 on page 1–1.

I. INP FILE

The INP file can have two forms, initiate-run and continue-run. Either can contain an optional message block that replaces or supplements the MCNP execution line information.

A. Message Block

A user has the option to use a message block before the problem identification title card in the INP file. In computer environments where there are no execution line messages, the message block is the only means for giving MCNP an execution message. Less crucially, it is a convenient way to avoid retyping an often-repeated message. The message block starts with the string MESSAGE: and is limited to columns 1−80. Alphabetic characters can be upper, lower, or mixed case. The message block ends with a blank line delimiter before the title card. All cards before the blank line delimiter are continuation cards. A $ and & in the message block are end-of-line markers. The syntax and components of the message are the same as for the regular execution line message discussed on page 1–12. Any filename substitution, program module execution option, or keyword entry on the execution line takes precedence over conflicting information in the message block. INP = *filename* is not a legitimate entry in the message block. The name INP can be changed on the execution line only.

B. Initiate-Run

This form is used to set up a Monte Carlo problem (describe geometry, materials, tallies, etc.) and to run it, using information from either the message block or the execution line. The initiate-run file has the following form:

Message Block	} Optional
Blank Line Delimiter	
Title Card	
Cell Cards	
.	
.	
Blank Line Delimiter	
Surface Cards	
.	
.	
Blank Line Delimiter	
Data Cards	
.	
.	
Blank Line Terminator	Recommended
Anything Else	Optional

The first card in the file after the optional message block is the required problem title card. It is limited to one 80–column line and is used as a title in various places in the MCNP output. It can contain any information the user desires (or can even be blank) and often contains information describing the particular problem. Note that a blank card elsewhere is used as a delimiter or as a terminator. Alphabetic characters can be upper, lower, or mixed case.

With a valid set of data cards, MCNP will run with or without the blank line terminator. With the terminator, MCNP will stop reading the input file there even if additional lines are in the file. Some users like to keep additional material, such as alternative versions of the problem or textual information, associated with the input file itself. The terminator will prevent such additional lines from being read.

C. Continue–Run

Continue-run is used to continue running histories in a problem that was terminated earlier–for example, to run the job 2 hours and then to run it an additional hour later. It can also be used to reconstruct the output of a previous run. A continue-run must contain C or CN in the MCNP execution line or message block to indicate a continue-run. It will start with the last dump unless C m is used to start with the m^{th} dump.

In addition to the C or CN option on the MCNP execution line, two files can be important for this procedure: (1) the restart file (default name RUNTPE), and (2) an optional continue-run input file (default name INP).

The run file, generated by MCNP in the initiate-run sequence, contains the geometry, cross sections, problem parameters, tallies, and all other information necessary to restart the job. In

addition, the problem results at various stages of the run are recorded in a series of dumps. See the PRDMP card (page 3–143) for a discussion of the selection of dump times. As discussed below, the run may be restarted from any of these dumps.

The CN execution message option differs from the C option only in that the dumps produced during the continue-run are written immediately after the fixed data portion of the RUNTPE file rather than after the dump from which the continue-run started. The new dumps overwrite the old dumps, providing a way for the user to prevent unmanageable growth of RUNTPE files. RUNTPE growth also can be controlled by the NDMP entry on the PRDMP card.

The optional continue-run input file must have the word CONTINUE as the first entry on the first line (title card), or after the optional Message Block and its blank line delimiter. Alphabetic characters can be upper, lower, or mixed case. This file has the following form:

Message Block Blank Line Delimiter	} Optional
CONTINUE	
Data Cards	
.	
.	
Blank Line Terminator	Recommended
Anything else	Optional

The data cards allowed in the continue-run input file are a subset of the data cards available for an initiate-run file. The allowed continue-run data cards are FQ, DD, NPS, CTME, IDUM, RDUM, PRDMP, LOST, DBCN, PRINT, KCODE, MPLOT, and ZA,ZB,ZC.

A very convenient feature is that if none of the above items are to be changed (and if the computing environment allows execution line messages), the continue-run input file is not required; only the run file RUNTPE and the C option on the MCNP execution line are necessary. For example, if you run a job for a minute but you want more particles run, execute with the C or CN message on the execute line, and the job will pick up where it stopped and continue until another time limit or the particle cutoff is reached, or until you stop it manually. This example assumes that a restart file called RUNTPE from the initial run is in your current directory.

The complete continue-run execution line option is C m or CN m, where m specifies which dump to pick up from the RUNTPE and to continue with. If m is not specified, the last dump is taken by default. If the initial run producing the RUNTPE was stopped because of particle cutoff (NPS card, page 3–141), NPS must be increased for a continue-run. The NPS card refers to total histories to be run, including preceding continue-runs and the initial run. CTME in a continue-run is the number of minutes more to run, not cumulative total time. To run more KCODE cycles, only the fourth entry KCT matters. Like NPS, KCT refers to total cycles to be run, including previous ones.

In a continue-run, a negative number entered on the NPS card produces a print output file at the time of the requested dump. No more histories will be run. This can be useful when the printed output has been lost or you want to alter the content of the output with the PRINT or FQ cards.

Be cautious if you use a FILES card in the initial run. See page 3–148.

D. Card Format

All input lines are limited to 80 columns. Alphabetic characters can be upper, lower, or mixed case. Most input is entered in horizontal form; however, a vertical input format is allowed for data cards. A comment can be added to any input card. A $ (dollar sign) terminates data entry and anything that follows the $ is interpreted as a comment. Blank lines are used as delimiters and terminators. Data entries are separated by one or more blanks.

Comment cards can be used anywhere in the INP file after the problem title card and before the last blank terminator card. These cards must have a C anywhere in columns 1−5 followed by at least one blank. Comment cards are printed only with the input file listing and not anywhere else in the MCNP output file. The FCn input card is available for user comments and is printed as a heading for tally n (as a tally title, for example). The SCn card is available for user comments and is printed as a heading for source probability distribution n.

1. Horizontal Input Format

Cell, surface, and data cards all must begin within the first five columns. The card name or number and particle designator is followed by data entries separated by one or more blanks. Blanks in the first five columns indicate a continuation of the data from the last named card. Alternatively, an & (ampersand) preceded by at least one blank ending a line indicates data will continue on the following card. Data on this continuation card can be in columns 1−80. Completely blank cards are reserved as delimiters between major sections of the input file. An individual entry must be entirely on one line. There can be only one card of any given type for a given particle designation (see page 3–7). Integers must be entered where integer input is required. Other numerical data can be entered as integer or floating point and will be read properly by MCNP. (In fact, noninteger numerical data can be entered in any form acceptable to a Fortran E-edit descriptor.)

Five features incorporated in the code facilitate input card preparation:

1. *n*R means *repeat* the immediately preceding entry on the card *n* times.
   For example, 2 4R is the same as 2 2 2 2 2.
2. *n*I means *insert n linear* interpolates between the entries immediately preceding and following this feature. For example, 1.5 2I 3.0 on a card is the same as 1.5 2.0 2.5 3. In the construct X *n*I Y, if X and Y are integers, and if Y − X is an exact multiple of *n*+1, correct integer interpolates will be created. Otherwise only real interpolates will be created, but Y will be stored directly in all cases. In the above example, the 2.0 may not be exact, but in the example 1 4I 6 = 1 2 3 4 5 6, all interpolates are exact.
3. *n*ILOG means to *insert n logarithmically* spaced interpolates between the entries immediately preceding and following this feature. For example, .01 2ILOG 10 on a card is the same as .01 .1 1 10. In the construct X *n*ILOG Y, X and Y must be nonzero and have the same sign (otherwise a FATAL error is produced).
4. *x*M is a *multiply* feature and when used on an input card, it is replaced by the value of the previous entry on the card multiplied by the factor *x*. For example, 1 1 2M 2M 2M 2M 4M 2M 2M is equivalent to 1 1 2 4 8 16 64 128 256.

5. *n*J can be used on an input card to *jump* over the entry where used and take the default value. As an example, the following two cards are identical in their effect:

```
DD      .1      1000
DD      J       1000
```

   J J J is also equivalent to 3J. You can jump to a particular entry on a card without having to explicitly specify prior items on the card. This feature is convenient if you know you want to use a default value but cannot remember it. DBCN 2J 10 15 is another example.

These features apply to both integer and floating point quantities. If *n* (an integer) is omitted in the constructs *n*R, *n*I, *n*ILOG, and *n*J, then *n* is assumed to be 1. If *x* (integer or floating point) is omitted in *x*M, it is a FATAL error. The rules for dealing with adjacent special input items are as follows:

1. *n*R must be preceded by a number or by an item created by R or M.
2. *n*I and *n*ILOG must be preceded by a number or by an item created by R or M, and must be followed by a number.
3. *x*M must be preceded by a number or by an item created by R or M.
4. *n*J may be preceded by a number or any input feature except I, and may begin the card input list.

Examples:

1 3M 2R	=	1 3 3 3
1 3M I 4	=	1 3 3.5 4
1 3M 3M	=	1 3 9
1 2R 2I 2.5	=	1 1 1 1.5 2.0 2.5
1 R 2M	=	1 1 2
1 R R	=	1 1 1
1 2I 4 3M	=	1 2 3 4 12
1 2I 4 2I 10	=	1 2 3 4 6 8 10
3J 4R	is	illegal.
1 4I 3M	is	illegal.
1 4I J	is	illegal.

2. Vertical Input Format

Column input is particularly useful for cell parameters and source distributions. Cell importances or volumes strung out on horizontal input lines are not very readable and often cause errors when users add or delete cells. In column format, all the cell parameters for one cell can be on a single line, labeled with the name of the cell. If a cell is deleted, the user deletes just one line of cell parameters instead of hunting for the data item that belongs to the cell in each of several multiline cell parameter cards. For source distributions, corresponding SI, SP, and SB values are side by side. Source options, other than defaults, are on the next line and must all be entered explicitly. The & continuation symbol is not needed, and if present, is ignored.

In column format, card names are put side by side on one input line and the data values are listed in columns under the card names. A # is put somewhere in columns 1–5 on the line with the card

names. The card names must be all cell parameters, all surface parameters, or all something else. If a card name appears on a # card, there must not be a regular horizontal card by that name in the same input file. If there are more entries on data value lines than card names on the # line, the first data entry is a cell or surface number. If any cell numbers are entered, all must be entered. If cell numbers are entered, the cells do not have to be in the same order as they are in the cell cards block. If cell numbers are omitted, the default order is the order of the cells in the cell card block. The same rules apply to surface parameters, but because we currently have only one surface parameter (AREA), column input of surface parameters is less useful.

There can be more than one block of column data in an input file. Typically, there would be one block for cell parameters and one for each source distribution. If a lot of cell parameter options are being used, additional blocks of column data will be needed.

The entries in each column do not need to be precisely under the card name at the top of the column, but you might want the columns to be reasonably neat for readability. The column format is intended for input data that naturally fit into columns of equal length, but less tidy data are not prohibited. If a longer column is to the right of a shorter column, the shorter column must be filled with enough J entries to eliminate any ambiguity about which columns the data items are in.

Special syntax items (R, M, I, and J) are not as appropriate in column format as they are on horizontal lines, but they are not prohibited. They are, of course, interpreted vertically instead of horizontally. Multiple special syntax items, such as 9R and 9M, are not allowed if cell or surface names are present.

The form of a column input block is as follows:

$$\begin{array}{cccccc} \# & S_1 & S_2 & \cdots & S_m \\ K_1 & D_{11} & D_{12} & \cdots & D_{1m} \\ K_2 & D_{21} & D_{22} & \cdots & D_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ K_n & D_{n1} & D_{n2} & \cdots & D_{nm} \end{array}$$

1. The # is somewhere in columns 1–5.
2. Each line can be only 80 columns wide.
3. Each column, S_i through D_{li}, where l may be less than n, represents a regular input card.
4. The S_i must be valid MCNP card names. They must be all cell parameters, all surface parameters, or all something else.
5. D_{1i} through D_{ni} must be valid entries for an S_i card, except that $D_{l+1,i}$ through D_{ni} may be some *J*'s possibly followed by some blanks.
6. If D_{ji} is nonblank, $D_{j,i\text{-}1}$ must also be nonblank. A *J* may be used if necessary to make $D_{j,i\text{-}1}$ nonblank.
7. The S_i must not appear anywhere else in the input file.
8. The K_j are optional integers. If any are nonblank, all must be nonblank.

9. If the S_i are cell parameter card names, the K_j, if present, must be valid cell numbers. The same is true with surface parameters.
10. If the K_j are present, the D_{ji} must not use multiple special syntax items, such as 9*R* or 9*M*.

E. Particle Designators

Several of the input cards require a particle designator to distinguish between input data for neutrons, for photons and for electrons. These cards are IMP, EXT, FCL, WWN, WWE, WWP, WWGE, DXT, DXC, F, F5X, F5Y, F5Z, FMESH, PHYS, ELPT, ESPLT, TSPLT, CUT and PERT. The particle designator consists of the symbol: (colon) and the letter N, P or E immediately after the name of the card. At least one blank must follow the particle designator. For example, to enter neutron importances, use an IMP:N card; enter photon importances on an IMP:P card. To specify the same value for more than one kind of particle, a single card can be used instead of several. Example: IMP:E,P,N 1 1 0. With a tally card, the particle designator follows the card name including tally number. For example, ∗F5:N indicates a neutron point detector energy tally. In the heating tally case, both particle designators may appear. The syntax F6:N,P indicates the combined heating tally for both neutrons and photons.

F. Default Values

Many MCNP input parameters have default values that are summarized on page 3–161. Therefore, every input parameter does not need to be specified for a problem if the defaults are desired. If an input card is left out, the default values for all parameters on the card are used. However, if a particular default parameter on a card needs to be changed, but that parameter is preceded by others, either specify the others or use the *n*J jump feature to jump over the parameters for which the defaults will be used. CUT:P 3J −.10 is a convenient way to use the defaults for the first three parameters on the photon cutoff card but change the fourth.

G. Input Error Messages

MCNP makes extensive checks (over 800) of the input file for user errors. A FATAL error message is printed, both at the terminal and in the OUTP file, if the user violates a basic constraint of the input specification, and MCNP will terminate before running any particles. The first FATAL error is real; subsequent error messages may or may not be real because of the nature of the first FATAL message. The FATAL option on the MCNP execution line instructs MCNP to ignore FATAL errors and run particles, but the user should be extremely cautious about doing this.

Most MCNP error messages are either warnings or comments and are not fatal. Warnings are intended to inform the user about unconventional input parameters or running conditions and may need further attention. Comments relay useful additional information to the user. The user should not ignore these messages but should understand their significance before making important calculations.

In addition to FATAL, WARNING, and COMMENT messages, MCNP issues BAD TROUBLE messages immediately before any impending catastrophe, such as a divide by zero, which would otherwise cause the program to “crash.” MCNP terminates as soon as the BAD TROUBLE

message is issued. User input errors in the INP file are the most common reason for issuing a BAD TROUBLE message. These error messages indicate what corrective action is required.

H. Geometry Errors

There is one important kind of input error that MCNP will not detect while processing data from the INP file. MCNP cannot detect overlapping cells or gaps between cells until a particle track actually gets lost. Even then the precise nature of the error may remain unclear. However, there is much that can and should be done to check the geometry before starting a long computer run.

Use the geometry-plotting feature of MCNP to look at the system from several directions and at various scales. Be sure that what is displayed is what is intended. Any gaps or overlaps in the geometry will probably show up as dashed lines. The intersection of a surface with the plot plane is drawn as a dashed line if there is not exactly one cell on each side of the surface at each point. Dashed lines can also appear if the plot plane happens to coincide with a plane of the problem, if there are any cookie-cutter cells in the source, or if there are DXTRAN spheres in the problem.

Set up and run a short problem in which the system is flooded with particle tracks from an external source. The necessary changes in the INP file are as follows:

1. Add a VOID card to override some of the other specifications in the problem and make all the cells voids, turn heating tallies into flux tallies, and turn off any FM cards.
2. Add another cell and a large spherical surface to the problem such that the surface surrounds the system and the old outside world cell is split by the new surface into two cells: the space between the system and the new surface, which is the new cell, and the space outside the new surface, which is now the outside world cell. Be sure that the new cell has nonzero importance. Actually, it is best to make all nonzero importances equal. If the system is infinite in one or two dimensions, use one or more planes instead of a sphere.
3. Replace the source specifications by an inward directed surface source to flood the geometry with particles:

   SDEF SUR=m NRM = −1

   where m is the number of the new spherical surface added in Step 2. If the new surface is a plane, you must specify the portion to be used by means of POS and RAD or possibly X, Y, and Z source distributions.

Because there are no collisions, a short run will generate a great many tracks through the system. If there are any geometry errors, they should cause some of the particles to get lost.

When a particle first gets lost, whether in a special run with the VOID card or in a regular production run, the history is rerun to produce some special output on the OUTP file. Event-log printing is turned on during the rerun. The event log will show all surface crossings and will tell you the path the particle took to the bad spot in the geometry. When the particle again gets lost, a

description of the situation at that point is printed. You can usually deduce the cause of the lost particle from this output. It is not possible to rerun lost particles in a multitasking run.

If the cause of the lost particle is still obscure, try plotting the geometry with the origin of the plot at the point where the particle got lost and with the horizontal axis of the plot plane along the direction the particle was moving. The cause of the trouble is likely to appear as a dashed line somewhere in the plot or as some discrepancy between the plot and your idea of what it should look like.

II. CELL CARDS

Form: *j* *m d* geom params
or: *j* LIKE *n* BUT list

j = cell number; $1 \le j \le 99999$.
If cell has transformation, $1 \le j \le 999$. See page 3–28.

m = 0 if the cell is a void.
= material number if the cell is not a void. This indicates that the cell is to contain material *m*, which is specified on the M*m* card. See page 3–122.

d = absent if the cell is a void.
= cell material density. A positive entry is interpreted as the atomic density in units of 10^{24} atoms/cm^3. A negative entry is interpreted as the mass density in units of g/cm^3.

geom = specification of the geometry of the cell. It consists of signed surface numbers and Boolean operators that specify how the regions bounded by the surfaces are to be combined.

params = optional specification of cell parameters by entries in the keyword = value form.

n = number of another cell

list = set of keyword = value specifications that define the attributes that differ between cell *n* and *j*.

In the geometry specification, a signed surface number stands for the region on the side of the surface where points have the indicated sense. The plus sign for positive sense is optional. The regions are combined by Boolean operators: intersection (no symbol—implicit, like multiplication in algebra); union, :; and complement, #. Parentheses can be used to control the order of the operations. Parentheses and operator symbols also function as delimiters; where they are present, blank delimiters are not necessary. The default order of operations is complement first, intersection second, and union last. A number immediately after a complement operator, without parentheses, is interpreted as a cell number and is shorthand for the geometry specification of that cell number.

```
Example:  3     0   -1    2   -4     $ definition of cell 3
          #3                         $ equivalent to next line
          #(-1  2   -4)
```

For a simple cell (no union or complement operators), the geometry specification is just a blank-delimited list of the bounding surfaces and ambiguity surfaces of the cell with signs determined by

the sense of the cell with respect to each surface. See the Geometry sections of Chapters 1, 2, and 4 for complete explanations of how to specify the geometry of cells in MCNP.

Cell parameters can be defined on cell cards instead of in the data card section of the INP file. A blank is equivalent to the equal sign. If a cell parameter is entered on any cell card, a cell-parameter card with that name cannot be present, nor can the mnemonic appear on any column-format input card. Some cell parameters can be specified on cell cards and a different subset on cell-parameter or column-format cards. The form is keyword=value, where the allowed keywords are IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, and TMP, with particle designators where necessary. Four cell parameter cards associated with the repeated structures capability are U, TRCL, LAT and FILL. Like any cell parameter card, these four cards can be placed in the data card section of the INP file. It is recommended that the mnemonic and entry for each cell be placed on the cell card line after the cell description. The entries on the TRCL card and the FILL card, in particular, can be quite long and involved and it seems to be conceptually simpler when they are placed on the cell card line.

The LIKE *n* BUT feature uses keywords for the cell material number and density. The mnemonics are MAT and RHO, respectively. These keywords only can be used following the LIKE *n* BUT construct. In a normal cell description, material number and density are still the second and third entries on the cell card.

TMP and WWN data can be entered on cell cards in two ways. The keyword=value form TMP1=value TMP2=value etc. can be used or a special syntax is available where the single keyword TMP is followed by all the temperatures of the cell in an order corresponding to the times on the THTME card. The form for the WWN card is analogous: WWN1:*n*=value or WWN:*n* followed by all the lower weight bounds for the energy intervals of the cell.

Example: 10 16 –4.2 1 –2 3 IMP:N=4 IMP:P=8 EXT:N=–.4X

This says that cell 10 is to be filled with material 16 at a density of 4.2 g/cm^3. The cell consists of the intersections of the regions on the positive side of surface 1, the negative side of surface 2, and the positive side of surface 3. The neutron importance in cell 10 is 4 and the photon importance is 8. Neutrons in cell 10 are subject to an exponential transform in the minus X direction with stretching parameter 0.4.

Here are some precautions when preparing cell cards:

1. Avoid excessively complicated cells. MCNP runs faster when the problem geometry is made up of many simpler cells rather than fewer more complicated cells.
2. Avoid adding unneeded surfaces to the geometry description of a cell through poor use of the complement operator. The extra surfaces make the problem run slower and may destroy the necessary conditions for volume and area calculations. See Chapter 4 page 4–15.
3. Always use the geometry-plotting feature of MCNP to check the geometry of a problem. See Appendix B.

4. Flood the system with particles from an outside source to find errors in the geometry. See page 3–8.
5. If you add or remove cells, change all the cell parameter cards accordingly. The difficulty of this can be reduced if the vertical format is used for cell parameter cards. See page 3–5. Alternatively, define the values of cell parameters on cell cards and eliminate cell parameter cards entirely.

A. Shorthand Cell Specification

The LIKE *n* BUT feature is very useful in problems with a lot of repeated structures. Cell *j* inherits from cell *n* the values of all attributes that are not specified in the list. The cell card for cell *n* must be before the cell card for cell *j* in the INP file. Any card name that appears after the BUT is a cell parameter on a cell card and, therefore, must appear on cell cards only, not on any cards in the data block of the INP file.

```
Example:  2    3   −3.7    −1    IMP:N=2    IMP:P=4
          3    LIKE 2 BUT       TRCL=1     IMP:N=10
```

This says that cell 3 is the same as cell 2 in every respect except that cell 3 has a different location (TRCL=1) and a different neutron importance. The material in cell 3, the density and the definition are the same as cell 2 and the photon importance is the same.

III. SURFACE CARDS

A. Surfaces Defined by Equations

Form: *j* *n* *a* list

j = surface number: $1 \le j \le 99999$, with asterisk for a reflecting surface or plus for a white boundary.
If surface defines a cell that is transformed with TRCL, $1 \le j \le 999$.
See page 3–28.

n = absent for no coordinate transformation.
= > 0, specifies number of TRn card.
= < 0, specifies surface *j* is periodic with surface *n*.

a = equation mnemonic from Table 3.1

list = one to ten entries, as required.

The surface types, equations, mnemonics, and the order of the card entries are given in Table 3.1. To specify a surface by this method, find the surface in Table 3.1 and determine the coefficients for the equation (you may need to consult a book on analytical geometry). The information is entered on a surface card according to the above form. Under certain conditions a surface can be defined by specifying geometrical points, as discussed in Sections III.B and C beginning on page 3–15. Surfaces also can be produced by combinatorial-geometry-like macrobodies, described in Section III.D beginning on page 3–18.

A point (x,y,z) is defined as having positive sense with respect to a surface when the expression for that surface evaluated at (x,y,z) is positive. The expression for a surface is the left side of the equation for the surface in Table 3.1. With the sphere, cylinder, cone, and torus, this definition is identical to defining the sense to be positive outside the figure. With planes normal to axes (PX, PY, or PZ), the definition gives positive sense for points with x, y, or z values exceeding the intercept of the plane. For the P, SQ and GQ surfaces, the user supplies all of the coefficients for the expression and thus can determine the sense of the surface at will. This is different from the other cases where the sense, though arbitrary, is uniquely determined by the form of the expression. Therefore, in a surface transformation (see the TRn card on page 3–30) a PX, PY, or PZ surface will sometimes be replaced by a P surface just to prevent the sense of the surface from getting reversed.

If the surface number is preceded by an asterisk, a reflecting surface is defined. A particle track that hits a reflecting surface is reflected specularly. If the surface number is preceded by a plus, a white boundary is defined. Detectors and DXTRAN (next-event estimators) usually should not be used in problems that have reflecting surfaces or white boundaries. Tallies in problems with reflecting surfaces will need to be normalized differently as discussed in Chapter 2 on page 2–12 and page 2–102.

A negative second entry n specifies that surface j is periodic with surface k. The following restrictions apply:

1. Surfaces j and k must be planes.
2. No surface transformation is allowed for the periodic planes.
3. The periodic cell(s) can be infinite or bounded by planes on the top and bottom that can be reflecting or white, but cannot be periodic.
4. Periodic planes can only bound other periodic planes or top and bottom planes.
5. A single zero–importance cell must be on one side of each periodic plane.
6. All periodic planes must have a common rotational vector normal to the geometry top and bottom.
7. Next–event estimators such as detectors and DXTRAN should not be used.

Table 3.1: MCNP Surface Cards

Mnemonic	Type	Description	Equation	Card Entries
P	Plane	General	$Ax + By + Cz - D = 0$	ABCD
PX		Normal to *X*-axis	$x - D = 0$	D
PY		Normal to *Y*-axis	$y - D = 0$	D
PZ		Normal to *Z*-axis	$z - D = 0$	D
SO	Sphere	Centered at Origin	$x^2 + y^2 + z^2 - R^2 = 0$	R
S		General	$(x-\bar{x})^2 + (y-\bar{y})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{x}\ \bar{y}\ \bar{z}\ R$
SX		Centered on *X*-axis	$(x-\bar{x})^2 + y^2 + z^2 - R^2 = 0$	$\bar{x}\ R$
SY		Centered on *Y*-axis	$x^2 + (y-\bar{y})^2 + z^2 - R^2 = 0$	$\bar{y}\ R$
SZ		Centered on *Z*-axis	$x^2 + y^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{z}\ R$
C/X	Cylinder	Parallel to *X*-axis	$(y-\bar{y})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{y}\ \bar{z}\ R$
C/Y		Parallel to *Y*-axis	$(x-\bar{x})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{x}\ \bar{z}\ R$
C/Z		Parallel to *Z*-axis	$(x-\bar{x})^2 + (y-\bar{y})^2 - R^2 = 0$	$\bar{x}\ \bar{y}\ R$
CX		On *X*-axis	$y^2 + z^2 - R^2 = 0$	R
CY		On *Y*-axis	$x^2 + z^2 - R^2 = 0$	R
CZ		On *Z*-axis	$x^2 + y^2 - R^2 = 0$	R
K/X	Cone	Parallel to *X*-axis	$\sqrt{(y-\bar{y})^2 + (z-\bar{z})^2} - t(x-\bar{x}) = 0$	$\bar{x}\ \bar{y}\ \bar{z}\ t^2 \pm 1$
K/Y		Parallel to *Y*-axis	$\sqrt{(x-\bar{x})^2 + (z-\bar{z})^2} - t(y-\bar{y}) = 0$	$\bar{x}\ \bar{y}\ \bar{z}\ t^2 \pm 1$
K/Z		Parallel to *Z*-axis	$\sqrt{(x-\bar{x})^2 + (y-\bar{y})^2} - t(z-\bar{z}) = 0$	$\bar{x}\ \bar{y}\ \bar{z}\ t^2 \pm 1$
KX		On *X*-axis	$\sqrt{y^2 + z^2} - t(x-\bar{x}) = 0$	$\bar{x}\ t^2 \pm 1$
KY		On *Y*-axis	$\sqrt{x^2 + z^2} - t(y-\bar{y}) = 0$	$\bar{y}\ t^2 \pm 1$
KZ		On *Z*-axis	$\sqrt{x^2 + y^2} - t(z-\bar{z}) = 0$	$\bar{z}\ t^2 \pm 1$ ± 1 used only for 1 sheet cone
SQ	Ellipsoid Hyperboloid Paraboloid	Axis parallel to X-, Y-, or Z-axis	$A(x-\bar{x})^2 + B(y-\bar{y})^2 + C(z-\bar{z})^2 + 2D(x-\bar{x}) + 2E(y-\bar{y}) + 2F(z-\bar{z}) + G = 0$	A B C D E F G $\bar{x}\ \bar{y}\ \bar{z}$
GQ	Cylinder Cone Ellipsoid Hyperboloid Paraboloid	Axes not parallel to *X-*, *Y-*, or *Z*-axis	$Ax^2 + By^2 + Cz^2 + Dxy + Eyz + Fzx + Gx + Hy + Jz + K = 0$	A B C D E F G H J K
TX	Elliptical or circular torus. Axis is parallel to *X-*, *Y-*, or *Z*-axis		$(x-\bar{x})^2/B^2 + (\sqrt{(y-\bar{y})^2 + (z-\bar{z})^2} - A)^2/C^2 - 1 = 0$	$\bar{x}\ \bar{y}\ \bar{z}$ A B C
TY			$(y-\bar{y})^2/B^2 + (\sqrt{(x-\bar{x})^2 + (z-\bar{z})^2} - A)^2/C^2 - 1 = 0$	$\bar{x}\ \bar{y}\ \bar{z}$ A B C
TZ			$(z-\bar{z})^2/B^2 + (\sqrt{(x-\bar{x})^2 + (y-\bar{y})^2} - A)^2/C^2 - 1 = 0$	$\bar{x}\ \bar{y}\ \bar{z}$ A B C
XYZP		Surfaces defined by points		See pages 3–15 and 3–17

Example 1: *j* PY 3

This describes a plane normal to the *y*–axis at $y = 3$ with positive sense for all points with $y > 3$.

Example 2: *j* K/Y 0 0 2 .25 1

This specifies a cone whose vertex is at $(x,y,z) = (0,0,2)$ and whose axis is parallel to the *y*-axis. The tangent *t* of the opening angle of the cone is 0.5 (note that t^2 is entered) and only the positive (right hand) sheet of the cone is used. Points outside the cone have a positive sense.

Example 3: *j* GQ 1 .25 .75 0 –.866
0 –12 –2 3.464 39

This is a cylinder of radius 1 cm whose axis is in a plane normal to the *x*–axis at $x = 6$, displaced 2 cm from the *x*–axis and rotated 30° about the *x*–axis off the *y*–axis toward the *z*–axis. The sense is positive for points outside the cylinder. Such a cylinder would be much easier to specify by first defining it in an auxiliary coordinate system where it is symmetric about a coordinate axis and then using the TRn input card (see page 3–30) to define the relation between the basic and auxiliary coordinate systems. The input would then be

j 7 CX 1
*TR7 6 1 –1.732 0 30 60

See Chapter 4 page 4–16 for additional examples of the TRn card.

The TX, TY, and TZ input cards represent elliptical tori (fourth degree surfaces) rotationally symmetric about axes parallel to the *x*, *y*, and *z* axes, respectively. A TY torus is illustrated in Figure 3-1a. Note that the input parameters $\bar{x}\ \bar{y}\ \bar{z}\ a\ b\ c$ specify the ellipse

$$\frac{s^2}{b^2} + \frac{(r-a)^2}{c^2} = 1$$

rotated about the *s*–axis in the *(r,s)* cylindrical coordinate system (Figure 3-1b) whose origin is at $\bar{x}\ \bar{y}\ \bar{z}$ in the *x*, *y*, *z* system. In the case of a TY torus,

$$s = (y - \bar{y})$$

and $$r = \sqrt{(x-\bar{x})^2 + (z-\bar{z})^2}$$

A torus is degenerate if $|a| < c$ where $0 < a < c$ produces the outer surface (Figure 3-1c), and $-c < a < 0$ produces the inner surface (Figure 3-1d).

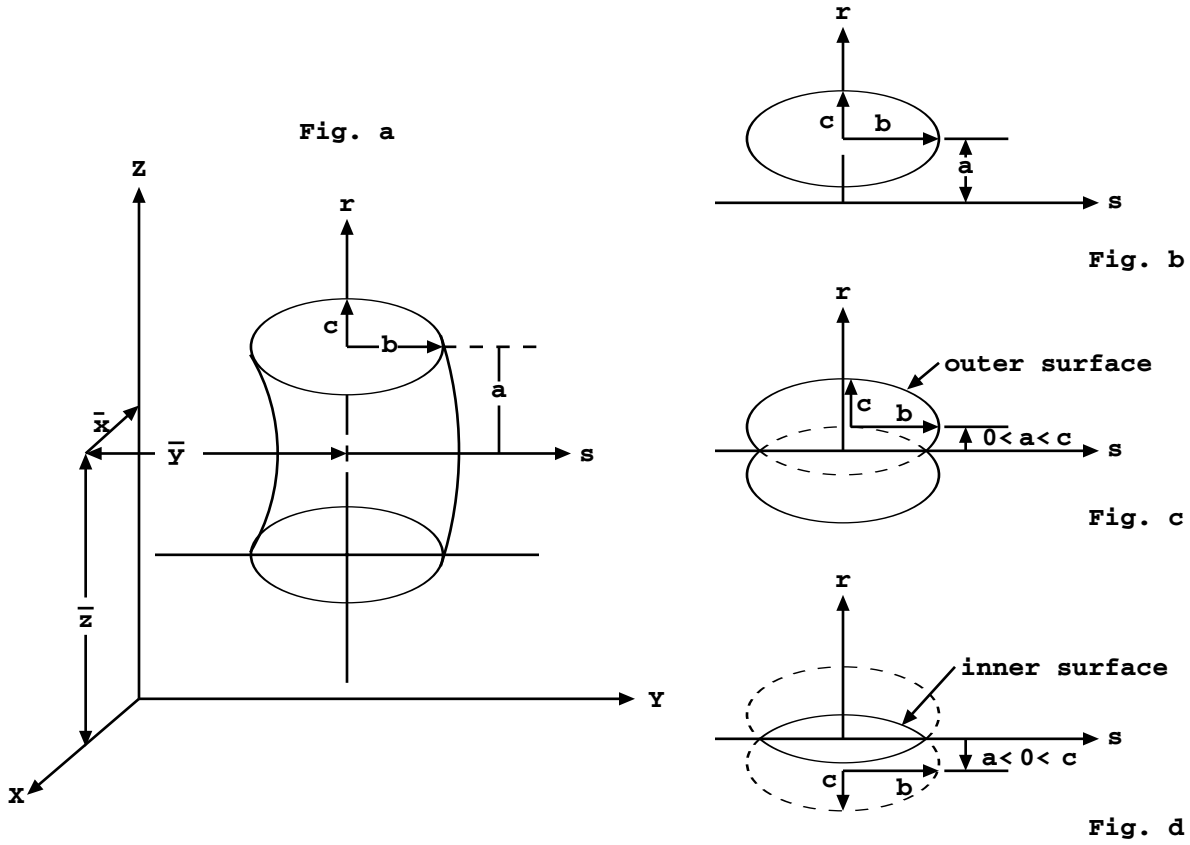


Figure 3-1. Torus

Coordinate transformations for tori are limited to those in which each axis of the auxiliary coordinate system is parallel to an axis of the main system.

B. Axisymmetric Surfaces Defined by Points

Form: *j* *n* *a* list

j = surface number: $1 \le j \le 99999$. If surface defines a cell that is transformed with TRCL, $1 \le j \le 999$. See page 3–28.
n = absent for no coordinate transformation, or number of TRn card.
a = the letter X, Y, or Z
list = one to three coordinate pairs.

Surface cards of type X, Y, and Z can be used to describe surfaces by coordinate points rather than by equation coefficients as in the previous section. The surfaces described by these cards must be symmetric about the *x*-, *y*-, or *z*-axis, respectively, and, if the surface consists of more than one sheet, the specified coordinate points must all be on the same sheet.

Each of the coordinate pairs defines a geometrical point on the surface. On the Y card, for example, the entries may be

j Y y_1 r_1 y_2 r_2

where $r_i = \sqrt{(x_i^2 + z_i^2)}$ and y_i is the coordinate of point i.

If one coordinate pair is used, a plane (PX, PY, or PZ) is defined.

If two coordinate pairs are used, a linear surface (PX, PY, PZ, CX, CY, CZ, KX, KY, or KZ) is defined.

If three coordinate pairs are used, a quadratic surface (PX, PY, PZ, SO, SX, SY, SZ, CX, CY, CZ, KX, KY, KZ, or SQ) is defined.

When a cone is specified by two points, a cone of only one sheet is generated.

The senses of these surfaces (except SQ) are determined by the code to be identical to the senses one would obtain by specifying the surface by equations. For SQ, the sense is defined so that points sufficiently far from the axis of symmetry have positive sense. Note that this is different from the equation-defined SQ, where the user could choose the sense freely.

Example 1: *j* X 7 5 3 2 4 3

This describes a surface symmetric about the *x*–axis, which passes through the three *(x,r)* points (7,5), (3,2), and (4,3). This surface is a hyperboloid of two sheets, converted in MCNP to its equivalent

j SQ −.083333333 1 1 0 0 0 68.52083 −26.5 0 0.

Example 2: *j* Y 1 2 1 3 3 4

This describes two parallel planes at Y = 1 and Y = 3 and is a FATAL error because the requirement that all points be on the same sheet is not met.

Example 3: *j* Y 3 0 4 1 5 0

This describes a sphere of radius 1 with center at *(x,y,z)* = (0,4,0).

Example 4: *j* Z 1 0 2 1 3 4

This surface is rejected because the points are on two different sheets of the hyperboloid

$$x^2 + y^2 - 7z^2 + 20z - 13 = 0$$

However, the surface

j Z 2 1 3 4 5 9.380832

which has the same surface equation as above is accepted because all coordinates lie on a single surface, the right sheet of the hyperboloid.

Example 5:

```
1   0    1    –2    3    $ cell  1

1   Y   –3  2   2  1
2   Y    2  3   3  3   4  2
3   Y    2  1   3  1   4  2
```

This final example defines a cell bounded by a cone, hyperboloid, and an ellipsoid. The three surfaces define the donut-like cell that is symmetric about the *y*–axis. A cross section of this cell is seen in Figure 3-2. To plot this view, type PX = 0 EX = 5. One surface goes through the points (-3,2) and (2,1). The second surface goes through (2,3), (3,3), and (4,2). The last surface is defined by the points (2,1), (3,1), and (4,2). These coordinate points are in the form *(y,r)*. Using these cards, MCNP indicates that surface 1 is a cone of one sheet, surface 2 is an ellipsoid, and surface 3 is a hyperboloid of one sheet. The equation coefficients for the standard surface equations are printed out for the various surfaces when the PRINT input card or execution option is used. For example, an SQ card defining surface 3 is

```
3    SQ   1  -1.5  1  0  0  0  –.625  0  2.5  0
```

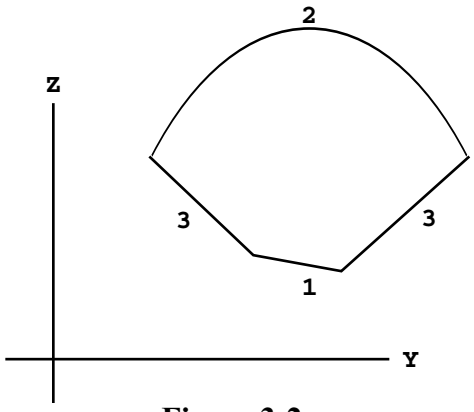


Figure 3-2.

C. General Plane Defined by Three Points

Form: *j* n P X_1 Y_1 Z_1 X_2 Y_2 Z_2 X_3 Y_3 Z_3

j	=	surface number: $1 \le j \le 99999$ or ≤ 999 if repeated structure.
n	=	absent for no coordinate transformation.
	=	> 0, specifies number of TRn card.
	=	< 0, specifies surface *j* is periodic with surface *n*.
$(X_i\ Y_i\ Z_i)$	=	coordinates of points to define the plane.

If there are four entries on a P card, they are assumed to be the general plane equation coefficients as in Table 3.1. If there are more than four entries, they give the coordinates of three points lying in the desired plane. The code uses the coordinate points to determine the required surface coefficients to produce the plane

$$Ax + By + Cz - D = 0$$

The sense of the plane is determined by requiring the origin to have negative sense. If the plane passes through the origin *(D = 0)*, the point $(0, 0, \infty)$ has positive sense. If this fails *(D = C = 0)*,

the point $(0, \infty, 0)$ has positive sense. If this fails *(D = C = B = 0)*, the point $(\infty, 0, 0)$ has positive sense. If this fails, the three points lie in a line and a FATAL error is issued.

D. Surfaces Defined by Macrobodies

Using a combinatorial-geometry-like macrobody capability is an alternative method of defining cells and surfaces. The combinatorial geometry bodies available are similar to those in the Integrated Tiger Series (ACCEPT) codes. The macrobodies can be mixed with the standard cells and surfaces. The macrobody surface is decomposed internally into surface equations and the facets are assigned individual numbers according to a predetermined sequence. The assigned numbers are the number selected by the user followed by a decimal point and 1, 2, ... The facets can be used for tallying, tally segmentation, other cell definitions, SDEF sources, etc. They cannot be used on the SSR/SSW cards, the surface flagging card, PTRAC, or MCTAL files.

The space inside a body has a negative sense with respect to the macrobody surface and all its facets. The space outside a body has a positive sense. The sense of a facet is the sense assigned to it by the macrobody "master" cell and the facet retains that assigned sense if it appears in other cell descriptions and must be properly annotated. See an example on page 3–23 for an illustration.

The following geometry bodies are available and their complete descriptions follow.

BOX	Arbitrarily oriented orthogonal box
RPP	Rectangular Parallelepiped
SPH	Sphere
RCC	Right Circular Cylinder
RHP or HEX	Right Hexagonal Prism
REC	Right Elliptical Cylinder
TRC	Truncated Right-angle Cone
ELL	Ellipsoid
WED	Wedge
ARB	Arbitrary polyhedron

BOX: Arbitrarily oriented orthogonal box (all corners are 90°).

BOX *Vx Vy Vz A1x A1y A1z A2x A2y A2z A3x A3y A3z*

where *Vx Vy Vz* = *x,y,z* coordinates of corner
A1x A1y A1z = vector of first side
A2x A2y A2z = vector of second side
A2x A3y A3z = vector of third side

Example: BOX –1 –1 –1 2 0 0 0 2 0 0 0 2
a cube centered at the origin, 2 cm on a side, sides parallel to the major axes.

RPP: Rectangular Parallelepiped, surfaces normal to major axes, *x,y,z* values relative to origin.

RPP *Xmin Xmax Ymin Ymax Zmin Zmax*

Example: RPP –1 1 –1 1 –1 1
equivalent to BOX above.

SPH: Sphere. Equivalent to surface equation for general sphere.

SPH *Vx Vy Vz R*

where *Vx Vy Vz* = *x,y,z* coordinates of center
R = radius

RCC: Right Circular Cylinder, can

RCC *Vx Vy Vz Hx Hy Hz R*

where *Vx Vy Vz* = center of base
Hx Hy Hz = cylinder axis vector
R = radius

Example: RCC 0 –5 0 0 10 0 4
a 10-cm high can about the *y*-axis, base plane at *y* = –5 with radius of 4 cm.

RHP or HEX: Right Hexagonal Prism. Differs from ITS (ACCEPT) format.

RHP *v1 v2 v3 h2 h2 h3 r1 r2 r3 s1 s2 s3 t1 t2 t3*

where *v1 v2 v3* = *x,y,z* coordinates of the bottom of the hex
h1 h2 h3 = vector from the bottom to the top
for a *z*-hex with height h, *h*1,*h*2,*h*3 = *0 0 h*
r1 r2 r3 = vector from the axis to the middle of the first facet
for a pitch 2*p* facet normal to *y*-axis, *r1,r2,r3 = 0 p 0*
s1 s2 s3 = vector to center of the second facet
t1 t2 t3 = vector to center of the third facet

Example: RHP 0 0 –4 0 0 8 0 2 0
a hexagonal prism about the *z*-axis whose base plane is at *z* = –4 with a height of 8 cm and whose first facet is normal to the *y*-axis at *y* = 2.

REC: Right Elliptical Cylinder

REC *Vx Vy Vz Hx Hy Hz V1z V1y V1z V2x V2y V2z*

where *Vx Vy Vz* = x,y,z coordinates of bottom cylinder
Hx Hy Hz = cylinder axis height vector
V1x V1y V1z = 2 ellipse major axis vector (normal to *Hx Hy Hz*)
V2x V2y V2z = ellipse minor axis vector (orthogonal to *H* and *V1*)

If there are ten entries instead of twelve, the tenth entry is the minor axis radius, where the direction is determined from the cross product of *H* and *V1*.

Example: REC 0 -5 0 0 10 0 4 0 0 2
A 10-cm high elliptical cylinder about the *y*-axis with the center of the base at x,y,z = 0,-5,0 and with major radius 4 in the *x*-direction and minor radius 2 in the *z*-direction.

TRC: Truncated Right-angle Cone

TRC *Vx Vy Vz Hx Hy Hz R1 R2*

where *Vx Vy Vz* = x,y,z coordinates of bottom of truncated cone
Hx Hy Hz = cone axis height vector
R1 = radius of lower cone base
R2 = radius of upper cone base

Example: TRC -5 0 0 10 0 0 4 2

A 10-cm high truncated cone about the x-axis with the center of the 4-cm radius base at x,y,z = -5,0,0 and with the 2-cm radius top at x,y,z = 5,0,0

ELL: ELLipsoids

ELL *V1x V1y V1z V2x V2y V2z Rm*

If *Rm* > 0:
V1x Vly V1z = first foci coordinate
V2x V2y V2z = second foci coordinate
Rm = length of major axis

If *Rm* < 0:
V1x Vly V1z = center of ellipsoid
V2x V2y V2z = major axis vector (length = major radius)
Rm = minor radius length

Examples: ELL 0 0 -2 0 0 2 6
ELL 0 0 0 0 0 3 -2

An ellipsoid at the origin with major axis of length 6 in the z-direction and minor axis radius of length 4 normal to the *z*-axis

WED: Wedge

WED *Vx Vy Vz V1x V1y V1z V2x V2y V2z V3x V3y V3z*

where *Vx Vy Vz* = vertex
V1x V1y V1z = vector of first side of triangular base
V2x V2y V2z = vector of second side of triangular base
V3x V3y V3z = height vector

A right-angle wedge has a right triangle for a base defined by *V1* and *V2* and a height of *V3*. The vectors *V1, V2*, and *V3* are orthogonal to each other.

Example: WED 0 0 -6 4 0 0 0 3 0 0 0 12

A 12-cm high wedge with vertex at x,y,z = 0,0,-6. The triangular base and top are a right triangle with sides of length 4 (*x*-direction) and 3 (*y*-direction) and hypotenuse of length 5.

ARB: ARBitrary polyhedron

ARB *ax ay az bx by bz cx cy cz ... hx by hz N1 N2 N3 N4 N5 N6*

There must be eight triplets of entries input for the ARB to describe the (x,y,z) of the corners, although some may not be used (just use zero triplets of entries). These are followed by six more entries, *N*, which follow the prescription: each entry is a four-digit integer that defines a side of the ARB in terms of the corners for the side. For example, the entry 1278 would define this plane surface to be bounded by the first, second, seventh, and eighth triplets (corners). Since three points are sufficient to determine the plane, only the first, second, and seventh corners would be used in this example to determine the plane. The distance from the plane to the fourth corner (corner 8 in the example) is determined by MCNP. If the absolute value of this distance is greater than 1.e-6, an error message is given and the distance is printed in the OUTP file along with the (x,y,z) that would lie on the plane. If the fourth digit is zero, the fourth point is ignored. For a four-sided ARB, four nonzero four-digit integers (last digit is zero for four-sided since there are only three corners for each side) are required to define the sides. For a five-sided ARB, five nonzero four-digit integers are required, and six nonzero four-digit integers are required for a six-sided ARB. Since there must be 30 entries altogether for an ARB (or MCNP gives an error message), the last two integers are zero for the four-sided ARB and the last integer is zero for a five-sided ARB.

Example: ARB -5 -10 -5 -5 -10 5 5 -10 -5 5 -10 5 0 12 0 0 0 0
0 0 0 0 0 0 1234 1250 1350 2450 3450 0
A five-sided polyhedron with corners at x,y,z = (-5,-10,-5), (-5,-10,6), (5,-10,-5), (5,-10,5), (0,12,0), and planar facets are constructed from corners 1234, etc.

The facets of the bodies are sequentially numbered and can be used on other MCNP cards. BOX and RPP can be infinite in a dimension, in which case those two facets are skipped and the numbers of the remaining facets are decreased by two. RHP can be infinite in the axial dimension in which case facets 7 and 8 do not exist. The order of the facet numbering follows for each geometry body. Facet numbering can be displayed graphically with MBODY=OFF in the geometry plotter.

BOX:
1 Plane normal to end of *A1x A1y A1z*
2 Plane normal to beginning of *A1x A1y A1z*
3 Plane normal to end of *A2x A2y A2z*
4 Plane normal to beginning of *A2x A2y A2z*
5 Plane normal to end of *A3x A3y A3z*
6 Plane normal to beginning of *A3x A3y A3z*

RPP:
1 Plane *Xmax*
2 Plane *Xmin*
3 Plane *Ymax*
4 Plane *Ymin*
5 Plane *Zmax*
6 Plane *Zmin*

SPH: Treated as a regular surface so no facet

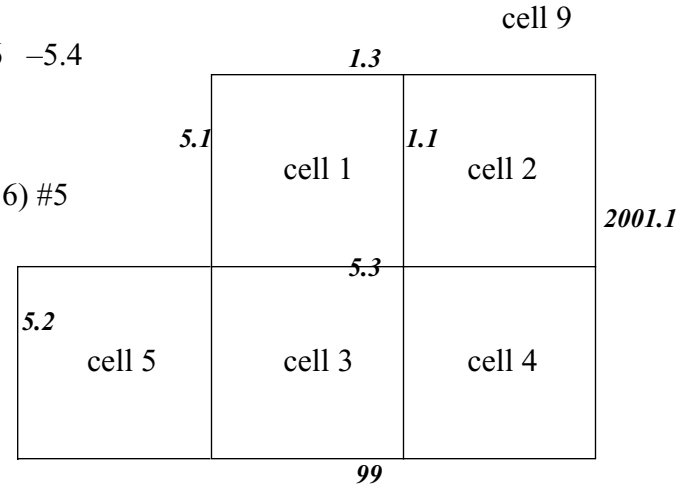
RCC:
1 Cylindrical surface of radius *R*
2 Plane normal to end of *Hx Hy Hz*

	3	Plane normal to beginning of *Hx Hy Hz*
RHP or HEX	1	Plane normal to end of *r1 r2 r3*
	2	Plane opposite facet 1
	3	Plane normal to end of *s1 s2 s3*
	4	Plane opposite facet 3
	5	Plane normal to end of *t1 t2 t3*
	6	Plane opposite facet 5
	7	Plane normal to end of *h1 h2 h3*
	8	Plane normal to beginning of *h1 h2 h3*
REC:	1	Elliptical cylinder
	2	Plane normal to end of *Hx Hy Hz*
	3	Plane normal to beginning of *Hx Hy Hz*
TRC:	1	Conical surface
	2	Plane normal to end of *Hx Hy Hz*
	3	Plane normal to beginning of *Hx Hy Hz*
ELL:	Treated as regular surface, so no facet	
WED:	1	Slant plane including top and bottom hypotenuses
	2	Plane including vectors *V2* and *V3*
	3	Plane including vectors *V1* and *V3*
	4	Plane including vectors *V1* and *V2* at end of *V3* (top triangle)
	5	Plane including vectors *V1* and *V2* at beginning of *V3* (bottom triangle, including vertex point)
ARB:	1	Plane defined by corners *N1*
	2	Plane defined by corners *N2*
	3	Plane defined by corners *N3*
	4	Plane defined by corners *N4*
	5	Plane defined by corners *N5*
	6	Plane defined by corners *N6*

The following input file describes five cells and illustrates a combination of the various body and cell/surface descriptions. Surface numbers are in italics alongside the planes they define. Note that the cell and surface numbers do not have to start with 1 or be consecutive.

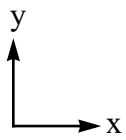
```
3   0  –1.2  –1.1   1.4  –1.5  –1.6  99
4   0   1.1  –2001.1  –5.3   –5.5  –5.6  –5.4
5   0  –5
1   0  –1
2   like 1 but trcl = (2 0 0)
9   0  (–5.1 : 1.3 : 2001.1 : –99 : 5.5 : 5.6) #5

5    rpp  –2  0   –2  0   –1  1
1    rpp   0  2    0  2   –1  1
99   py   –2
```



alternative descriptions of cell 3:

```
3  0     5.1  –1.1  –5.3  –5.5  –5.6   99
3  0     5.1  –1.1   1.4  –5.5  –5.6  –5.4
3  0   –1.2   –1.1  –5.3  –5.5  –5.6  –5.4
```



IV. DATA CARDS

All MCNP input cards other than those for cells and surfaces are entered after the blank card delimiter following the surface card block. The mnemonic must begin within the first five columns. These cards fall into the following categories:

These card categories are described below. Only the cards listed on page 3–3 are allowed in a continue-run input file. No data card can be used more than once with the same number or particle type designations. For example, M1 and M2 are acceptable, as are CUT:N and CUT:P, but two M1 cards or two CUT:N cards are disallowed.

A. Problem Type (MODE) Card

Form: MODE $x_1 \ldots x_i$

x_i = N for neutron transport
P for photon transport
E for electron transport

Default: If the MODE card is omitted, MODE N is assumed.

Use: A MODE card is required unless MODE=N. The entries are space delineated.

B. Geometry Cards

Mnemonic	Card Type	Page
VOL	Cell Volume	3–24
AREA	Surface Area	3–25
U	Universe	3–26
TRCL	Cell Transformation	3–28
LAT	Lattice	3–28
FILL	Fill	3–29
TRn	Coordinate Transformation	3–30
URAN	Stochastic Geometry Card for HTGRs	3–32

1. VOL Cell Volume Card

Form: VOL $x_1\ x_2\ \ldots\ x_i$

or: VOL NO $x_1\ x_2\ \ldots\ x_i$

x_i = volume of cell i where i=1, 2, ... number of cells in the problem.
NO = no volumes or areas are calculated.

Default: MCNP attempts to calculate the volume of all cells unless “NO” appears on the VOL card. If no value is entered for a cell on the VOL card, the calculated volume is used.

Use: Optional card used to input cell volumes.

With the VOL card, if the number of entries does not equal the number of cells in the problem, it is a FATAL error. Use the nJ feature to skip over cells for which you do not want to enter values. The entry NO on the VOL card will bypass the volume calculation altogether. The x_i entries following NO are optional. If present, x_i entries are the volume values the code will use. For some problems the NO option saves considerable computer time.

Volumes or masses of cells are required for some tallies. MCNP calculates the volumes of all cells that are rotationally symmetric (generated by surfaces of revolution) about any axis, even a skew axis. It will also calculate the volumes of polyhedral cells. As a by-product of the volume calculation, areas and masses are also calculated. These volumes, areas, and masses can be printed

in the OUTP file by using the PRINT card. The user can enter values on the VOL card for the volume of any cell, and these values, instead of the calculated values, will be used for tally purposes. If a cell volume required for a tally cannot be calculated and is not entered on the VOL or SDn cards, a FATAL error message is printed.

The VOL card provides an alternative way to enter volumes required by tallies. Normally the SDn card would be used. The VOL card can be used only for cell volumes, whereas the SDn card can be used for cell and segment volumes or masses.

Volumes of cells or segments that cannot be calculated by MCNP or by the user can be obtained in a separate MCNP run using the ray-tracing technique described in Chapter 2 on page 2–190.

2. AREA Surface Area Card

Form: AREA $x_1 \ \ldots \ x_i \ \ldots \ x_n$

x_i = area of surface i where i=1, 2, ... number of surfaces in the problem.

Default: MCNP attempts to calculate the area of all surfaces. If no value is entered for a surface on the AREA card, the calculated area, if any, is used.

Use: Optional card used to input surface areas.

This card is analogous to the VOL card. MCNP calculates the area of surfaces as a by-product of the volume calculation. If the volume of all cells on either side of the surface can be calculated, the area of the surface will be calculated. Otherwise the area calculation will fail. A FATAL error occurs if an area is required for tallying purposes and is not available either from the MCNP calculation or from an AREA or SDn card.

The AREA card provides an alternative way to enter areas required by tallies. Normally the SDn card would be used. The AREA card can be used only for areas of whole surfaces, whereas the SDn card can be used for areas of surface segments as well as whole surfaces.

3. Repeated Structures Cards

The primary goal of the repeated-structures capability is to make it possible to describe only once the cells and surfaces of any structure that appears more than once in a geometry. The amount of input data the user has to provide and the amount of computer memory needed by problems that have a lot of geometrical repetition is reduced. Problems that would be impractical because they take an unreasonable amount of work to set up or they use too much memory can be run. One example of such a problem is a reactor core that has dozens of nearly identical fuel modules. Another example is a room containing some complicated, nearly identical objects arranged in some not necessarily regular order. This feature reduces input and memory use, but problems will not run any faster with any other description. Examples of the use of repeated structures cards are in Chapter 4 beginning on page 4–20.

The repeated structures capability extends the concept of an MCNP cell. The user can specify that a cell is to be filled with something called a universe. A universe is either a lattice or an arbitrary

collection of cells. A single universe, described only once, can be designated to fill each of any number of cells in the geometry. Some or all of the cells in a universe may themselves be filled with universes. Several concepts and cards combine in order to use this capability.

- Remember that cell parameters can be defined on cell cards.
- The "*LIKE m BUT*" feature is a shorthand making it possible to make one cell equivalent to another except for assorted attributes that can be specified with keyword=value entries. See page 3–10.
- The *universe* card, the U card, is used to specify to what universe the cell belongs.
- The *fill* card is used to specify with which universe a cell is to be filled.
- The *TRCL* card makes it possible to define only once the surfaces that bound several cells identical in size and shape but located at different places in the geometry. It follows the transformation rules established for the TR card. See page 3–30.
- The *lattice* card, the LAT card, is used to define an infinite array of hexahedra or hexagonal prisms. The order of specification of the surfaces of a lattice cell identifies which lattice element lies beyond each surface.
- A *general source* description can be defined in a repeated structures part of the geometry. Surface source surfaces must be regular MCNP surfaces, not surfaces associated with a repeated structures part of the geometry. No check is made that this requirement is met. The user MUST remember that THIS notification is the only warning.
- An *importance* in a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell. Weight-window lower bounds are not multipliers. Mesh-based weight windows (MESH card) automatically address this problem.

Chapter 4 contains several examples that illustrate the repeated structures input and logic. The reader is strongly encouraged to become familiar with these examples and to use them as teaching aids to help understand the card descriptions that follow.

1. U Universe Card

As mentioned earlier, a universe can be either a lattice or a collection of ordinary cells. A nonzero entry on the U card is the number of the universe that the corresponding cell belongs to. Lack of a U card or a zero entry means that the cell does not belong to any universe. Universe numbers are arbitrary integers chosen by the user. The FILL card, page 3–29, indicates that a cell is filled by all the cells having a corresponding integer entry on the U card. The cells of a universe may be finite or infinite, but they must fill all of the space inside any cell that the universe is specified to fill.

One way to think about the connection between a filled cell and the filling universe is that the filled cell is a "window" that looks into a second level, like a window in a wall provides a view of the outdoors. Cells in the second level can be infinite because they will be "ended" when they bump into or intersect the surfaces of the "window." The second level can have its own origin, in a primed coordinate system, unrelated to the upper level origin. However, if the filled cell and filling universe have all their surfaces in the same coordinate system, one TRCL card, explained on page 3–28, will

define the coordinate system of both filled and filling cells. The first repeated structures example in Chapter 4 illustrates this fact (see page 4–20).

A cell in a universe can be filled by another universe, in which case a third level is introduced. There is a maximum of 10 levels, more than most problems will need. To clarify some jargon about hierarchies, the highest to lowest level is in inverse order to the associated numerical value. The highest level is level zero, lower is level one, lower still is level two, etc.

Planar surfaces of a filled cell and those in a filling universe CAN be coincident. In other words, the cells of a universe can fit exactly into the filled cell. The following cell and surface cards illustrate this feature. They represent a $50 \times 20 \times 10$ –cm box filled with a lattice of 10 x 10 x 10-cm cubes, each of which is filled with a sphere.

A problem will run faster by preceding the U card entry with a minus sign for any cell that is not truncated by the boundary of any higher level cell. The minus sign indicates that calculating distances to boundary in higher level cells can be omitted. In the problem below, cell 3 has a negative universe number. It is a finite cell and is not truncated by any other cell. Cell 4 cannot have a negative universe number because it is an infinite region that is truncated by cell 2.

CAUTION: Use this capability AT YOUR OWN RISK. MCNP cannot detect errors in this feature as the logic that enables detection is omitted by the presence of the negative universe. Extremely wrong answers can be quietly calculated. Use this feature with EXTREME CAUTION. Plot several views of the geometry or run with the VOID card (see page 3–8) to check for errors.

```
1     0      1 –2 –3 4 –5 6          fill=1
2     0      –7 1 –3 8       u=1     fill=2     lat=1
3     0      –11             u=–2
4     0      11              u=2
5     0      –1:2:3:–4:5:–6

1     px     0
2     px     50
3     py     10
4     py     –10
5     pz     5
6     pz     –5
7     px     10
8     py     0
10    py     10
11    s      5  5  0  4
```

Every cell in the problem is either part of the real world (universe level 0) or part of some universe, but the surfaces of a problem are less restricted. A single planar surface can be used to describe cells in more than one universe. Coincident surfaces cannot be reflecting or periodic, source surfaces, or tally surfaces. Materials are normally put into the cells of the lowest level universe, not in the higher level, but there is an exception in the case of a lattice.

The above example can be described with macrobodies as follows:

```
1    0    –20     fill=1
2    0    –30     u=1   fill=2   lat=1
3    0    –11     u=–2
4    0     11     u=2
5    0     20

20    rpp   0  50    –10  10    –5  5
30    rpp   0  10      0  10    –5  5
11    s     5   5   0   4
```

2. TRCL Cell Transformation Card

The TRCL card makes it possible to describe just once the surfaces that bound several cells identical in size and shape but located at different places in the geometry. It is especially valuable when these cells are filled with the same universe. If the surfaces of these filled cells and the surfaces of the cells in the universe that fills them are all described in the same auxiliary coordinate system, a single transformation will completely define the interior of all these filled cells because the cells of the universe will inherit the transformation of the cells they fill. TRCL is intended to be used with LIKE BUT, LAT, etc. With a regular cell description, it is suggested the TR on the surface cards be used.

The basic form of an entry is an integer that is interpreted as the number of a TR card that contains a transformation for all of the surfaces of the cell and is located in the data card section of the INP file. The absence of the TRCL card or zero means there is no transformation, the default. The actual transformation can be entered following the TRCL mnemonic, enclosed by parentheses. If the actual transformation is entered, all the rules applying to the TR card (page 3–30) are valid. If the symbol ∗TRCL is used, the rotation matrix entries are angles in degrees instead of cosines, the same as the ∗TR card.

If a cell has a transformation, a set of new surfaces with unique names is generated from the original surfaces. The name of the generated surface is equal to the name of the original surface plus 1000 times the name of the cell. This formula gives generated names that are predictable and can be used on other cell cards and on tally cards. This method, however, limits cell names and original surface names to no more than three digits. These generated surfaces are only the bounding surfaces of the transformed cell, not the surfaces of any universe that fills it. MCNP requires only one full description of each universe, no matter how many times that universe is referenced in the problem.

3. LAT Lattice Card

LAT=1 means the lattice is made of hexahedra, solids with six faces. LAT=2 means the lattice is made of hexagonal prisms, solids with eight faces. A nonzero entry on the LAT card means that the corresponding cell is the (0,0,0) element of a lattice. The cell description of a lattice cell has two main purposes. It is a standard MCNP cell description, and the order of specification of the surfaces of the cell identifies which lattice element lies beyond each surface.

After you have designed your lattice, decide which element you want to be the (0,0,0) element and in which directions in the lattice you want the three lattice indices to increase. In the case of a hexagonal prism lattice you have two constraints: the first and second indices must increase across adjacent surfaces and the third index must increase in one or the other direction along the length of the prism. You will then enter the bounding surfaces of the (0,0,0) element on the cell card in the right order, in accordance with the following conventions. For a hexahedral lattice cell, beyond the first surface listed is the (1,0,0) element, beyond the second surface listed is the (-1,0,0) element, then the (0,1,0), (0,-1,0), (0,0,1), and (0,0,-1) lattice elements in that order. This method provides the order of arrangement of the lattice to the code so that when you specify element (7,9,3), the code knows which one that is. For a hexagonal prism lattice cell, on the opposite side of the first surface listed is element (1,0,0), opposite the second listed surface is (-1,0,0), then (0,1,0), (0,-1,0), (-1,1,0), (1,-1,0), (0,0,1), and (0,0,-1). These last two surfaces must be the base surfaces of the prism. Example 7, page 4–35, illustrates a hexagonal prism lattice cell.

The hexahedra need not be rectangular and the hexagonal prisms need not be regular, but the lattices made out of them must fill space exactly. This means that opposite sides have to be identical and parallel. A hexahedral lattice cell may be infinite in one or two of its dimensions. A hexagonal prism lattice cell may be infinite in the direction along the length of the prism. The cross section must be convex (no butterflies). It does not matter whether the lattice is left-handed or right-handed. A lattice must be the only thing in its universe. The real world (universe level 0) itself can be a lattice. If a particle leaves the last cell of a real-world, limited-extent lattice (see the FILL card for how the extent of a lattice can be limited), it is killed (escapes).

4. FILL Fill Card

A nonzero entry on the FILL card indicates the number of the universe that fills the corresponding cell. The same number on the U card identifies the cells making up the filling universe. The FILL entry may optionally be followed by, in parentheses, either a transformation number or the transformation itself. This transformation is between the coordinate systems of the filled cell and the filling universe, with the universe considered to be in the auxiliary coordinate system. If no transformation is specified, the universe inherits the transformation, if any, of the filled cell. A ∗FILL may be used if the rotation matrix entries are angles in degrees rather than cosines. In the data card section of the INP file you cannot have both a FILL and a ∗FILL entry. If you want to enter some angles by degrees (∗FILL) and some angles by cosines (FILL), all FILL and ∗FILL data must be placed on the cell cards of the INP file.

If the filled cell is a lattice, the FILL specification can be either a single entry, as described above, or an array. If it is a single entry, every cell of the lattice is filled by the same universe. If it is an array, the portion of the lattice covered by the array is filled and the rest of the lattice does not exist. It is possible to fill various elements of the lattice with different universes, as shown below and in examples in Chapter 4, section III beginning on page 4–20.

The array specification for a cell filled by a lattice has three dimension declarators followed by the array values themselves. The dimension declarators define the ranges of the three lattice indices. They are in the same form as in Fortran, but both lower and upper bounds must be explicitly stated with positive, negative, or zero integers, separated by a colon. The indices of each lattice element are determined by its location with respect to the (0,0,0) element. Reread the LAT card section, if needed, with particular emphasis on how the order of specification of the surfaces of the cell

identifies the ordering of the lattice elements. The first two surfaces listed on the cell card define the direction of the first lattice index. The numerical range of the indices depends on where in the lattice the (0,0,0) element is located. For example, −5:5, 0:10, and −10:0 all define a range of 11 elements. The third and fourth surfaces listed in the cell description define the direction of the second lattice index.

The array values follow the dimension declarators. Each element in the array corresponds to an element in the lattice. Only those elements of the lattice that correspond to elements in the array actually exist. The value of each array element is the number of the universe that is to fill the corresponding lattice. There are two values that can be used in the array that have special meanings. A zero in a real world (level zero) lattice means that the lattice element does not exist, making it possible, in effect, to specify a nonrectangular array. If the array value is the same as the number of the universe of the lattice, that element is not filled with any universe but with the material specified on the cell card for the lattice cell. A real world (level zero) lattice, by default, is universe zero and can only be universe zero. Therefore, using the universe number of the lattice as an array value to fill that element with the cell material is not possible. As with a single entry FILL specification, any value in the array optionally can be followed by, in parentheses, a transformation number or the transformation itself.

Example: FILL=0:2 1:2 0:1 4 4 2 0 4 0 4 3 3 0 4 0

Only eight elements of this lattice exist. Elements (0,1,0), (1,1,0), (1,2,0), (0,1,1), and (1,2,1) are filled with universe 4. Element (2,1,0) is filled with universe 2. Elements (1,1,1) and (2,1,1) are filled with universe 3.

5. TRn Coordinate Transformation Card

Form: TRn O_1 O_2 O_3 B_1 B_2 B_3 B_4 B_5 B_6 B_7 B_8 B_9 M

n	=	number of the transformation: $1 \le n \le 999$. ∗TRn means that the B_i are angles in degrees rather than being the cosines of the angles.
$O_1\ O_2\ O_3$	=	displacement vector of the transformation.
B_1 to B_9	=	rotation matrix of the transformation.
M	=	1 (the default) means that the displacement vector is the location of the origin of the auxiliary coordinate system, defined in the main system.
	=	−1 means that the displacement vector is the location of the origin of the main coordinate system, defined in the auxiliary system.

Default: TRn 0 0 0 1 0 0 0 1 0 0 0 1 1

Use: Optional

The maximum number of transformations in a single problem is 999. A cone of one sheet can be rotated only from being on or parallel to one coordinate axis to being on or parallel to another coordinate axis (multiples of 90°). A cone of one sheet can have any origin displacement vector

appropriate to the problem. A cone of two sheets can be transformed anywhere. A cone of two sheets with an ambiguity surface in the cell description to cut off one half (the cell looks like one sheet) can be transformed. The ambiguity surface must have the same transformation number as the cone of two sheets. Ambiguity surfaces are described in Chapter 2 on page 2–10.

The *B* matrix specifies the relationship between the directions of the axes of the two coordinate systems. B_i is the cosine of the angle (or the angle itself, in degrees in the range from 0 to 180, if the optional asterisk is used) between an axis of the main coordinate system *(x,y,z)* and an axis of the auxiliary coordinate system $x'y'z'$ as follows:

Element	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9
Axes	x,x'	y,x'	z,x'	x,y'	y,y'	z,y'	x,z'	y,z'	z,z'

The meanings of the B_i do not depend on M. It is usually not necessary to enter all of the elements of the *B* matrix. These patterns are acceptable:

1. All nine elements.
2. Two of the three vectors either way in the matrix (6 values). MCNP will create the third vector by cross product.
3. One vector each way in the matrix (5 values). The component in common must be less than 1. MCNP will fill out the matrix by the Eulerian angles scheme.
4. One vector (3 values). MCNP will create the other two vectors in some arbitrary way.
5. None. MCNP will create the identity matrix.

A vector consists of the three elements in either a row or a column in the matrix. In all cases, MCNP cleans up any small nonorthogonality and normalizes the matrix. In this process, exact vectors like (1,0,0) are left unchanged. A warning message is issued if the nonorthogonality is more than about 0.001 radian.

Pattern #5 is appropriate when the transformation is a pure translation. Pattern #4 is appropriate when the auxiliary coordinate system is being used to describe a set of surfaces that are all surfaces of rotation about a common skew axis. Patterns 2 and 3 are about equally useful in more general cases. Pattern #1 is required if one of the systems is right-handed and the other is left-handed.

Coordinate transformations in MCNP are used to simplify the geometrical description of surfaces and to relate the coordinate system of a surface source problem to the coordinate system of the problem that wrote the surface source file. See the surface source SSR card on page 3–72. Periodic boundary surfaces cannot have surface transformations.

To use a transformation to simplify the description of a surface, choose an auxiliary coordinate system in which the description of the surface is easy, include a transformation number n on the surface card, and specify the transformation on a TRn card. See Chapter 4 page 4–16 for an example showing how much easier it is to specify a skewed cylinder this way than as a GQ surface. Often a whole cluster of cells will have a common natural coordinate system. All of their surfaces can be described in that system, which can then be specified by a single TRn card.

Example: 17 4 PX 5

TR4 7 .9 1.3 0 –1 0 0 0 1 –1 0 0

Surface 17 is set up in an auxiliary coordinate system that is related to the main coordinate system by transformation number 4. (Presumably there are many other surfaces in this problem that are using the same transformation, probably because they came from the input file of an earlier problem. Otherwise there would be no reason to use a transformation to set up a surface as simple as a plane perpendicular to a coordinate axis.) MCNP will produce coefficients in the main coordinate system as if surface 17 had been entered as

17 P 0 –1 0 4.1

It will not produce

17 PY 4.1 .

The surface represented by PY as shown above has the wrong sense. More examples of the transformation are in Chapter 4 beginning on page 4–16.

6. URAN Stochastic Geometry Card for HTGRs

Form: URAN n_1 dx_1 dy_1 dz_1 n_2 dx_2 dy_2 dz_2

n_1 = Universe number for applying stochastic transformation (only when used to fill a lattice element)
dx_1 = maximum translation in +/- x-direction
dy_1 = maximum translation in +/- y-direction
dz_1 = maximum translation in +/- z-direction

n_2, dx_2, dy_2, dz_2 – optional second stochastic transformation universe and parameters

Default: None

The URAN card provides a limited means of modeling stochastic geometry in MCNP for both fixed-source and eigenvalue problems. It is primarily intended for modeling the randomly located fuel kernels in high-temperature gas-cooled reactor (HTGR) geometries. (This feature may have other possible applications, but users should proceed carefully and perform their own verification calculations to ensure that the feature adequately represents the physical problem they are modeling.)

MCNP has been frequently used to model HTGRs with explicit geometric representation of fuel compacts or pebbles, including the microscopic fuel kernels within them.[6,7] Each fuel kernel typically has a spherical (~0.5 mm diameter) uranium oxycarbide region surrounded by layers of graphite, pyrolytic graphite, and silicon carbide. Modular HTGRs contain cylindrical fuel compacts filled with randomly located fuel kernels in a graphite matrix. Pebble bed HTGRs contain spherical fuel pebbles filled with randomly located fuel kernels in a graphite matrix.

Modeling these geometries in multigroup deterministic codes requires the use of shielding factors to account for the double-heterogeneities (i.e., fuel kernels and fuel particles). Monte Carlo codes that permit hierarchical geometry models, such as MCNP with its embedded lattices and universes, can explicitly model the pebble bed double-heterogeneities. The random locations of fuel kernels

within each fuel compact or pebble are typically modeled in MCNP using a regular lattice arrangement, ignoring any randomness.

To provide a limited form of randomness to the locations of fuel kernels in HTGR models, the URAN card may be used to flag selected universes in a lattice as stochastic. This feature provides an additional, random transformation to the geometry each time a neutron enters the lattice element. That is, when a neutron enters a lattice element containing an embedded universe flagged as stochastic, the universe coordinates are transformed randomly according to

$$x = x + (2\xi_1 - 1) \cdot \delta_X$$

$$y = y + (2\xi_2 - 1) \cdot \delta_Y$$

$$z = z + (2\xi_3 - 1) \cdot \delta_Z$$

where ξ_1, ξ_2, ξ_3 are random numbers uniformly distributed on (0,1), and $\delta_X, \delta_Y, \delta_Z$ are user-defined parameters supplied on the URAN card. Different translation parameters can be declared for different levels of the geometry, and the random translations are performed only upon entering lattice elements containing universes that the user declares as stochastic on the URAN card. **To preserve mass and packing fractions, the translation parameters should be chosen such that fuel kernels or other objects are not displaced beyond the edges of the enclosing cell or lattice element.**

In addition to the random translation applied to a neutron entering a stochastic universe, special treatment is needed for saving the fission sites in an eigenvalue calculation. When a fission occurs and the site parameters are saved in the fission bank, the current values of the random translation parameters must be saved along with the normal fission site data. In the next cycle of the calculation, these saved translation parameters are used for the neutron starting at that fission site, so as to continue the flight from the same stochastic realization in effect when the site was saved.

This stochastic geometry treatment has been verified for several realistic HTGR problems.[6,7] There is no stochastic geometry plotting capability associated with the URAN card. **Users should be extremely cautious in supplying information using the URAN card because MCNP has no means of checking whether the supplied parameters properly represent the physical model being simulated.**

C. Variance Reduction

The following cards define parameters for variance reduction cards.

Either an IMP or WWN card is required; most of the other cards are for optional variance reduction techniques.

Entries on a cell or surface parameter card correspond in order to the cell or surface cards that appear earlier in the INP file. To get to the particular cell(s) or surface(s) on a card, you must supply the appropriate default values on the cards as spacers (the nR repeat or nJ jump features may help). The number of entries on a cell or surface parameter card should always equal the number of cells or surfaces in the problem or a FATAL error will result.

Many of these cards require a knowledge of both the Monte Carlo method and the particular variance reduction technique being used. Chapter 2 and its references may provide some of this knowledge.

1. IMP Cell Importance Cards

Form: IMP:*n* $x_1\ x_2\ \ldots\ x_i\ \ldots\ x_I$

n = *N* for neutrons, *P* for photons, *E* for electrons. *N,P* or *P,E* or *N,P,E* is allowed if importances are the same for different particle types.
x_i = importance for cell *i*
I = number of cells in the problem

Default: If an IMP:P card is omitted in a MODE N P problem, all photon cell importances are set to unity unless the neutron importance is 0. Then the photon importance is 0 also.

Use: An IMP:n card is required with an entry for every cell unless a WWN weight window bound card is used.

The importance of a cell is used to terminate the particle's history if the importance is zero, for geometry splitting and Russian roulette as described in Chapter 2 on page 2–145 to help particles move to more important regions of the geometry, and in the weight cutoff game described on page

3–140. An importance in a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell.

Neutrons, photons, and electrons can be split differently by having separate IMP:N, IMP:P, and IMP:E cards. It is a FATAL error if the number of entries on any IMP:n card is not equal to the number of cells in the problem. The nJ feature is allowed and provides the default importance of zero. The nR repeat and nM multiply features are especially useful with this card.

Example: IMP:N 1 2 2M 0 1 20R

The neutron importance of cell 1 is 1, cell 2 is 2, cell 3 is 4, cell 4 is 0, and cells 5 through 25 is 1. A track will be split 2 for 1 going from cell 2 into cell 3, each new track having half the weight of the original track before splitting. A track moving in the opposite direction will be terminated in about half (that is, probability=0.5) the cases but followed in the remaining cases with twice the weight.

Remember that both tracks and contributions to detectors and DXTRAN spheres are killed in cells of zero importance.

A track will neither be split nor rouletted when it enters a void cell even if the importance ratio of the adjacent cells would normally call for a split or roulette. However, the importance of the nonvoid cell it left is remembered and splitting or Russian roulette will be played when the particle next enters a nonvoid cell. As an example of the benefit of not splitting into a void, consider a long, void pipe surrounded by a material like concrete where the importances are decreasing radially away from the pipe. Considerable computer time can be wasted by tracks bouncing back and forth across the pipe and doing nothing but splitting, then immediately undergoing roulette. Splitting into a void increases the time per history but has no counterbalancing effect on the expected history variance. Thus the figure of merit (FOM) is reduced by the increased time per history.

If a superimposed weight window mesh is used, the IMP card is required but splitting/Russian roulette is not done at surfaces. Cell importances are only used for the weight cutoff game in zero–window meshes.

2. VAR Variance Reduction Card

Form: VAR keyword=specification

Default: No modifications of variance reduction methods

Use: Optional

The VAR card is used to control variance reduction methods across several variance reduction techniques. Current keyword and specification options are:

RR = ‘off’ or ‘no’

Turns off the roulette game for weight windows and cell/energy/time importances.

NOTE: Turning off roulette can be helpful for F8 tallies using variance reduction.

3. ESPLT Energy Splitting and Roulette Card

Form: ESPLT:n $R_1 E_1$ ... R_{20} E_{20}

n = N for neutrons, P for photons, E for electrons.

Default: Omission of this card means that energy splitting will not take place for those particles for which the card is omitted.

Use: Optional; cannot be used in multigroup calculations

The meanings of the R_i differ depending on whether or not there is a weight window present for the particle type n, as will be explained in the next two sections on pages 3–36 and 3–37. (Note that the R_i's on the ESPLT card are the splitting/roulette ratios for decreasing energy in contrast with the TSPLT card.) These splitting/roulette ratios are internally converted in the code to an absolute importance function with an $R_0 = 1$ inserted to set the importance to unity for energies greater than the maximum of the E_i.

The ESPLT card is intended to be used with a time-dependent weight window. The ESPLT card is not recommended for an energy-dependent weight window as these two cards may interfere with one another. Instead of a single- range weight window and an ESPLT card, consider using an energy-dependent weight window.

Without Weight Window

E_i = energy (MeV) at which particles are to undergo splitting or Russian roulette.

For particles crossing E_i on a decrease in energy:

R_i = number of tracks into which a particle will be split (for $R_i > 1$) or probability of Russian roulette (for $0 < R_i < 1$).

For particles crossing E_i on an increase in energy (e.g. fission) generally (see exception for $R_1 < 0$):

$1/R_i$ = number of tracks into which a particle will be split (for $1/R_i > 1$) or probability of Russian roulette (for $0 < 1/R_i < 1$).

Exception: If the first entry is negative (i.e. $R_1 < 0$), then no game is played on energy increases.

Default: Omission of this card means that energy importances will not take place for those particles for which the card is omitted.

The ESPLT card allows for problem-wide splitting and Russian roulette of particles in energy, as the IMP card allows for splitting and Russian roulette as a function of geometry. The ESPLT card can be used with all problems except for multigroup problems. The changes to a particle's weight caused by the ESPLT card will create compensating weight adjustments to the weight cutoff and weight-window values.

The entries on this card consist of pairs of energy-importance ratio parameters, R_i and E_i, with a maximum of twenty pairs allowed. A warning message is issued if the E_i are not monotonic. R_i can be noninteger and also can be between 0 and 1. For an energy decrease below an E_i with an associated R_i greater than 1, particle splitting will occur. For R_i between 0 and 1, R_i becomes the survival probability in the Russian roulette game. If R_i is greater than 0, when the energy increases above an E_i and $1/R_i$ is greater than 1, particle splitting will occur. A $1/R_i$ between 0 and 1 is the survival probability in the Russian roulette game. If a particle's energy becomes less than E_i, the specified splitting or roulette is sampled.

If more than one energy boundary is passed during a particle trajectory, the product of the R_i values is used to determine the outcome.

If the particle's energy falls below E_i, the specified splitting or roulette always occurs. If the particle's energy increases above E_i, the inverse game is normally played (see next paragraph for an exception). For example, suppose roulette is specified at 0.1 MeV with a survival probability of 0.5; if a particle's energy increases above 0.1 MeV, it is split 2 for 1.

A neutron's energy may increase by fission or from thermal up-scattering. There are cases when it may not be desirable to have the inverse splitting or roulette game played on energy increases (particularly in a fission-dominated problem). If $R_1 < 0$, then splitting or roulette will be played only for energy decreases and not for energy increases.

```
Example:   ESPLT:N 2 .1   2 .01   .25 .001
```

This example specifies a 2 for 1 split when the neutron energy falls below 0.1 MeV, another 2 for 1 split when the energy falls below 0.01 MeV, and Russian roulette with survival probability of 0.25 when the energy falls below 0.001 MeV. Thus a neutron that enters a collision at 0.5 MeV and exits at 0.005 MeV will be split 4 to 1.

With Weight Window

If weight windows are specified, then (by default) the energy splitting/roulette is accomplished solely with the weight window. The R_i in this case are energy importance modifications to the weight window. That is, if the energy falls below E_i the existing weight windows will be adjusted by dividing the windows by R_i. Conversely, if the energy increases above E_i, then the weight windows are multiplied by R_i. If more than one energy boundary is crossed, the windows are adjusted by the product of the R_i values.

```
Example:   ESPLT:N 2 .1  2 .01  .25 .001
           WWP:N   5 3 5 0 0 0 J J
```

This example divides the weight windows by 2 when the energy falls below 0.1 MeV, divides by 2 again when the energy falls below 0.01 MeV, and divides by 0.2 when the energy falls below 0.001 MeV.

If the eighth entry on the WWP card is 1 (0 is the default), then in addition to the weight window adjustment of the previous paragraph, the particle will be explicitly split or rouletted upon crossing E_i, just as is the case without a weight window. It is anticipated that the default will be appropriate for almost all problems.

Example: ESPLT:N 2 .1 2 .01 .25 .001
WWP:N 5 3 5 0 0 0 J 1

This example divides the weight windows by 2 when the energy falls below 0.1 MeV, divides by 2 again when the energy falls below 0.01 MeV, and divides by 0.2 when the energy falls below 0.001 MeV. In addition, this example specifies a 2 for 1 split when the neutron energy falls below 0.1 MeV, another 2 for 1 split when the neutron energy falls below 0.01 MeV, and Russian roulette with a survival probability of 0.2 when the neutron energy falls below 0.001 MeV.

4. TSPLT Time Splitting and Roulette Card

Form: TSPLT:n $R_1T_1...R_{20}T_{20}$

n = N for neutrons, P for photons, E for electrons.

Default: Omission of this card means that time splitting will not take place for those particles for which the card is omitted.

Use: Optional; cannot be used in multigroup calculations

The meanings of the R_i differ depending on whether or not there is a weight window present for the particle type n, as will be explained in the next two sections on pages 3–39 and 3–39. (Note that the R_i's on the TSPLT card are the splitting/roulette ratios for increasing time in contrast with the ESPLT card.) These splitting/roulette ratios are internally converted in the code to an absolute importance function with an R_0 =1 inserted to set the importance to unity for times less than the minimum of the T_i.

The TSPLT card is intended to be used with an energy-dependent weight window. The TSPLT card is not recommended for a time-dependent weight window as these two cards may interfere with one another. Instead of a single- range weight window and a TSPLT card, consider using a time-dependent weight window.

Normally in a coupled mode problem (for example, MODE N P), if particle type x is important late in time, then all particles producing particle type x will also be important late in time. Thus in a MODE N P problem (for example, if a TSPLT:P card is specified), then a TSPLT:N card would normally be specified as well. Note also that if the neutrons are important late in time, then the photons are often important late in time. For these reasons, it is suggested that the user have a TSPLT card for each particle type.

Without Weight Window

R_i = number of tracks into which a particle will be split (for $R_i > 1$) or probability of Russian roulette (for $0 < R_i < 1$).

T_i = time (shakes) at which particles are to undergo splitting or Russian roulette. T_i must be monotonically increasing or decreasing.

Default: Omission of this card means that time importances will not take place for those particles for which the card is omitted.

The TSPLT card allows for problem-wide splitting and Russian roulette of particles in time, as the IMP card allows for splitting and Russian roulette as a function of geometry. The TSPLT card can be used with all problems except for multigroup problems. The changes to a particle's weight caused by the TSPLT card will create compensating weight adjustments to the weight cutoff and weight-window values.

The entries on this card consist of pairs of time-importance ratio parameters, R_i and T_i, with a maximum of twenty pairs allowed. A warning message is issued if the T_i are not monotonic. R_i can be noninteger and also can be between 0 and 1. For R_i greater than 1, particle splitting will occur. For R_i between 0 and 1, R_i becomes the survival probability in the Russian roulette game. T_i is in units of shakes. If a particle's time becomes greater than T_i, the specified splitting or roulette is sampled.

If more than one time boundary is passed during a particle trajectory, the product of the R_i values is used to determine the outcome.

```
Example:    TSPLT:N 2 100   2 1000   0.2 10000
```

This example specifies a 2 for 1 split when the neutron time exceeds 100 shakes, another 2 for 1 split when the time exceeds 1000 shakes, and Russian roulette with a survival probability of 0.2 when the time exceeds 10000 shakes. A neutron that crosses both 1000 and 10000 shakes will have a survival probability of 0.4.

With Weight Window

If weight windows are specified, then (by default) the time splitting/roulette is accomplished solely with the weight window. The R_i in this case are time importance modifications to the weight window. That is, if the particle crosses T_i, the existing weight windows will be adjusted by dividing the windows by R_i. If more than one time boundary is crossed, the windows are divided by the product of the R_i values.

```
Example:    TSPLT:N 2 100   2 1000   0.2 10000
            WWP:N   5 3 5 0 0 0 J J
```

This example divides the weight windows by 2 when the neutron time exceeds 100 shakes, divides by 2 again when the time exceeds 1000 shakes, and divides by 0.2 when the time exceeds 10000

shakes. Thus the weight window will be divided by a factor of 4 for a particle whose time at the start of the transport step was 90 shakes and whose time at the end of the transport step was 1010 shakes.

If the eighth entry on the WWP card is 1 (0 is the default), then in addition to the weight-window adjustment of the previous paragraph, the particle will be explicitly time-split or rouletted upon crossing T_i, just as is the case without a weight window. It is anticipated that the default will be appropriate for almost all problems.

Example: TSPLT:N 2 100 2 1000 0.2 10000
WWP:N 5 3 5 0 0 0 J 1

This example divides the weight windows by 2 when the neutron time exceeds 100 shakes, divides by 2 again when the time exceeds 1000 shakes, and divides by 0.2 when the time exceeds 10000 shakes. In addition, this example specifies a 2 for 1 split when the neutron time exceeds 100 shakes, another 2 for 1 split when the time exceeds 1000 shakes, and a Russian roulette survival probability of 0.2 when the time exceeds 10000 shakes.

5. PWT Photon Weight Card

Form: PWT W_1 W_2 ... W_i ... W_I

W_i = relative threshold weight of photons produced at neutron collisions in cell i
I = number of cells in the problem.

Default: -1 for neutrons and photons on the MODE card.

Use: Recommended for MODE N P and MODE N P E problems; is not used with weight windows turned on.

The PWT card is used in MODE N P or MODE N P E problems. Its purpose is to control the number and weight of neutron-induced photons produced at neutron collisions. Only prompt photons are produced from neutron collisions. Delayed gammas are neglected by MCNP. The PWT card application is further discussed in Chapter 2 on page 2–32.

For each cell with a *positive* W_i entry, only neutron-induced photons with weights greater than $W_i * I_s/I_i$ are produced, where I_s and I_i are the neutron importances of the collision and source cells, respectively. Russian roulette is played to determine if a neutron-induced photon with a weight below this value survives.

For each cell with a *negative* W_i entry, only neutron-induced photons with weights greater than $-W_i * W_s * I_s/I_i$ are produced, where W_s is the starting weight of the neutron for the history being followed, and I_s and I_i are the neutron importances of the collision and source cells, respectively. Russian roulette is played to determine if a neutron-induced photon with weight below this value survives.

If $W_i = 0$, exactly one photon will be generated at each neutron collision in cell i, provided that photon production is possible. If $W_i = -1.0E6$, photon production in cell i is turned off.

The PWT card controls the production of neutron-induced photons by comparing the total weight of photons produced with a relative threshold weight specified on the PWT card. This threshold weight is relative to the neutron cell importance and, if $W_i < 0$, to the source neutron weight. If more neutron-induced photons are desired, the absolute value of W_i should be lowered to reduce the weight and therefore increase the number of photons. If fewer neutron-induced photons are desired, the absolute value of W_i should be increased.

For problems using photon cell importances (IMP:P), rather than photon weight windows (WWNn:P), a good first guess for PWT card entries is either the default value, $W_i = -1$, or set W_i in every cell to the average source weight.

For problems with photon weight windows, the PWT card is ignored and the correct number of photons are produced within the weight windows.

6. EXT Exponential Transform Card

Form: EXT:*n* A_1 A_2 ... A_i ... A_I

n = N for neutrons, P for photons, not available for electrons.
A_i = entry for cell i. Each entry A_i is of the form $A = QVm$, where Q describes the amount of stretching and Vm defines the stretching direction.
I = number of cells in the problem.

Default: No transform, $A_i = 0$.

Use: Optional. Use cautiously. Weight windows strongly recommended.

The exponential transform should not be used in the same cell as forced collisions or without good weight control, such as the weight window. The transform works well only when the particle flux has an exponential distribution, such as in highly absorbing problems.

The exponential transform method stretches the path length between collisions in a preferred direction by adjusting the total cross section as follows:

$\Sigma_t^* = \Sigma_t(1 - p\mu)$, where
Σ_t^* = artificially adjusted total cross section;
Σ_t = true total cross section;
p = the stretching parameter; and
μ = cosine of angle between particle direction and stretching direction.

The stretching parameter p can be specified by the stretching entry Q three ways:

$Q = 0$, $p = 0$ exponential transform not used
$Q = p$, $0 < p < 1$ constant stretching parameter
$Q = S$, $p = \Sigma_a\Sigma_t$, where Σ_a is the capture cross section.

Letting $p = \Sigma_a/\Sigma_t$ can be used for implicit capture along a flight path, as described in Chapter 2 on page 2–34.

The stretching direction is defined by the *Vm* part of each A_i entry on the EXT card with three options.

1. Omit the *Vm* part of the A_i entry; that is, enter only the stretching entry $A_i = Q$ for a given cell. This causes the stretching to be in the particle direction ($\mu = 1$), independent of the particle direction and is not recommended unless you want to do implicit capture along a flight path, in which case $A_i = Q = S$ and the distance to scatter rather than the distance to collision is sampled.
2. Specify the stretching direction as *Vm*, the line from the collision point to the point $(x_{m'}y_{m'}z_m)$, where $(x_{m'}y_{m'}z_m)$ is specified on the VECT card (see page 3–42). The direction cosine μ is now the cosine of the angle between the particle direction and the line drawn from the collision point to point $(x_{m'}y_{m'}z_m)$. The sign of A_i governs whether stretching is toward or away from $(x_{m'}y_{m'}z_m)$.
3. Specify the stretching direction as $Vm = X$, Y, or Z, so the direction cosine μ is the cosine of the angle between the particle direction and the X-, Y-, or Z-axis, respectively. The sign of A_i governs whether stretching is toward or away from the X-, Y-, or Z-axis.

Example:
```
EXT:N   0    0    .7V2    S    –SV2   –.6V9   0    .5V9    SZ   –.4X
VECT    V9   0 0 0    V2   1 1 1
```

The 10 entries are for the 10 cells in this problem. Path length stretching is not turned on for photons or for cells 1, 2, and 7. Following is a summary of path length stretching in the other cells .

Cell	A_i	Q	Vm	Stretching Parameter	Direction
3	.7V2	.7	V2	$p = .7$	toward point (1,1,1)
4	S	S		$p = \Sigma_a/\Sigma_t$	particle direction
5	–SV2	S	–V2	$p = \Sigma_a/\Sigma_t$	away from point (1,1,1)
6	–.6V9	.6	–V9	$p = .6$	away from origin
8	.5V9	.5	V9	$p = .5$	toward origin
9	SZ	S	Z	$p = \Sigma_a/\Sigma_t$	along +*Z*-axis
10	–.4X	.4	–X	$p = .4$	along –*X*-axis

7. VECT Vector Input Card

Form: VECT *Vm* $x_m\ y_m\ z_m$ ... *Vn* $x_n\ y_n\ z_n$ ...

m,n = any numbers to uniquely identify vectors *Vm*, *Vn* ...
$x_m\ y_m\ z_m$ = coordinate triplets to define vector *Vm*.

Default: None.

Use: Optional.

The entries on the VECT card are quadruplets which define any number of vectors for either the exponential transform or user patches. See the EXT card (page 3–41) for a usage example.

8. FCL Forced Collision Card

Form: FCL:n $x_1\ x_2 \ldots x_i \ldots x_I$

n = N for neutrons, P for photons, not available for electrons.
x_i = forced collision control for cell i, where $-1 \le x_i \le 1$
I = number of cells in the problem.

Default: $x_i = 0$, no forced collisions.

Use: Optional. Exercise caution.

The FCL card controls the forcing of neutron or photon collisions in each cell. This is particularly useful for generating contributions to point detectors or DXTRAN spheres. The weight window game at surfaces is not played when entering forced collision cells.

If $x_i \neq 0$, all particles entering cell i are split into collided and uncollided parts with the appropriate weight adjustment (see Chapter 2 page 2–156). If $|x_i| < 1$, Russian roulette is played on the collided parts with survival probability $|x_i|$ to keep the number of collided histories from getting too large. Fractional x_i entries are recommended if a number of forced collision cells are adjacent to each other.

If $x_i < 0$, the forced collision process applies only to particles entering the cell. After the forced collision, the weight cutoff is ignored and all subsequent collisions are handled in the usual analog manner. Weight windows are not ignored and are applied after contributions are made to detectors and DXTRAN spheres.

If $x_i > 0$, the forced collision process applies both to particles entering cell i and to the collided particles surviving the weight cutoff or weight-window games. Particles will continue to be split into uncollided and (with probability $|x_i|$) collided parts until killed by either weight cutoff or weight windows.

Usage tips:

Let $x_i = 1$ or -1 unless a number of forced collision cells are adjacent to each other or the number of forced collision particles produced is higher than desired. Then fractional values are usually needed.

When cell–based weight window bounds bracket the typical weight entering the cell, choose $x_i > 0$. When cell–based weight window bounds bracket the weight typical of forced collision particles, choose $x_i < 0$. For mesh–based windows, $x_i > 0$ is usually recommended.

When using importances, use $x_i > 0$ because $x_i < 0$ turns off the weight-cutoff game.

9. Weight Window Cards

Weight windows can be either cell-based or mesh-based. Mesh-based windows eliminate the need to subdivide geometries finely enough for importance functions.

Weight windows provide an alternative means to importances (IMP:n cards) and energy splitting (ESPLT:n cards) for specifying space and energy importance functions. They also can provide time–dependent importance functions. The advantages of weight windows are that they (1) provide an importance function in space and time or space and energy; (2) control particle weights; (3) are more compatible with other variance reduction features such as the exponential transform (EXT:n card); (4) can be applied at surface crossings, collisions, or both; (5) control the severity of splitting or Russian roulette; (6) can be turned off in selected space or energy regions; and (7) can be automatically generated by the weight window generator. The disadvantages are that (1) weight windows are not as straightforward as importances; and (2) when the source weight is changed, the weight windows may have to be renormalized. Reading the section on weight windows in Chapter 2, beginning on page 2–147, is strongly advised.

In repeated structures, an additional difference between cell importances and weight windows exists. For cell importances (IMP card), an importance in a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell (see page 3–35) and action is taken based on the ratio of importances. The weight window bounds are absolute bounds, not multipliers. The lower window bound in cell j and energy range k is unaffected by the repeated structures. Mesh based windows are recommended in repeated structures.

1. WWE Weight Window Energies or Times

Form: WWE:*n* $E_1\ E_2 \ldots E_i \ldots E_j;\ j \le 99$

n = N for neutrons, P for photons, E for electrons
E_i = upper energy or time bound of i^{th} window
E_{i-1} = lower energy or time bound of i^{th} window
E_0 = 0, by definition

Default: If this card is omitted and the weight window is used, a single energy or time interval is established corresponding to the energy or time limits of the problem being run.

Use: Optional. Use only with WWN card.

The WWE card defines the energy or time intervals for which weight window bounds will be specified on the WWN card. The minimum energy, which is not entered on the WWE card, is zero. The minimum time is $-\infty$. Whether energy or time is specified is determined by the 6th entry on the WWP card.

2. WWN Cell–Based Weight Window Bounds

Form: WWN*i*:*n* $w_{i1}\ w_{i2} \ldots w_{ij} \ldots w_{iJ}$

n = N for neutrons, P for photons, E for electrons
w_{ij} = lower weight bound in cell j and energy or time interval $E_{i-1} < E < E_i$, $E_0 = 0$, as defined on the WWE card. If no WWE card, $i = 1$.
J = number of cells in the problem.

Default: None.

Use: Weight windows (WWN and WWP cards) are required unless importances (IMP card) or mesh-based windows are used.

The WWN card specifies the lower weight bound of the space- and energy-dependent weight windows in cells. It must be used with the WWP card and, if the weight windows are energy or time dependent, with the WWE card. The IMP:n card should not be used if a WWN:n card, where n is the same particle type, is used.

If $w_{ij} < 0$, any particle entering cell j is killed. That is, negative entries correspond to zero importance. If negative entries are used for one energy group, they should be used for all the other energy groups in the same cell.

If $w_{ij} > 0$, particles entering or colliding in cell j are split or rouletted according to the options on the WWP card (see page 3–46).

If $w_{ij} = 0$, the weight window game is turned off in cell j for energy bin i and the weight cutoff game is turned on with a 1-for-2 roulette limit. Sometimes it is useful to specify the weight cutoffs on the CUT card as the lowest permissible weights desired in the problem. Otherwise, too many particles entering cells with $w_{ij} = 0$ may be killed by the weight cutoff. Usually the 1-for-2 roulette limitation

is sufficient to use the default weight cutoffs, but caution is needed and the problem output file should be examined carefully. The capability to turn the weight window game off in various energy and spatial regions is useful when these regions cannot be characterized by a single importance function or set of weight window bounds.

In terms of the weight window, particle weight bounds are always absolute and not relative; you have to explicitly account for weight changes from any other variance reduction techniques such as source biasing. You must specify one lower weight bound per cell per energy interval. There must be no holes in the specification; that is, if WWNi is specified, WWNj for $1 < j < i$ must also be specified.

Example 1:

WWE:N	E_1	E_2	E_3	
WWN1:N	w_{11}	w_{12}	w_{13}	w_{14}
WWN2:N	w_{21}	w_{22}	w_{23}	w_{24}
WWN3:N	w_{31}	w_{32}	w_{33}	w_{34}

These cards define three energy or time intervals and the weight window bounds for a four-cell neutron problem.

Example 2: WWN1:P w_{11} w_{12} w_{13}

This card, without an accompanying WWE card, defines an energy or time independent photon weight window for a three-cell problem.

10. WWP Weight Window Parameter Card

Form: WWP:*n* WUPN WSURVN MXSPLN MWHERE SWITCHN MTIME WNORM ETSPLT

n = *N* for neutrons, *P* for photons, *E* for electrons

WUPN = If the particle weight goes above WUPN times the lower weight bound, the particle will be split.
Required: WUPN ≥ 2.

WSURVN = If the particle survives the Russian roulette game, its weight becomes MIN(WSURVN times the lower weight bound,WGT∗MXSPLN).
Required: 1 < WSURVN < WUPN.

MXSPLN = No particle will ever be split more than MXSPLN-for-one or be rouletted more harshly than one-in-MXSPLN.
MXSPLN=2 in zero window cells or meshes.
Required: MXSPLN > 1.

MWHERE = decides where to check a particle's weight.
−1 means check the weight at collisions only
0 means check the weight at surfaces and collisions
1 means check the weight at surfaces only

SWITCHN = decides where to get the lower weight window bounds.
< 0 means get them from an external WWINP file. Requires IMP card.
0 means get them from WWNi cards.
> 0 means set the lower weight window bounds equal to SWITCHN

divided by the cell importances from the IMP card.

MTIME = 0 energy dependent windows (WWE card)
1 time dependent windows (WWE card)

WNORM = >0 multiplier for weight window lower bounds

ETSPLT = 0 (default) entries on the ESPLT and TSPLT cards are used solely to scale the weight window.
1 entries on the ESPLT and TSPLT cards are used to split/roulette particles as well as scale the weight windows.
For further discussion, see the ESPLT and TSPLT cards.

Defaults: WUPN=5; WSURVN=0.6∗WUPN; MXSPLN=5; MWHERE=0; SWITCHN=0, MTIME=0, WNORM=1, ETSPLT=0

Use: Weight windows are required unless importances are used.

The WWP card contains parameters that control use of the weight window lower bounds specified on the WWN cards, the IMP cards, or an external file, depending on the value of SWITCHN. Having SWITCHN > 0 and also having WWNi cards is a FATAL error. If SWITCHN is zero, the lower weight-window bounds must be specified with the WWNi cards. If SWITCHN < 0, an external WWINP file with either cell- or mesh-based lower weight-window bounds must exist and an IMP card is required. This file name can be changed on the MCNP execution line using "WWINP = filename." The different formats of the WWINP file will indicate to the code whether the weight windows are cell or mesh based. For mesh-based weight windows, the mesh geometry will also be read from the WWINP file. The WWINP file format is provided in Appendix J beginning on page J–1.

Using Existing Cell Importances to Specify the Lower Weight Bound

An energy-independent weight window can be specified using existing importances from the IMP card and setting the fifth entry (SWITCHN) on the WWP card to a positive constant C. If this option is selected, the lower weight bounds for the cells become C/I, where I is the cell importance. The remaining entries on the WWP card are entered as described above. A suggested value for C is one in which source particles start within the weight window such as .25 times the source weight. If that is not possible, your window is probably too narrow or you need to respecify your source.

11. Weight Window Generation Cards

The weight-window generator estimates the importances of the space-energy regions of phase space specified by the user. The space-energy weight window parameters are then calculated inversely proportional to the importances.

Recall that the cell–based generator estimates the average importance of a phase-space cell. If the cells are too large, the importance variation inside the cell will be large and the average importance will not represent the cell. Inadequate geometry specification also occurs with large importance differences between adjacent cells. Fortunately, the generator provides information about whether the geometry specification is adequate for sampling purposes. If geometries are inadequately subdivided for importances, mesh-based weight windows should be used.

The user is advised to become familiar with the section on the weight window in Chapter 2, beginning on page 2–147, before trying to use the weight window generator.

1. WWG Weight Window Generation

Form: WWG I_t I_c W_g J J J J I_E

I_t = problem tally number (n of the Fn card). The particular tally bin for which the weight window generator is optimized is defined by the TFn card.

I_c = invokes cell- or mesh-based weight window generator.
> 0 means use the cell-based weight window generator with I_c as the reference cell (typically a source cell).
0 means use the mesh-based weight window generator (MESH card).

W_g = value of the generated lower weight window bound for cell I_c or for the reference mesh (see MESH card).
0 means lower bound will be half the average source weight.

J = unused

I_E toggles energy- or time-dependent weight windows.
0 means interpret WWGE card as energy bins.
1 means interpret WWGE card as time bins.

Default: No weight-window values are generated.

Use: Optional.

The WWG card causes the optimum importance function for tally I_t to be generated. For the cell-based weight-window generator, the importance function is written on WWE and WWNi cards that are printed, evaluated, and summarized in the OUTP file and are also printed on the weight-window generator output file WWOUT. For the mesh-based weight-window generator, the importance function and the mesh description are written only on the WWOUT file. (The format of the mesh-based WWOUT file is provided in Appendix J.) In either case, the generated weight window importance function easily can be used in subsequent runs using SWITCHN < 0 on the WWP card. For many problems, this importance function is superior to anything an experienced user can guess on an IMP card. To generate energy- or time-dependent weight-windows, use the WWGE card described below.

2. WWGE Weight Window Generation Energies or Times

Form: WWGE:n E_1 E_2 ... E_i ... E_j; $j \le 15$

n = N for neutrons, P for photons, E for electrons

E_i = upper energy or time bound for weight window group to be generated, $E_{i+1} > E_i$.

Default: If this card is omitted and the weight window is used, a single energy or time interval will be established corresponding to the energy/time limits of the problem being run. If the card is present but has no entries, ten energy/time bins will be generated with energies/times of $E_i = 10^{i-8}$ MeV/shake and $j = 10$. Both the single time/energy and the energy/time–dependent windows are generated.

Use: Optional.

If this card is present, time/energy-dependent weight windows are generated and written on the WWOUT file and, for cell-based weight windows, on the OUTP file. If $I_E = 1$ on the WWG card, time-dependent windows are generated. In addition, single-group energy- or time-independent weight windows are written on a separate output file, WWONE. Energy- and time-independent weight windows are useful for trouble-shooting the energy- and time-dependent weight windows on the WWOUT file. The WWONE file format is the same as that of the WWOUT file provided in Appendix J beginning on page J–1.

12. MESH Superimposed Importance Mesh for Mesh-Based Weight Window Generator

Form: MESH mesh variable=specification

Default: See Table 3.2.

Use: Required if mesh-based weight windows are used or generated.

The equal sign is optional. Keywords can be entered in any order. Special input features I, M, and R can be used except with GEOM. Table 3.2 summarizes the superimposed mesh variables and lists their defaults. The default geometry is rectangular and the default ORIGIN point is (0,0,0). The cylindrical mesh is based on right circular cylinders. The default cylindrical axis is parallel to the MCNP geometry *z* axis and the half-plane defining $\theta=0$ is the MCNP geometry positive *x* axis. The reference point must always be specified.

Table 3.2: Superimposed Mesh Variables

Variable	Meaning	Default
GEOM	Mesh geometry; either Cartesian ("xyz" or "rec") or cylindrical ("rzt" or "cyl").	xyz
REF	*x*,*y*,*z* point used to specify the normalization constant for the mesh-based weight window generator	None (variable must be present)
ORIGIN	*x*, *y*, and *z* coordinates in MCNP cell geometry of the origin (bottom center for cylindrical, or bottom, left, back corner for rectangular) of the superimposed mesh	0., 0., 0.
AXS	Vector giving the direction of the axis of the cylindrical mesh	0., 0., 1.
VEC	Vector defining, along with AXS, the plane for θ= 0	1., 0., 0.
IMESH	Locations of the coarse meshes in the *x* direction for rectangular geometry or in the *r* direction for cylindrical geometry	None
IINTS	Number of fine meshes within corresponding coarse meshes in the *x* direction for rectangular geometry or in the *r* direction for cylindrical geometry	1 in each coarse mesh
JMESH	Locations of the coarse meshes in the *y* direction for rectangular geometry or in the *z* direction for cylindrical geometry	None
JINTS	Number of fine meshes within corresponding coarse meshes in the *y* direction for rectangular geometry or in the *z* direction for cylindrical geometry	1 in each coarse mesh
KMESH	Locations of the coarse meshes in the *z* direction for rectangular geometry or in the θ direction for cylindrical geometry	None
KINTS	Number of fine meshes within corresponding coarse meshes in the *z* direction for rectangular geometry or in the θ direction for cylindrical geometry	1 in each coarse mesh

The location of the n^{th} coarse mesh in the *u* direction (ru_n in what follows) is given in terms of the most positive surface in the *u* direction. For a rectangular mesh, the coarse mesh locations rx_n, ry_n, and rz_n are given as planes perpendicular to the *x*, *y*, and *z* axes, respectively, in the MCNP cell coordinate system; thus, the ORIGIN point (x_0, y_0, z_0) is the most negative point of the mesh. For a cylindrical mesh, (r_0, z_0, θ_0) = (0., 0., 0.), corresponds to the bottom center point, which is the cylindrical ORIGIN point in the MCNP cell coordinate system. The coarse mesh locations must increase monotonically (beginning with the ORIGIN point for a rectangular mesh).

The fine meshes are evenly distributed within the n^{th} coarse mesh in the *u* direction. The mesh in which the reference point lies becomes the reference mesh for the mesh-based weight window generator; this reference mesh is analogous to the reference cell used by the cell-based weight-window generator. The mesh cell containing the REF point will have its smallest (over energy) weight window equal to the third entry on the WWG card.

For a cylindrical mesh, the AXS and VEC vectors need not be orthogonal but they must not be parallel; the one half-plane that contains them and the ORIGIN point will define $\theta = 0$. The AXS vector will remain fixed. The length of the AXS or VEC vectors must not be zero. The θ coarse mesh locations are given in revolutions and the last one must be 1.

The code uses a default value of one fine mesh per coarse mesh if IINTS, JINTS, or KINTS keywords are omitted. If IINTS, JINTS, or KINTS keywords are present, the number of entries must match the number of entries on the IMESH, JMESH, and KMESH keywords, respectively. Entries on the IINTS, JINTS, and KINTS keywords must be greater than zero. A reference point must be specified using the REF keyword.

A second method of providing a superimposed mesh is to use one that already exists, either written on the WWOUT file or on the WWONE file. To implement this method, use the WWG card with I_c=0 in conjunction with the MESH card where the only keyword is REF. The reference point must be within the superimposed mesh and must be provided because there is no reference point in either WWOUT or WWONE. If the mesh-based weight-window generator is invoked by this method, MCNP expects to read a file called WWINP. WWOUT or WWONE can be renamed in the local filespace or the files can be equivalenced on the execution line using "WWINP=filename."

It is not necessary to use mesh-based weight windows from the WWINP file in order to use the mesh from that file. Furthermore, previously generated mesh-based weight windows can be used (WWP card with SWITCHN < 0 and WWINP file in mesh format) while the mesh-based weight-window generator is simultaneously generating weight windows for a different mesh (input on the MESH card). However, it is not possible to read mesh-based weight windows from one file but a weight-window generation mesh from a different file.

The superimposed mesh should fully cover the problem geometry; i.e., the outer boundaries of the mesh should lie outside the outer boundaries of the geometry, rather than being coincident with them. This requirement guarantees that particles remain within the weight-window mesh. A line or surface source should not be made coincident with a mesh surface. A point source should never be coincident with the intersection of mesh surfaces. In particular, a line or point source should never lie on the axis of a cylindrical mesh. These guidelines also apply to the WWG reference point specified using the REF keyword.

If a particle does escape the weight-window generation mesh, the code prints a warning message giving the coordinate direction and surface number (in that direction) from which the particle escaped; for example, “warning. particle escaped wwg mesh in z direction” (the mesh index number appears with NPS on the next line). The code prints the total number of particles escaping the mesh (if any) after the tally fluctuation charts in the standard output file. Similarly, if a track starts outside the mesh, the code prints a warning message giving the coordinate direction that was missed and which side of the mesh the particle started on; for example, “warning. track started outside wwg mesh: x too great.” The code prints the total number of particles starting outside the mesh (if any) after the tally fluctuation charts in the standard output file.

I_c = 0 on the WWG card with no MESH card is a FATAL error. If AXS or VEC keywords are present and the mesh is rectangular, a warning message is printed and the keyword is ignored. If there are FATAL errors and the FATAL option is on, weight-window generation is disabled.

```
MESH:   GEOM=cyl   REF=1e–6  1e–7  0   ORIGIN=1  2  3
        IMESH   2.55   66.34
        IINTS     2      15    $ 2 fine bins from 0 to 2.55, 15 from 2.55 to 66.34
        JMESH   33.1   42.1   53.4   139.7
        JINTS     6      3      4      13
        KMESH   .5     1
        KINTS     5      5

MESH:   GEOM=rec   REF=1e–6  1e–7  0   ORIGIN=–66.34   –38.11   –60
        IMESH   –16.5   3.8   53.66
        IINTS      10     3     8   $ 10 fine bins from –66.34 to –16.5, etc.
```

13. PDn Detector Contribution Card

Form: PDn P_1 P_2 ... P_i ...P_I

n = tally number
P_i = probability of contribution to detector n from cell i
I = number of cells in the problem.

Default: $P_i = 1$.

Use: Optional. Consider also using the DD card, described on page 3–112.

The PDn card reduces the number of contributions to detector tallies from selected cells that are relatively unimportant to a given detector, thus saving computing time. At each collision in cell i, the detector tallies are made with probability P_i $(0 \le P_i \le 1)$. The tally is then increased by the factor $1/P_i$ to obtain unbiased results for all cells except those where $P_i = 0$. This enables you to increase the running speed by setting $P_i < 1$ for cells many mean free paths from the detectors. It also selectively eliminates detector contributions from cells by setting the P_i's to zero.

A default set of probabilities can be established for all tallies by use of a PD0 (zero) card. These default values will be overridden for a specific tally n by values entered on a PDn card.

14. DXC DXTRAN Contribution Card

Form: DXCm:nP_1P_2 ... P_i ... P_I

m = which DXTRAN sphere the DXC card applies to. If 0 or absent, the DXC card applies to all the DXTRAN spheres in the problem.
n = N for neutrons, P for photons, not available for electrons.
P_i = probability of contribution to DXTRAN spheres from cell i
I = number of cells in the problem

Default: $m = 0$, $P_i = 1$

Use: Optional. Consider also using the DD card, page 3–112.

This card is analogous to the above PDn card but is used for contributions to DXTRAN spheres.

15. BBREM Bremsstrahlung Biasing Card

Form: BBREM b_1 b_2 b_3 ... b_{49} m_1 m_2 ... m_n

b_1 = any positive value (currently unused).
$b_2 \ldots b_{49}$ = bias factors for the bremsstrahlung energy spectrum.
$m_1 \ldots m_n$ = list of materials for which the biasing is invoked.

Default: None

Use: Optional

The bremsstrahlung process generates many low-energy photons, but the higher-energy photons are often of more interest. One way to generate more high-energy photon tracks is to bias each sampling of a bremsstrahlung photon toward a larger fraction of the available electron energy. For example, a bias such as

```
BBREM  1.  1.  46I  10.  888  999
```

would create a gradually increasing enhancement (from the lowest to the highest fraction of the electron energy available to a given event) of the probability that the sampled bremsstrahlung photon will carry a particular fraction of the electron energy. This biasing would apply to each instance of the sampling of a bremsstrahlung photon in materials 888 and 999. The sampling in other materials would remain unbiased. The bias factors are normalized by the code in a manner that depends both on material and on electron energy, so that although the ratios of the photon weight adjustments among the different groups are known, the actual number of photons produced in any group is not easily predictable. For the el03 treatment, there are more than 49 relative photon energy ratios so the lower energy bins have a linear interpolation between b_1 and b_2 for their values.

In most problems the above prescription will increase the total number of bremsstrahlung photons produced because there will be more photon tracks generated at higher energies. The secondary electrons created by these photons will tend to have higher energies as well, and will therefore be able to create more bremsstrahlung tracks than they would at lower energies. This increase in the population of the electron-photon cascade will make the problem run more slowly. The benefits of better sampling of the high-energy domain must be balanced against this increase in run time.

For a more detailed discussion of the bremsstrahlung energy biasing scheme, see Chapter 2 page 2–77.

D. Source Specification

Every MCNP problem has one of four sources: general source (SDEF card), surface source (SSR card), criticality source (KCODE card), or user-supplied source (default if SDEF, SSR, and KCODE are all missing). All can use source distribution functions, specified on SIn, SPn, SBn, and DSn cards.

The following cards are used to specify the source.

Mnemonic	Card Type	Page
SDEF	General Source	3–54
SIn	Source Information	3–63
SPn	Source Probability	3–63
SBn	Source Bias	3–63
DSn	Dependent Source Distribution	3–66
SCn	Source Comment	3–67
SSW	Surface Source Write	3–70
SSR	Surface Source Read	3–72
KCODE	Criticality Source	3–77
KSRC	Source Points for KCODE Calculation	3–78
HSRC	Mesh for Shannon entropy of fission source distribution	3–78

The MODE card also serves as part of the source specification, in some cases by implying the type of particle to be started from the source.

The source has to define the values of the following MCNP variables for each particle it produces:

ERG	the energy of the particle (MeV). See ∗ below
TME	the time when the particle started (shakes)
UUU, VVV, WWW	the direction of the flight of the particle
XXX, YYY, ZZZ	the position of the particle
IPT	the type of the particle
WGT	the statistical weight of the particle
ICL	the cell where the particle started
JSU	the surface where the particle started, or zero if the starting point is not on any surface

Additional variables may have to be defined if there are point detectors or DXTRAN spheres in the problem.

∗ERG has a different meaning in a special case. If there is a negative IGM on the MGOPT card, which indicates a special electron-photon multigroup problem, ERG on the SDEF card is interpreted as an energy group number, an integer.

1. SDEF General Source Card

Form: SDEF source variable = specification ...

Example: SDEF (no entries)

Default: The default is a 14-MeV isotropic point source at position 0,0,0 at time 0 with weight 1 (all defaults).

Use: Required for problems using the general source. Optional for problems using the criticality source.

The equal signs are optional. The source variables are not quite the same as MCNP variables that the source must set. Many are intermediate quantities that control the sampling of the final variables. All have default values. The specification of a source variable has one of these three forms:

1. explicit value,
2. a distribution number prefixed by a D, or
3. the name of another variable prefixed by an F, followed by a distribution number prefixed by a D. Var = Dn means that the value of source variable var is sampled from distribution n. Var Fvar′ Dn means that var is sampled from distribution n that depends on the variable var′. Only one level of dependence is allowed. Each distribution may be used for only one source variable.

The above scheme translates into three levels of source description. The first level exists when a source variable has an explicit or default value (for example, a single energy) or a default distribution (for example, an isotropic angular distribution). The second level occurs when a source variable is given by a probability distribution. This level requires the SI and/or SP cards. The third level occurs when a variable depends on another variable. This level requires the DS card.

MCNP samples the source variables in an order set up according to the needs of the particular problem. Each dependent variable must be sampled after the variable it depends on has been sampled. If the value of one variable influences the default value of another variable or the way it is sampled, as SUR influences DIR, they may have to be sampled in the right order. The scheme used in MCNP to set up the order of sampling is complicated and may not always work. If it fails, a message will be printed. The fix in such instances may be to use explicit values or distributions instead of depending on defaults.

Table 3.3 summarizes the source variables and lists their defaults.

Table 3.3: Source Variables

Variable	Meaning	Default
CEL	Cell	Determined from XXX, YYY, ZZZ and possibly UUU, VVV, WWW
SUR	Surface	Zero (means cell source)
ERG	Energy (MeV)	14 MeV
TME	Time (shakes)	0

Table 3.3: Source Variables

Variable	Meaning	Default
DIR	μ, the cosine of the angle between VEC and UUU, VVV, WWW (Azimuthal angle is always sampled uniformly in 0^o to 360^o)	Volume case: μ is sampled uniformly in −1 to 1 (isotropic) Surface case: $p(\mu) = 2\mu$ in 0 to 1 (cosine distribution)
VEC	Reference vector for DIR	Volume case: required unless isotropic Surface case: vector normal to the surface with sign determined by NRM
NRM	Sign of the surface normal	+ 1
POS	Reference point for position sampling	0,0,0
RAD	Radial distance of the position from POS or AXS	0
EXT	Cell case: distance from POS along AXS Surface case: Cosine of angle from AXS	0
AXS	Reference vector for EXT and RAD	No direction
X	x-coordinate of position	No X
Y	y-coordinate of position	No Y
Z	z-coordinate of position	No Z
CCC	Cookie-cutter cell	No cookie-cutter cell
ARA	Area of surface (required only for direct contributions to point detectors from plane surface source.)	None
WGT	Particle weight	1
EFF	Rejection efficiency criterion for position sampling	.01
PAR	Particle type source will emit	1=neutron if MODE N or N P or N P E 2=photon if MODE P or P E 3=electron if MODE E
TR	Source particle transformation TR=n or distribution of transformations TR=Dn	None

The specification of WGT, EFF and PAR must be only an explicit value. A distribution is not allowed. The allowed value for PAR is 1 or N for neutron, 2 or P for photon, or 3 or E for electron. The default is the lowest of these three that corresponds to an actual or default entry on the MODE card. Only one kind of particle is allowed in an SDEF source. A special syntax allows PAR to be specified as 4 or F to make the source type a positron rather than an electron in a MODE E or P E or N P E problem.

Most of the source variables are scalars. VEC, POS, and AXS are vectors. Where a value of a source variable is required, as on SDEF, SI, or DS cards, usually a single number is appropriate, but with VEC, POS, and AXS, the value must actually be a triplet of numbers, the x, y, and z components of the vector.

The source variables SUR, POS, RAD, EXT, AXS, X, Y, Z, and CCC are used in various combinations to determine the coordinates (x,y,z) of the starting positions of the source particles. With them you can specify three different kinds of volume distributions and three different kinds of distributions on surfaces. Degenerate versions of those distributions provide line and point sources. More elaborate distributions can be approximated by combining several simple distributions, using the S option of the SIn and DSn cards.

The three volume distributions are cartesian, spherical, and cylindrical. The value of the variable SUR is zero for a volume distribution. A volume distribution can be used in combination with the CEL variable to sample uniformly throughout the interior of a cell. A cartesian, spherical, or cylindrical region that completely contains a cell is specified and is sampled uniformly in volume. If the sampled point is found to be inside the cell, it is accepted. Otherwise it is rejected and another point is sampled. If you use this technique, you must make sure that the sampling region really does contain every part of the cell because MCNP has no way of checking for this. Cookie-cutter rejection, described below, can be used instead of or in combination with CEL rejection.

A cartesian volume distribution is specified with the variables X, Y, and Z. A degenerate case of the cartesian distribution, in which the three variables are constants, defines a point source. A single point source can be specified by giving values to the three variables right on the SDEF card. If there are several source points in the problem, it would usually be easier to use a degenerate spherical distribution for each point. Other degenerate cases of the cartesian distribution are a line source and a rectangular plane source. A cartesian distribution is an efficient shape for the CEL rejection technique when the cell is approximately rectangular. It is much better than a cylindrical distribution when the cell is a long thin slab. The cartesian distribution is limited in that the faces can only be perpendicular to the coordinate axes.

A spherical volume distribution is specified with the variables POS and RAD. X, Y, Z, and AXS must not be specified or it will be taken to be a cartesian or cylindrical distribution. The sampled value of the vector POS defines the center of the sphere. The sampled value of RAD defines the distance from the center of the sphere to the position of the particle. The position is then sampled uniformly on the surface of the sphere of radius RAD. Uniform sampling in volume is obtained if the distribution of RAD is a power law with $a = 2$, which is the default in this case. A common use of the spherical volume distribution is to sample uniformly in the volume between two concentric spherical surfaces. The two radii are specified on the SIn card for RAD and the effect of a SPn−21 2 card is obtained by default (see page 3–63). If RAD is not specified, the default is zero. This is useful because it specifies a point source at the position POS. A distribution for POS, with an L on the SIn card, is the easiest way to specify a set of point sources in a problem.

A cylindrical volume distribution is specified with the variables POS, AXS, RAD, and EXT. The axis of the cylinder passes through the point POS in the direction AXS. The position of the particles is sampled uniformly on a circle whose radius is the sampled value of RAD, centered on the axis of the cylinder. The circle lies in a plane perpendicular to AXS at a distance from POS which is the

sampled value of EXT. A common use of the cylindrical distribution is to sample uniformly in volume within a cylindrical shell. The distances of the ends of the cylinder from POS are entered on the SIn card for EXT and the inner and outer radii are entered on the SIn card for RAD. Uniform sampling between the two values of EXT and power law sampling between the two values of RAD, with $a = 1$ which gives sampling uniform in volume, are provided by default. A useful degenerate case is EXT=0, which provides a source with circular symmetry on a plane.

Warning: Never position any kind of degenerate volume distribution in such a way that it lies on one of the defined surfaces of the problem geometry. Even a bounding surface that extends into the interior of a cell can cause trouble. If possible, use one of the surface distributions instead. Otherwise, move to a position just a little way off of the surface. It will not make any detectable difference in the answers, and it will prevent particles from getting lost.

The value of the variable SUR is nonzero for a distribution on a surface. If X, Y, and Z are specified, their sampled values determine the position. You must in this case make sure that the point really is on the surface because MCNP does not check. If X, Y, and Z are not specified, the position is sampled on the surface SUR. The shape of the surface, which can be either a spheroid, sphere, or plane, determines the way the position is sampled. Sampling with CEL rejection is not available, but cookie-cutter rejection can be used to do anything that CEL rejection would do. Cylindrical surface sources must be specified as degenerate volume sources.

If the value of SUR is the name of a spheroidal surface, the position of the particle is sampled uniformly in area on the surface. A spheroid is an ellipse revolved around one of its axes. A spheroid for this purpose must have its axis parallel to one of the coordinate axes. There is currently no provision for easy nonuniform or biased sampling on a spheroidal surface. A distribution of cookie-cutter cells could be used to produce a crude nonuniform distribution of position.

If the value of SUR is the name of a spherical surface, the position of the particle is sampled on that surface. If the vector AXS is not specified, the position is sampled uniformly in area on the surface. If AXS is specified, the sampled value of EXT is used for the cosine of the angle between the direction AXS and the vector from the center of the sphere to the position point. The azimuthal angle is sampled uniformly in the range from $0°$ to 360^{o}. A nonuniform distribution of position, in polar angle only, is available through a nonuniform distribution of EXT. A biased distribution of EXT can be used to start more particles from the side of the sphere nearest the tallying regions of the geometry. The exponential distribution function (−31; see page 3–66) is usually most appropriate for this.

If the value of SUR is the name of a plane surface, the position is sampled on that plane. The sampled value of POS must be a point on the plane. You must make sure that POS really is on the plane because MCNP, for the sake of speed, does not check it. The sampled position of the particle is at a distance from POS equal to the sampled value of RAD. The position is sampled uniformly on the circle of radius RAD centered on POS. Uniform sampling in area is obtained if the distribution of RAD is a power law with $a = 1$, which is the default in this case.

Cookie-cutter rejection is available for both cell and surface sources. If CCC is present, the position sampled by the above procedures is accepted if it is within cell CCC and is resampled if it is not, exactly like CEL rejection in the cell source case. You must be careful not to specify a cookie-cutter

cell such that MCNP mistakes it for a real cell. There should be no trouble if the cookie-cutter cells are bounded by surfaces used for no other purpose in the problem and if the cookie-cutter cell cards are at the end of the list of cell cards. Do not make a cookie-cutter cell more complicated than it has to be. For a surface source, the only thing that matters is the intersection of the cookie-cutter cell with the source surface. An infinitely long cell of uniform cross section, bounded by planes and cylinders, is usually adequate for a plane surface source.

Warning: The combination of either CEL or CCC rejection with biased sampling of the position is nearly always an unfair game. If you use this combination, you must make sure that it really is a fair game because MCNP is not able to detect the error.

The source variables SUR, VEC, NRM, and DIR are used to determine the initial direction of flight of the source particles. The direction of flight is sampled with respect to the reference vector VEC, which, of course, can itself be sampled from a distribution. The polar angle is the sampled value of the variable DIR. The azimuthal angle is sampled uniformly in the range from 0° to 360°. If VEC and DIR are not specified for a volume distribution of position (SUR=0), an isotropic distribution of direction is produced by default. If VEC is not specified for a distribution on a surface (SUR $\neq$0), the vector normal to the surface, with the sign determined by the sign of NRM, is used by default. If DIR is not specified for a distribution on a surface, the cosine distribution p(DIR)=2$*$DIR, 0<DIR<1, is used by default. A biased distribution of DIR can be used to make more source particles start in a direction towards the tallying regions of the geometry. The exponential distribution function (–31; see page 3–66) is usually most appropriate for this.

Discrete values of DIR are allowed. DIR=1 gives a monodirectional source in the direction of VEC. This is sometimes useful as an approximation to an actual source that is at a large distance from the geometry of the problem. In most cases discrete values of DIR will prevent direct contributions to point detectors from being scored. The direct contribution will be scored only if the source is on a plane surface, is sampled uniformly in area within a circle (using RAD sampled from SP –21 1), VEC is perpendicular to the surface (the default), and DIR=1. A cookie-cutter cell is allowed and a value of ARA is necessary. Discrete values of DIR with DXTRAN are generally wrong because p(μ) = .5 is assumed. (See Chapter 2 page 2–160)

The efficiency criterion EFF applies to both CCC and CEL rejection. If in any source cell or cookie-cutter cell the acceptance rate is too low, the problem is terminated for inefficiency. The criterion for termination is MAX(number of successes, 10) < EFF $*$ number of tries. The default value of EFF, 0.01, lets a problem get by at rather low efficiency, but for the rare problem in which low source efficiency is unavoidable, you may need to specify a lower value for EFF.

A general transformation of the generated source may be specified with a single transformation TR = n or with a distribution of transformations TR = Dn. In either case, all SDEF parameters relating to particle position or direction are interpreted as being in an auxiliary coordinate system in which the source specification is simpler. A general transformation is applied to a source particle after its coordinates and direction cosines have been determined in the auxiliary coordinate system. Both rotation and translation modify particle coordinates. Cosines are modified only by rotation. The source after transformation is treated as a volume source (surface number not defined); the cell for the source particle is determined after transformation (SUR and CEL are used only in the initial generation procedure). It may be wise NOT to place the transformed source exactly on a surface of

the physical geometry (to avoid lost particles in some cases). With the form TR = n, the transformation card TRn must be specified. With the form TR = Dn, the user must provide SIn, SPn and possibly SBn cards as discussed below.

This section discusses a source in a geometry called a repeated structure and is one that includes FILL, U, or LAT cards. The user is strongly encouraged to study Print Table 110 carefully to ensure that the proper source path and position are being sampled when repeated structures are used in a source description.

Warning: Defining a source on a lattice cell bounding plane or on a "window" cell plane coincident with a lattice surface generally does not work and is not recommended.

Source cell path for repeated structures or lattices

The only part of the MCNP source specification that is different when the source is in a repeated structure part of the geometry is the use of the CEL parameter on the SDEF card. CEL must have a value that is a path, enclosed in parentheses, from level *n* to level 0, where level *n* is not necessarily the bottom:

$$(c_n < c_{n-1} < .... < c_0)$$

c_i is a cell in the universe that fills cell c_{i-1}, or is zero, or is Dm for a distribution of cells in the repeated structure case. Dm is not valid for a lattice. c_i can have a minus sign and is discussed more below. Dm cannot have a minus sign. If $c_i = 0$, the cell at that level is searched for. Recall that level n is not necessarily the bottom level in the problem. If c_i is one specific element in a lattice, it is indicated as: ... < c_i [j1 j2 j3]< ...

The coordinate system for position and direction sampling (pds) is the coordinate system of the first negative or zero c_i in the source path starting from the right and proceeding left. Each entry in the source path represents a geometry level, where level zero is the last source path entry, level one the second to the left, etc., and level zero is above level one, level two is below level one. The pds level is the level associated with the pds cell or pds coordinate system. All levels above the pds level must be included in the source path. Levels below the pds level need not be specified, and when given, may include one or more zero entries. The default pds level is the first entry in the source path when the path has no negative or zero entry.

Position rejection is done in cells at all levels where $c_i \neq 0$, but if any c_i has a negative universe number on its cell card and is at or above the pds level, higher level cells are not checked.

The following chart illustrates the idea of the pds level.

CEL Source Path	Cell of pds Level	pds Level
(5<6<7<8)	5	3
(6<-7<8)	7	1
(0<4<0<-6<7<8)	6	2
(0<6[0 0 0]<-7[1 0 0]<8)	7	1
(0<6[0 0 0]<7[1 0 0]<8)	Will be determined	3

Lattice cell elements that are defined using the expanded FILL card (see page 3–29) can be uniformly sampled automatically. This feature is applied to lattice cell entries in the source path that lack an explicit lattice index AND that are *at or above* the pds level. Lattice cells not defined by the expanded FILL card must include an explicit lattice index when at or above the pds level. Rejection of automatically sampled lattice elements depends on the entry before the lattice cell number in the source path.

Assume the following cell cards:

```
7    0    surfaces    lat=1    u=1    fill=0:2 0:0 0:0    1    2    3
cells 8 and 9 belong to universe 2
cells 10 and 11 belong to universe 3
```

Cell 7 is a lattice with three existing elements: [0 0 0] is filled by itself [u=1], [1 0 0] is filled by cells 8 and 9 [u=2], and [2 0 0] is filled by cells 10 and 11 [u=3]. The following combinations show which elements are accepted and which are rejected.

CEL Source Path	Accepted	Rejected
7	All elements	None
(0<7)	All elements	None
(8<7)	[1 0 0]	[0 0 0], [2 0 0]
(10<7)	[2 0 0]	[0 0 0], [1 0 0]

The sampling efficiency for cell 7 in the OUTP file will reflect the element rejections. Lattice cell entries that lack an explicit lattice index AND are *below* the pds level are not sampled. Instead, the appropriate lattice element is determined by the input source position.

Lattice element sampling is independent from position sampling. First a lattice element is chosen, then a position is chosen. If the sampled position is not in the sampled lattice element, the position is resampled until it is in the specified source path and in the lattice element chosen or until an efficiency error occurs. The lattice elements will not be resampled to accommodate the sampled position. Lattice element rejection is done only as described above.

Using the previous description of lattice cell 7, add that cell 6 is filled by cell 7. The source path becomes (0<7<6). Three elements of the lattice exist [fill=0:2 0:0 0:0] but element [0 0 0] now is cut off by cell 6. Lattice element [0 0 0] still will be sampled one-third of the time. The first time element [0 0 0] is sampled a FATAL error will occur because the sampled position, no matter what it is, will be rejected because element [0 0 0] does not exist. CAUTION: Implement automatic lattice sampling carefully and ensure that all of the lattice elements specified on the expanded FILL card really do exist.

See Chapter 4 page 4–27 for a detailed example of specifying a source in a lattice geometry.

Note that the format of the CEL Source Path is the same as for tally cards. See page 3–92 for more information about specifying the path for repeated structures or lattices for tallies.

Shorthand notation for specifying multiple cell paths for repeated structures or lattices

The source cell path input format also allows a shorthand notation for one source cell path to represent a number of source paths, similar to the way that one "tally 4" path sequence enclosed in parentheses can represent a number of separate tallies. For example, the input source path (5<7 8 9 10 11<1) is interpreted by MCNP as the five paths (5<7<1) (5<8<1) (5<9<1) (5<10<1) (5<11<1), where the sequence order of these paths is determined from left to right in the original input master path. Similarly, single or multiple lattice indexes within the square brackets of path (5<3[ ]<2) can have the following four optional input forms for the I index data for lattice cell element(s) with the FILL array defined on the cell 3 card:

I	Indicates the I^{th} lattice element of cell 3 as defined by the FILL array using only one count index; e.g., I=1 is the first element.
I_1 I_2 I_3	Indicates a lattice element from the FILL array using the three indexes.
I_1:I_2 I_3:I_4 I_5:I_6	Indicates a range of one or more lattice elements, where the ":" and last entry of any of the three pairs can be omitted if that lattice element does not vary.
u=m	Specifies all of the lattice elements that have universe "m."

MCNP will create "n" source paths for the third specification, where

$$n=(I_2-I_1+1) \times (I_4-I_3+1) \times (I_6-I_5+1)$$

with the order of these "n" paths being the order of the indexes changing from left to right with the left index varying most rapidly. For the fourth specification, the "n" source paths are the number of lattice elements with universe "m," where the order of the source paths is the order in the FILL matrix for cell 3. Since the SPn card must specify the corresponding probabilities, this sequence order may be important. This sequence of the split paths is shown in the "cell" column of Print Table 10 of the OUTP file.

When there are more than one cell (or lattice cells) specified on more than one level in the source input path, MCNP splits into multiple paths with the variation most rapid from the left. However, the first level (level n) and the last level (level 0) entered in the source input path can only have one entry. The path in this new format must always be enclosed in parentheses, but there must not be any inner parentheses in the path.

2. SIn Source Information Card
3. SPn Source Probability Card
4. SBn Source Bias Card

Form: SI*n* option $I_1 \ldots I_k$

n = distribution number (*n* = 1,999)
option = how the I_i's are to be interpreted. Allowed values are:
omitted or H—bin boundaries for a histogram distribution,
for scalar variables only. This is the default.

L–discrete source variable values
A–points where a probability density distribution is defined
S–distribution numbers

$I_1 \ldots I_k$ = source variable values or distribution numbers

Default: SI*n* H$I_i \ldots I_k$

Form: SP*n* option $P_1 \ldots P_k$
or: SP*n* *f* *a* *b*

n = distribution number (*n* = 1,999)
option = how the P_i are to be interpreted. Allowed values are:
omitted—same as D for an H or L distribution. Probability density for an A distribution on SI card.
D–bin probabilities for an H or L distribution on SI card. This is the default.
C–cumulative bin probabilities for an H or L distribution on SI card.
V–for cell distributions only. Probability is proportional to cell volume (times P_i if the P_i are present).
$P_i \ldots P_k$ = source variable probabilities
f = designator (negative number) for a built-in function
a b = parameters for the built-in function (see Table 3.4)

Default: SP*n* D $P_1 \ldots P_k$

Form: SB*n* option $B_1 \ldots B_k$
or: SB*n* *f* *a b*

n, option, *f*, *a*, and *b* are the same as for the SPn card, except that the only values allowed for *f* are –21 and –31
$B_i \ldots B_k$ = source variable biased probabilities

Default: SB*n* D $B_1 \ldots B_k$

The first form of the SP card, where the first entry is positive or nonnumeric, indicates that it and its SI card define a probability distribution function. The entries on the SI card are either values of the source variable or, when the S option is used, distribution numbers. The entries on the SP card are probabilities that correspond to the entries on the SI card.

When the H option is used, the numerical entries on the SI card are bin boundaries and must be monotonically increasing. The first numerical entry on the SP card must be zero and the following entries are bin probabilities or cumulative bin probabilities, depending on whether the D or C option is used. The probabilities need not be normalized. The variable is sampled by first sampling a bin according to the bin probabilities and then sampling uniformly within the chosen bin.

When the A option is used, the entries on the SI card are values of the source variable at which the probability density is defined. The entries must be monotonically increasing, and the lowest and highest values define the range of the variable. The numerical entries on the SP card are values of

the probability density corresponding to the values of the variable on the SI card. They need not be normalized. In the sampling process, the probability density is linearly interpolated between the specified values. The first and last entries on the SP card will typically be zero, but nonzero values are also allowed.

When the L option is used, the numerical entries on the SI card are discrete values of the source variable, such as cell numbers or the energies of photon spectrum lines. The entries on the SP card are either probabilities of those discrete values or cumulative probabilities, depending on whether the D or C option is used. The entries on the SI card need not be monotonically increasing.

The S option allows sampling among distributions, one of which is chosen for further sampling. This feature makes it unnecessary to fold distributions together and is essential if some of the distributions are discrete and others are linearly interpolated. The distributions listed on an SI card with the S option can themselves also have the S option. MCNP can handle this structure to a depth of about 20, which should be far more than necessary for any practical problem. Each distribution number on the SI card can be prefixed with a D, or the D can be omitted. If a distribution number is zero, the default value for the variable is used. A distribution can appear in more than one place with an S option, but a distribution cannot be used for more than one source variable.

The V option on the SP card is a special case used only when the source variable is CEL. This option is useful when the cell volume is a factor in the probability of particle emission. If MCNP cannot calculate the volume of such a cell and the volume is not given on a VOL card, you have a FATAL error.

The SB card is used to provide a probability distribution for sampling that is different from the true probability distribution on the SP card. Its purpose is to bias the sampling of its source variable to improve the convergence rate of the problem. The weight of each source particle is adjusted to compensate for the bias. All rules that apply to the first form of the SP card apply to the SB card.

The second form of the SP card, where the first entry is negative, indicates that a built-in analytic function is to be used to generate a continuous probability density function for the source variable. Built-in functions can be used only for scalar variables. See Table 3.4 for a description of these functions.

The use of a distribution of transformations is invoked by specifying TR = Dn on the SDEF card. The cards SI, SP and, optionally, SB are used:

SI*n*	*L*	$I_1 \ldots I_k$
SP*n*	option	$P_1 \ldots P_k$
SB*n*	option	$B_1 \ldots B_k$

The L option on the SI card is *required*. The “option” on the SP and SB cards may be blank, D or C. The values $I_1 \ldots I_k$ identify k transformations which must be supplied.

Table 3.4: Built-In Functions for Source Probability and Bias Specification

Source Variable	Function No. and Input Parameters	Description
ERG	−2 *a*	Maxwell fission spectrum
ERG	−3 *a b*	Watt fission spectrum
ERG	−4 *a b*	Gaussian fusion spectrum
ERG	−5 *a*	Evaporation spectrum
ERG	−6 *a b*	Muir velocity Gaussian fusion spectrum
ERG	−7 *a b*	Spare
DIR, RAD, or EXT	−21 *a*	Power law $p(x) = c\|x\|^a$
DIR or EXT	−31 *a*	Exponential: $p(\mu) = ce^{a\mu}$
TME, X, Y, or Z	−41 *a b*	Gaussian distribution of time *t* or position coordinates *x,y,z*.

f = −2 Maxwell fission energy spectrum: $p(E) = C\,E^{1/2}\exp(-E/a)$, where *a* is a temperature in MeV.
Default: $a = 1.2895$ MeV

f = −3 Watt fission energy spectrum: $p(E) = C\exp(-E/a)\sinh(bE)^{1/2}$.
Defaults: $a = 0.965$ MeV, $b = 2.29$ MeV^{-1}.
See Appendix H page H–3 for additional parameters appropriate to neutron-induced fission in various materials and for spontaneous fission.

f = −4 Gaussian fusion energy spectrum: $p(E) = C\exp[-((E-b)/a)^2]$, where *a* is the width in MeV and *b* is the average energy in MeV. Width here is defined as the ΔE above *b* where the value of the exponential is equal to e^{-1}. If $a < 0$, it is interpreted as a temperature in MeV and *b* must also be negative. If $b = -1$, the D–T fusion energy is calculated and used for *b*. If $b = -2$, the D–D fusion energy is calculated and used for *b*. Note that *a* is not the "full-width-at-half-maximum," but is related to it by FWHM = $a\,(\ln 2)^{1/2}$.
Defaults: $a = -0.01$ MeV, $b = -1$ (DT fusion at 10 keV).

f = −5 Evaporation energy spectrum: $p(E) = C\,E\exp(-E/a)$.
Default: $a = 1.2895$ MeV.

f = −6 Muir velocity Gaussian fusion energy spectrum: $p(E) = C\exp -((E^{1/2} - b^{1/2})/a)^2$, where *a* is the width in MeV$^{1/2}$, and *b* is the energy in MeV corresponding to the average speed. Width here is defined as the change in velocity above the average velocity $b^{1/2}$, where the value of the exponential is equal to e^{-1}. To get a spectrum somewhat comparable to *f* = −4, the width can be determined by $a = (b + a_4)^{1/2} - b^{1/2}$, where a_4 is the width used with the Gaussian fusion energy spectrum. If $a < 0$, it is interpreted as a temperature in MeV. If $b = -1$, the D–T fusion energy is calculated and used for *b*. If $b = -2$, the D–D fusion energy is calculated and used for *b*.
Defaults: $a = -0.01$ MeV, $b = -1$ (DT fusion at 10 keV).

f = −7 Spare energy spectrum. The basic framework for another energy spectrum is in place to make it easier for a user to add a spectrum of his own. The subroutines to change are SPROB, SPEC, SMPSRC, and possibly CALCPS.

f = −21 Power law: $p(x) = c|x|^a$.
The default depends on the variable. For DIR, $a = 1$. For RAD, $a = 2$, unless AXS is defined or JSU $\neq 0$, in which case $a = 1$. For EXT, $a = 0$.

f = −31 Exponential: $p(\mu) = ce^{a\mu}$.
Default: $a = 0$.

f = −41 Gaussian distribution of time t or position coordinates *x,y,z*: $p(t)=c\ exp[-(1.6651092(t-b)/a)^2]$, where *a* is the width at half maximum and *b* is the mean; for time, *a* and *b* are in shakes, while, for position variables, the units are centimeters. Note: this distribution may be written in normal form as $p(t)=c\ exp[-(t-b)^2/2\sigma^2]$. The FWHM is thus $a=(8\ ln\ 2)^{1/2}\ \sigma$.

The built-in functions can be used only for the variables shown in Table 3.3. Any of the built-in functions can be used on SP cards, but only −21 and −31 can be used on SB cards. If a function is used on an SB card, only that same function can be used on the corresponding SP card. The combination of a regular table on the SI and SP cards with a function on the SB card is not allowed.

A built-in function on an SP card can be biased or truncated or both by a table on SI and SB cards. The biasing affects only the probabilities of the bins, not the shape of the function within each bin. If it is biased, the function is approximated within each bin by *n* equally probable groups such that the product of *n* and the number of bins is as large as possible but not over 300. Unless the function is −21 or −31, the weight of the source particle is adjusted to compensate for truncation of the function by the entries on the SI card.

Special defaults are available for distributions that use built-in functions.

1. If SB *f* is present and SP *f* is not, an SP *f* with default input parameters is, in effect, provided by MCNP.
2. If only an SI card is present for RAD or EXT, an SP −21 with default input parameters is, in effect, provided.
3. If only SP −21 or SP −31 is present for DIR or EXT, an SI 0 1, for −21, or SI −1 1, for −31, is, in effect, provided.
4. If SI *x* and SP −21 are present for RAD, the SI is treated as if it were SI 0 *x*.
5. If SI *x* and SP −21 or SP −31 are present for EXT, the SI is treated as if it were SI −*x x*.

5. DSn Dependent Source Distribution Card

Form: DS*n* option $J_1 \ldots J_k$
or: DS*n* *T* $I_1 J_1 \ldots I_k J_k$
or: DS*n* *Q* $V_1 S_1 \ldots V_k S_k$

n = distribution number (*n* = 1,999)
option = how the J_i are to be interpreted. Allowed values are:
blank or H−source variable values in a continuous distribution, for scalar variables only
L−discrete source variable values

S–distribution numbers

T = values of the dependent variable follow values of the independent variable, which must be a discrete scalar variable

I_i = values of the independent variable

J_i = values of the dependent variable

Q = distribution numbers follow values of the independent variable, which must be a scalar variable

V_i = monotonically increasing set of values of the independent variable

S_i = distribution numbers for the dependent variable

Default: DS*n*H $J_1 \ldots J_k$

The DS card is used instead of the SI card for a variable that depends on another source variable, as indicated on the SDEF card. No SP or SB card is used. MCNP first determines the value of the independent variable as usual by sampling the probability function of the independent variable. Then the value of the dependent variable is determined according to the form of the DS card.

The first form of the DS card has several possibilities. If the SI card of the independent variable has a histogram distribution of n bins ($n + 1$ entries) and the DS card has the blank or H option, the DS card must have $n + 1$ entries to specify n bins. The first entry need not be zero. If the sampled value of the independent variable is $I_i + [f(I_{i+1} - I_i)]$, then the value of the dependent variable is $J_i + [f(J_{i+1} - J_i)]$, where the terms in f are used only for continuous distributions. The interpolation factor f always exists whether or not it is needed for the independent distribution.

If the L or S option is used on the DS card, n entries are required to specify n discrete values. It is not necessary for the distributions of the independent and dependent variables to be both discrete or both continuous. All combinations work correctly.

When the T option is used on a DS card, the sampled value of the independent variable is sought among the I_i, and if a match is found, the independent variable gets the value J_i. If no match is found, the dependent variable gets its default value. The purpose of the T option is to shorten the input when a dependent variable should usually get the default value.

When the Q option is used on a DS card, the V_i define a set of bins for the independent variable. The sampled value of the independent variable is compared with the V_i, starting with V_1, and if the sampled value is less than or equal to V_i, the distribution Si is sampled for the value of the dependent variable. The value of V_k must be greater than or equal to any possible value of the independent variable. If a distribution number S_i is zero, the default value for the variable is used. The Q option is the only form of the DS card that can be used when the distribution of the independent variable is a built-in function.

6. SCn Source Comment Card

Form: SC*n* comment

n = distribution number (*n*=1,999)

The comment is printed as part of the header of distribution *n* in the source distribution table and in the source distribution frequency table. The & continuation symbol is considered as part of the comment, not as a continuation command.

Default: No comment.

Use: Recommended for complex source descriptions.

Examples of the General Source

Example 1:	SDEF	ERG=D1	POS=*x y z*	WGT=*w*
	SI1	H E_1	E_2 ... E_k	
	SP1	D 0	P_2 ... P_k	
	SB1	D 0	B_2 ... B_k	

This is a point isotropic source at *x,y,z* with a biased continuous-energy distribution and average source particle weight *w*. The starting cell is not specified. MCNP will determine it from the values of *x*, *y*, and *z*.

Example 2:	SDEF	SUR=*m*	AXS=*i j k*	EXT=D6
	SB6	−31 1.5		

This is a source on surface *m*. The presence of AXS and EXT implies that surface *m* is a sphere because AXS and EXT are not otherwise used together for sources on a surface. By default, the particles are emitted in a cosine distribution. They are emitted outward if the positive normal to the sphere is outward, which it is for all the spherical surface types but might not be if the sphere is specified as type SQ. The position on the surface is biased toward the direction *i,j,k* by an exponential bias (specified by −31). Table 2.8 shows the effect of the biasing parameter on the maximum and minimum source particle weights and the cumulative probability distribution. By default, MCNP provides the effect of two cards: SI6 −1 1 and SP6 −31 0.

Example 3:	SDEF	SUR=*m*	NRM=−1	DIR=D1	WGT=*w*
	SB1	−21 2			

This is an inward-directed source on spherical surface *m*, assuming the positive normal of the surface is directed outward. If $w = \pi r^2$, where *r* is the radius of sphere *m*, this source in conjunction with a VOID card, a VOL card, and type 2 and type 4 tallies, is suitable for estimating the areas of surfaces and the volumes of cells. See Chapter 2 page 2–190. By default, MCNP provides the effect of two cards: SI1 0 1 and SP1 −21 1. The directional bias by the SB1 card causes higher track density toward the center of the sphere, where presumably the cells of greatest interest lie, than it would be if the unbiased cosine distribution were used. This bias, incidentally, provides a zero-variance estimate of the (known) volume of the sphere *m*.

Example 4:	SDEF	ERG=D1	POS=*x y z*	CEL=m	RAD=D2
		EXT=D3	AXS=*i j k*		
	SP1	−3			
	SI2	r_1 r_2			
	SI3	*l*			

This source is distributed uniformly in volume throughout cell *m*, which presumably approximates a cylinder. The cell is enclosed by a sampling volume centered at *x,y,z*. The axis of the sampling volume is the line through *x,y,z* in the direction *i,j,k*. The inner and outer radii of the sampling volume are r_1 and r_2, and it extends along *i,j,k* for a distance $\pm l$ from *x,y,z*. The user has to make sure that the sampling volume totally encloses cell *m*. The energies of the source particles are sampled from the Watt fission spectrum using the default values of the two parameters, making it a Cranberg spectrum. By default, MCNP interprets SI3 *l* as if it were actually SI3 $-l$ $+l$ and provides the effect of two cards: SP2 −21 1 and SP3 −21 0.

```
Example 5:   SDEF   SUR=m   POS=x y z   RAD=D1   DIR=1   CCC=n
             SI1    r
```

This is a monodirectional source emitted from surface *m* in the direction of the positive normal to the surface. The presence of POS and RAD implies that surface *m* is a plane because POS and RAD are not otherwise used together for sources on a surface. The position is sampled uniformly in area on the surface within radius *r* of point *x,y,z*. The user must make sure that point *x,y,z* actually lies on surface *m*. The sampled position is rejected and resampled if it is not within cookie-cutter cell *n*. The starting cell is found from the position and the direction of the particle. By default, MCNP interprets SI1 *r* as if it were actually SI1 0 *r* and provides the effect of card SP1 −21 1.

```
Example 6:   SDEF    POS D1    ERG FPOS D2
             SI1     L  5  3.3  6     75  3.3  6
             SP1     .3  .7
             DS2     S  3  4
             SI3     H  2  10  14
             SP3     D  0  1  2
             SI4     −3  a  b
```

This is a point isotropic source in two locations, shown by two *x,y,z*'s on the SI1 card. The code will determine the starting cell. With probability .3 the first location will be picked, and with probability .7 the second location will be chosen. Each location has a different energy spectrum pointed to by the DS2 card. All other needed source variables will use their default values.

```
Example 7:   SDEF  DIR = 1 VEC = 0 0 1 X = D1 Y = 0 Z = −2 TR = 1
             SI1     0.0 0.5
             SP1     0.0 1.0
             TR77    0.5 0.5 0   0.4 0.3 0   −0.3 0.4 0
```

This example generates a source uniform on a straight line from (*x,y,z*) = (0.5,0.5,-2.0) to (*x,y,z*) = (0.9,0.8,−2.0) in the +*z* direction. In the auxiliary coordinate system, the source is easily created as uniform from (0.0,0.0,−2.0) to (0.5,0.0,−2.0) and then transformed.

Example 8:
```
999  0        -999                          $ cookie cutter cell CCC
. . .
999  SQ     25 100 0 0 0 0 -4 0 0 0         $ surface for cell CCC
. . .
SDEF  DIR=1 VEC=0 0 1 X=D1 Y=D2 Z=0 CCC=999 TR=D3
SP1         –41 .470964 0
SP2         –41 .235482 0
SI3         L 11 22 33
SP3         1 2 3
SB3         1 1 1
TR11        0 0 –2  1 0 0  0 1 0  0 0 1
TR22        –2 0 0  0 1 0  0 0 1  1 0 0
TR33        0 -2 0  .707107 0 .707107  .707107 0 –.707107  0 1 0
```

In this example, the source particle coordinates are generated in an auxiliary coordinate system in the $(x', y', 0)$ plane around the origin with a Gaussian profile (FWHM = .470964) in the x'-coordinate and a Gaussian profile (FWHM = .235482) in the y'-coordinate. The beam is truncated by "cookie cutter cell" CCC, which restricts the source to an ellipse corresponding to two standard deviations of the Gaussian distributions in the x'- and y'-coordinates. The subsequent application of the transformation TR = D3 results in three intersecting beams with the following characteristics:

– beam 1 is centered at (0,0,–2) with the major axis of the beam distribution along the x-axis, emitted in the $+z$ direction, with relative intensity 1;
– beam 2 is centered at (–2,0,0) with the major axis of the beam distribution along the y-axis, emitted in the $+x$ direction, with relative intensity 2;
– beam 3 is centered at (0,–2,0) with the major axis of the beam distribution along the line $x = z$, emitted in the $+y$ direction, with relative intensity 3.

7. SSW Surface Source Write Card

Form: SSW S_1 S_2 $(C_1 \cdots C_k)$ S_3 S_n keyword=values

The = signs are optional.

S_i = problem surface number, with the appropriate sense of inward or outward particle direction, for which particle-crossing information is to be written to the surface source file WSSA. Macrobody surfaces are not allowed.

C_i = problem cell number. A positive entry denotes an other-side cell. A negative entry specifies a just-left cell.

SYM m symmetry option flag
- m = 0, no symmetry assumed.
- m = 1, spherical symmetry assumed. The list of problem surface numbers must contain only one surface and it must be a sphere.
- m = 2, write particles to a surface bi-directionally. Otherwise, only particles going out of a positive surface and into a negative surface are recorded.

PTY n_1 n_2 ... tracks to record, blank delimited
absent = record all tracks. This is the default.

n_i = N, record neutron tracks
n_i = P, record photon tracks
n_i = E, record electron tracks

CEL C_1 C_2 · · · C_n
list of names of all the cells from which KCODE fission source neutrons are to be written, active cycles only.

Default: SYM=0PTY absent=record all particle types

Use: Optional, as needed.

This card is used to write a surface source file or KCODE fission volume source file for use in a subsequent MCNP calculation. Care must be taken to include enough geometry beyond the specified surfaces to account for albedo effects. The card allows a list, in parentheses, of one or more cell names, positive or negative, after any of the surface names. If the list of cells is absent, any track that crosses the surface in the correct direction will be recorded. If the list is present, a track will be recorded if it crosses the surface in the correct direction and is either entering a cell in the list whose entry is positive or leaving a cell in the list whose entry is negative.

If the SYM=1 option is used, the geometry inside the surface must be spherically symmetric and the materials must be symmetric. In very few cases will the SYM=1 option apply. The user must determine whether SYM=1 is appropriate for the problem. If the SYM=1 option is used, fewer words per particle need to be written to the surface source file and certain biasing options become available when reading the surface source file. In a KCODE calculation, particles are written only for active cycles.

Example 1: SSW 4 –7 19 (45 –46) 16 –83 (49) · · ·

A track that crosses surface 19 in the correct direction will be recorded only if it is either entering cell 45 or leaving cell 46. A track that crosses surface 83 in the correct direction will be recorded only if it is entering cell 49. A track that crosses surface 4 or 7 or 16 in the correct direction will be recorded regardless of what cells it happens to be leaving or entering.

Fission volume sources from a KCODE calculation can be written from active cycles only. The fission neutrons and prompt photons can then be transported in a subsequent calculation using the SSR surface source read fixed-source capability. In a KCODE criticality calculation the fission neutron sources and prompt photons produced from fission during each cycle are written to the WSSA surface source file if the SSW card has the CEL keyword followed by the names of all the cells from which fission source neutrons are to be written. Particles crossing specified surfaces can also be written by specifying S_i. The SYM=1 option (spherically symmetric surface source) cannot be used if CEL is specified.

Example 2: SSW 1 2 (3 4) CEL 8 9

A track that crosses surface 2 in the correct direction will be recorded only if it enters cell 3 or 4. A track crossing surface 1 in the correct direction always will be recorded. And particles created from fission events in cells 8 and 9 will be recorded.

During execution, surface source information is written to the scratch file WXXA. Upon normal completion, WXXA becomes WSSA. If the run terminates abnormally, the WXXA file will appear instead of WSSA and must be saved along with the RUNTPE file. The job must be continued for at least one more history. At the subsequent normal termination, WXXA disappears and the correct surface source file WSSA is properly written.

8. SSR Surface Source Read Card

Form: SSR keyword=values keyword=values

The = signs are optional.

OLD $S_1\ S_2\ ...\ S_n$
list of problem surface numbers, a subset of the surfaces on the SSW card that created the file WSSA, now called RSSA.

CEL $C_1\ C_2\ ...\ C_n$
like OLD but for cells in which KCODE fission neutrons or photons were written

NEW $S_{11}\ S_{12}\ ...\ S_{1n}\ S_{21}\ S_{22}\ ...\ S_{2n}\ ...\ S_{m1}\ S_{m2}\ ...\ S_{mn}$
List of problem surface numbers upon which the surface source is to start particles in this run. For m=1, each particle written from surface S_i in the OLD list will start on surface S_{1i}. For m>1, each particle written on surface S_i in the OLD list will start on one of the surfaces S_{ji}, j=1, ... ,m, where j represents one of the m transformations determined by TR = Dn described below.

PTY $n_1\ n_2$ ... tracks to read, blank delimited
absent = read all tracks for the particle types in the problem. This is the default.
n_1 = N, read neutron tracks
n_2 = P, read photon tracks
n_3 = E, read electron tracks

COL m collision option flag
m = −1, start from the surface source file only those particles that came directly from the source without a collision
m = 1, start from the surface source file only those particles that had collisions before crossing the recording surface
m = 0, start particles without regard to collisions

WGT x Each particle weight is multiplied by the constant x as it is accepted for transport.

TR n Transformation number. Track positions and velocities are transformed from the auxiliary coordinate system (the coordinate system of the problem that wrote the surface source file) into the coordinate system of the current problem, using the transformation on the TRn card, which must be present in the INP file of the current problem. For each surface S_i in the OLD list, a corresponding surface S_{1i} must appear in the NEW list such that TRn transforms the coordinates of a particle written from S_i to be on surface S_{1i} in the current problem. However, if the surfaces S_{1i} are “dummy” surfaces not used in constructing the real

geometry, then the transformed source will effectively be treated as a volume source not specifically defined to be on any surface.

TR Dn Distribution number for a set of SIn, SPn, and SBn cards. If the surface source is transformed into several locations, the SIn card lists the transformation numbers and the SPn and SBn cards give the probabilities and bias of each transformation. If NEW is present with m>1, then the distribution must specify exactly m transformations that properly represent the relationship of the m×n surfaces on the NEW list to the n surfaces on the OLD list. Otherwise, the NEW specification is ignored (if present) and the application of TR = Dn is analogous to its use on the SDEF card. The source after transformation is treated as a volume source (surface number not defined); the cell for the source particle is determined after transformation. It may be wise not to place the transformed source exactly on a surface of the physical geometry (to avoid lost particles in some cases).

PSC *c* A nonnegative constant that is used in an approximation to the PSC evaluation for the probability of the surface source emitting a particle into a specified angle relative to the surface normal.

The following four keywords are used only with spherically symmetric surface sources, that is, sources generated with SYM=1 on the SSW card.

AXS *u v w* Direction cosines that define an axis through the center of the surface sphere in the auxiliary (original) coordinate system. This is the reference vector for EXT.

EXT Dn *n* is the number of a distribution (SIn, SPn, and SBn cards) that will bias the sampling of the cosine of the angle between the direction AXS and the vector from the center of the sphere to the starting point on the sphere surface.

POA *c* Particles with a polar angle cosine relative to the source surface normal that falls between 1 and *c* will be accepted for transport. All others are disregarded and no weight adjustment is made.

BCW*r zb ze* $0 < zb < ze$ All particles with acceptable polar angles relative to the surface normal are started so that they will pass through a cylindrical window of radius *r*, starting at *zb* from the center of the source sphere, and ending at *ze* from the center. The axis of the cylinder is parallel to the *z*-axis of the auxiliary (original) coordinate system and contains the center of the source sphere. The weight of each source particle is adjusted to compensate for this biasing of position and direction.

Defaults:
OLD accept all surfaces in the original run.
CEL accept all cells in the original run.
NEW the surfaces in the OLD list.
PTY read tracks for all particle types
COL $m = 0$
WGT 1
TR no transformation

AXS	no axis
EXT	no position bias
POA	$c = 0$
BCW	no cylindrical window
PSC	no default value

Use: Required for surface source problems.

The RSSA file can contain three types of particles. By default, all particle types defined with the MODE card are read from the RSSA file if available. Particle types not defined with the MODE card are rejected without weight adjustment. Particle types can be selected from the RSSA file using the PTY keyword. For example, only neutron surface source particles will be started in a MODE N P E problem by using SSR ... PTY n ....

The problem summary tables for a surface source problem represent the weights of the particles read from the RSSA file, not the weights in the original problem that wrote the surface source. To understand the resultant Problem Summary Tables for an SSR problem, consider the following example:

Run 1	MODE	N		E	
	SSW			$	neutrons and electrons written to WSSA file
Run 2	MODE	N	P	E	
	SSR			$	no photons available on RSSA to read

The weight creation and loss columns for all particles are normed by the number of histories run in the problem. For this example, the neutron and electron average energies are determined by norming by the respective starting source weights from the RSSA file. Because no photons were available to be read, the photon summary table average energies will be normed by the first particle source weight from RSSA in the problem, where neutrons have first priority (as in this example), then photons, then electrons.

For the general SSR problem, one or more particle types will have source weights. The average energies in a particle Problem Summary Table are obtained in the following order: 1) if source particles are read from the RSSA file, then the average energies are determined by norming by the starting source weight; or else 2) the first particle type with source weight will be used for obtaining average summary table energies.

The number of particle histories reported in the output file for an SSR calculation is related to the number written to the WSSA file, so that proper normalization is preserved. However, a user may specify a different value on the NPS card than that used in the initial SSW calculation. If this NPS value is smaller than that of the initial calculation, an appropriate ratio of tracks will be rejected. If this NPS value is larger than that of the initial calculation, an appropriate duplication of tracks will be sampled. For example, if the SSW calculation used an NPS of 100 and the SSR calculation uses an NPS of 200, then every track is duplicated, each with a different random number seed and each with half the original weight. It is important to note that a larger value of NPS on the SSR calculation will indeed lower the tally errors until the weight variance contained on the RSSA file dominates (thus the reason to maximize the number of tracks on the RSSA file). Since the NPS

value can readjust particle weights as described above, some variance reduction parameters (e.g., weight-window bounds) may need to be renormalized for SSR applications. See further discussion below.

An exact treatment of point detectors or DXTRAN spheres with a surface source is not possible because the $p(cos\theta)$ values required for the source contribution are not readily available. (See the description of detector tallies in Chapter 2 beginning on page 2–91.) To use detectors or DXTRAN with a surface source, an approximate $p(cos\theta)$ must be specified on the SSR card. The most common azimuthally symmetric approximation for an angular emission probability density function is given by

$$p(cos\theta) = C_n(cos\theta)^n \qquad n \geq 0$$

The PSC=value entered is n, the power to which $p(cos\theta)$ is raised. C_n is a normalization constant calculated in MCNP and θ is the angle between the direction vector to the point detector and the surface normal at the point where the particle is to be started. Because surface crossings are recorded in only one direction specified on the SSW card, the limits on μ are always between 1 and 0. A PSC entry of zero specifies an isotropic angular distribution on the surface. An entry of 1 specifies a cosine angular distribution that produces an isotropic angular flux on the surface. In the case of a 1-dimensional spherical surface source of radius R, a cosine distribution is adequate if the point detector or DXTRAN sphere is more than 4R away from the source.

Warning: Remember that the value entered is only an approximation. If the point detector or DXTRAN sphere is close to the source sphere and the approximation is poor, the answers will be WRONG.

Fission neutrons and photons written to the surface source file in a KCODE calculation can be used as a volume-distributed source in a subsequent calculation. A NONU card should be used so that fission neutrons and photons are not counted twice. Generally a TOTNU card also should be used. Total $\bar{\upsilon}$ is the default for KCODE sources but prompt $\bar{\upsilon}$ is the default for non-KCODE sources. Delayed gammas are ignored in MCNP. The keyword CEL specifies which fission cells to accept of those from the KCODE calculation that wrote the RSSA file.

The following observations and comments are relevant for using some variance reduction techniques with SSW/SSR calculations. This discussion applies to any technique that requires the input of normalized weight parameters (e.g., weight-window bounds, negative entries on the DD card, etc.).

1. In general, weight window bounds generated in a SSW calculation are not useful in the SSR calculation, unless the tally identified on the WWG card of the SSW calculation is the same as that desired for the SSR calculation AND plenty of tracks contributed to that tally during the SSW calculation.
2. A window generated in an SSR calculation will likely have to be renormalized in subsequent runs that use those windows, unless the value on the NPS card remains unchanged. If the value on the NPS card is changed, the WGT keyword on the SSR card can be used to renormalize the source weights to ensure weights are within the window in the source region. Whenever the WGT keyword is used in this fashion, tallies must be

properly normalized by using this value on the SD card or the inverse of this value as a multiplier on the FM card.

```
Example 1:   Original run:  SSW   1   2   3
             Current run:   SSR   OLD  3   2  NEW  6  7    12  13  TR D5  COL 1
                            SI5   L  4  5
                            SP5     .4  .6
                            SB5     .3  .7
```

Particles starting on surface 1 in the original run will not be started in the current run because 1 is absent from the list of OLD surface numbers. Particles recorded on surface 2 in the original run will be started on surfaces 7 and 13 and particles recorded on surface 3 in the original run will be started on surfaces 6 and 12, as prescribed by the mapping from the OLD to the NEW surface numbers. The COL keyword causes only particles that crossed surfaces 2 and 3 in the original problem after having undergone collisions to be started in the current problem. The TR entry indicates that distribution function 5 describes the required surface transformations. According to the SI5 card, surfaces 6 and 7 are related to surfaces 3 and 2, respectively, by transformation TR4; surfaces 12 and 13 are related to 3 and 2 by TR5. The physical probability of starting on surfaces 6 and 7 is 40% according to the SP5 card, and the physical probability of starting on surfaces 12 and 13 is 60%. The SB5 card causes the particles from surfaces 3 and 2 to be started on surfaces 6 and 7 30% of the time with weight multiplier 4/3 and to be started on surfaces 12 and 13 70% of the time with weight multiplier 6/7.

```
Example 2:   Original run:  SSW   3  SYM 1
             Current run:   SSR   AXS  0  0  1   EXT  D99
                            SI99       –1  .5   1
                            SP99   C   .75  1
                            SB99       .5   .5
```

All particles written to surface 3 in the original problem will be started on surface 3 in the new problem, which must be exactly the same because no OLD, NEW, COL, or TR keywords are present. Because this is a spherically symmetric problem, indicated by the SYM 1 flag in the original run, the position on the sphere can be biased. It is biased in the *z* direction with a cone bias described by distribution 99.

```
Example 3:   Original run:  SSW    2 4 6
             Current run:   SSR    OLD 2 TR=D1 WGT 6.0
                            SI1    L 11 22 33
                            SP1    1 2 3
                            SB1    1 1 1
                            TR11   0 0  –3  1 0 0  0 1 0  0 0 1
                            TR22   –3 0 0  0 1 0  0 0 1  1 0 0
                            TR33   0 –3 0  .707 0 .707  .707 0 –.707  0 1 0
```

All particles written from surface 2 in the original problem will be accepted; those written from surfaces 4 and 6 will be rejected. The distribution D1 will be sampled for each accepted particle and one of the transformations TR11, TR22 or TR33 will be applied. In this case, the particle current across surface 2 in the original problem will be applied as three intersecting beams in the

x, y and *z* directions. The relative intensities are 2:3:1 respectively, but the sampling rate is the same in all three directions through use of the SB card.

9. KCODE Criticality Source Card

Form: KCODE NSRCK RKK IKZ KCT MSRK KNRM MRKP KC8

NSRCK = number of source histories per cycle
RKK = initial guess for k_{eff}
IKZ = number of cycles to be skipped before beginning tally accumulation
KCT = number of cycles to be done
MSRK = number of source points to allocate storage for
KNRM = normalize tallies by 0=weight / 1=histories
MRKP = maximum number of cycle values on MCTAL or RUNTPE
KC8 = summary and tally information averaged over
0 = all cycles
1 = active cycles only

Defaults: NSRCK=1000; RKK=1.0; IKZ=30; KCT=IKZ+100; MSRK=4500 or 2* NSRCK; KNRM=0; MRKP=6500; KC8=1

Use: This card is required for criticality calculations.

The KCODE card specifies the MCNP criticality source that is used for determining k_{eff}. The criticality source uses total fission nubar values unless overridden by a TOTNU NO card and applies only to neutron problems. In a MODE N P problem, secondary photon production from neutrons is turned off during inactive cycles. SSW particles are not written during inactive cycles. See Chapter 1 for further information.

The NSRCK entry is the nominal source size for each cycle. The IKZ entry is the number of cycles to skip before beginning tally accumulation (this is important if the initial source guess is poor). The KCT entry specifies the number of cycles to be done before the problem ends. A zero entry means never terminate on the number of cycles but terminate on time. The MSRK is the maximum number of source points for which storage will be allocated. If an SRCTP file with a larger value of MSRK is read for the initial source, the larger value is used.

Fission sites for each cycle are those points generated by the previous cycle. For the initial cycle, fission sites can come from an SRCTP file from a similar geometry, from a KSRC card, or from a volume distribution specified by an SDEF card.

If in the first cycle the source being generated overruns the current source, the initial guess (RKK) is probably too low. The code then proceeds to print a comment, continues without writing a new source, calculates k'_{eff} , reads the initial source back in, and begins the problem using k'_{eff} instead of RKK. If the generated source again overruns the current source after the first cycle, the job terminates and either a better initial guess (RKK) or more source space (MSRK) should be specified on the next try.

KC8=0 causes tallies and summary table information to be for both active and inactive cycles and should not be used. KC8=0 also results in a strange MCTAL file normalization.

10. KSRC Source Points for KCODE Calculation

Form: KSRC $x_1\ y_1\ z_1\ \ x_2\ y_2\ z_2$ ...

x_i, y_i, z_i = location of initial source points

Default: None. If this card is absent, an SRCTP source file or SDEF card must be supplied to provide initial source points for a criticality calculation.

Use: Optional card for use with criticality calculations.

This card contains up to NSRCK (*x,y,z*) triplets that are locations of initial source points for a KCODE calculation. At least one point must be in a cell containing fissile material and points must be away from cell boundaries. It is not necessary to input all NSRCK coordinate points. MCNP will start approximately (NSRCK/number of points) particles at each point. Usually one point in each fissile region is adequate, because MCNP will quickly calculate and use the new fission source distribution. The energy of each particle in the initial source is sampled from a Watt fission spectrum hardwired into MCNP, with $a = 0.965$ MeV and $b = 2.29$ MeV^{-1}.

An SRCTP file from a previous criticality calculation can be used instead of a KSRC card. If the current problem has a lot in common with the previous problem, using the SRCTP file may save some computer time. Even if the problems are quite different, the SRCTP file may still be usable if some of the points in the SRCTP file are in cells containing fissile material in the current problem. Points in void or zero importance cells will be deleted. The number of particles actually started at each point will be such as to produce approximately NSRCK initial source particles.

An SDEF card also can be used to sample initial source points in fissile material regions. The SDEF card parameters applicable to volume sampling can be used: CEL, POS, RAD, EXT, AXS, X, Y, Z; and CCC, ERG, and EFF. If a uniform volume distribution is chosen, the early values of k_{eff} will likely be low because too many particles are put near where they can escape, just the opposite of the usual situation with the KSRC card. Do not change the default value of WGT for a KCODE calculation.

11. HSRC Mesh for Shannon Entropy of Fission Source Distribution

Form: HSRC $n_x\ \ x_{min}\ \ x_{max}\ \ \ n_y\ \ y_{min}\ \ y_{max}\ \ \ n_z\ \ z_{min}\ \ z_{max}$

n_x = number of mesh intervals in x-direction, $n_x>0$
x_{min} = minimum x-value for mesh
x_{max} = maximum x-value for mesh

Similar for y- and z-directions.
All nine entries should be supplied.

Default: None. If this card is absent, or if fewer than nine entries are supplied, or if $n_x * n_y * n_z \le 0$, MCNP will automatically determine a mesh that encloses all of the fission source sites in a cycle. This automatic mesh will be expanded if necessary on later cycles. The minimum number of mesh cells for the automatic

mesh is 4x4x4. If the HSRC card is supplied, one or more intervals may be specified for each of the x-, y-, and z-directions.

Use: Optional card to specify the mesh for computing Shannon entropy of the fission source distribution in criticality calculations.

To assist users in assessing the convergence of the fission source distribution, MCNP computes a quantity called the Shannon entropy of the fission source distribution, H_{src}. To compute H_{src}, it is necessary to superimpose a 3-D grid on a problem encompassing all of the fissionable regions, and then to tally the number of fission sites in a cycle that fall into each of the grid boxes. The user may specify a particular grid to use in determining H_{src} by means of the HSRC input card. If the HSRC card is provided, users should use a small number of grid boxes (e.g., 5-10 in each of the XYZ directions), chosen according to the symmetry of the problem and layout of the fuel regions. If the HSRC card is not provided, MCNP will automatically determine a grid that encloses all of the fission sites for the cycle. The number of grid boxes will be determined by dividing the number of histories per cycle by 20, and then finding the nearest integer for each direction that will produce this number of equal-sized grid boxes, although not fewer than 4x4x4 will be used. If the grid is automatically determined by MCNP, it will be expanded as necessary if fission source sites for a cycle fall outside of the grid. (The grid size will not be reduced.) If the grid is provided by the user using the HSRC card, then MCNP will issue warning messages if either 90% of the grid-boxes have zero scores for a cycle or if 25% of the fission source is located outside of the grid. Either of these messages is an indication that the user-supplied grid was poorly chosen for computing H_{src}. While H_{src} may not be computed reliably, there is no effect on k_{eff} or other tallies.

12. Subroutines SOURCE and SRCDX

If SDEF, SSR, or KCODE cards are not present in the INP file, a user supplied source is assumed and is implemented by calling subroutine SOURCE, which the user must provide. Chapter 4 has examples of a SOURCE subroutine and discusses the SRCDX subroutine beginning on page 4–60. The parameters that must be specified within the subroutine are listed and defined on page 3–54. Prior to calling subroutine SOURCE, isotropic direction cosines *u,v,w* (UUU, VVV, WWW) are calculated and need not be specified if you want an isotropic distribution.

The SIn, SPn, and SBn cards also can be used with the SOURCE subroutine, although modifications to other parts of MCNP may be required for proper initialization and to set up storage. A random number generator RANG( ) is available for use by SOURCE for generating random numbers between 0 and 1. Up to 50 numerical entries can be entered on each of the IDUM and RDUM cards for use by SOURCE. The IDUM entries must be integers and the RDUM entries floating point numbers.

If you are using a detector or DXTRAN and your source has an anisotropic angular distribution, you will need to supply an SRCDX subroutine to specify PSCs for each detector or DXTRAN sphere (see Chapters 2 and 4).

There are unused variables stored in the particle bank that are reserved for the user called SPARE(M), M=1,MSPARE, where MSPARE=3. Depending on the application, you may need to reset them to 0 in SOURCE for each history; MCNP does not reset them.

E. Tally Specification

The tally cards are used to specify what type of information the user wants to gain from the Monte Carlo calculation; that is, current across a surface, flux at a point, heating in a region, etc. This information is requested by the user by using a combination of the following cards. To obtain tally results, only the Fn card is required; the other tally cards provide various optional features.

Mnemonic	Card Type	Page
Fna	Tally	3–81
FCn	Tally Comment	3–95
En	Tally Energy	3–96
Tn	Tally Time	3–96
Cn	Cosine	3–97
FQn	Print Hierarchy	3–98
FMn	Tally Multiplier	3–99
DEn/DFn	Dose Energy/Dose Function	3–103
EMn	Energy Multiplier	3–104
TMn	Time Multiplier	3–104
CMn	Cosine Multiplier	3–105
CFn	Cell Flagging	3–105
SFn	Surface Flagging	3–106
FSn	Tally Segment	3–106
SDn	Segment Divisor	3–108
FUn	TALLYX Input	3–109
TFn	Tally Fluctuation	3–111
DDn	Detector Diagnostics	3–112
DXT	DXTRAN	3–114
FTn	Special Treatments for Tallies	3–116
FMESHn	Superimposed Mesh Tally	3–118
SPDTL	Lattice Speed Tally Enhancement	3–120

The *n* is a user-chosen tally number < 999; choices of *n* are given in the following section beginning on page 3–81. When a choice of *n* is made for a particular tally type, any other input card used with that tally (such as En for energy bins) is given the same value of *n* by the user.

Much of the information on these cards is used to describe tally "bins," subdivisions of the tally space into discrete and contiguous increments such as cosine, energy, or time. Usually when the user subdivides a tally into bins, MCNP can also provide the total tally summed over appropriate bins (such as over energy bins). Absence of any bin specification card results in one unbounded bin rather than one bin with a default bound. No information is printed about the limits on the unbounded bin.

If there are reflecting surfaces or periodic boundaries in the problem, the user may have to normalize the tallies in some special way (this can be done by setting the weight of the source particles or by using the FMn card).

Printed with each tally bin is the relative error of the tally corresponding to one standard deviation. These errors *cannot* be believed reliable (hence neither can the tally itself) unless the error is fairly

low. Results with errors greater than 50% are useless, results between 20% and 50% can be believed to within a factor of a few, results between 10% and 20% are questionable, results less than 10% are generally (but not always) reliable except for detectors, and detector results are generally reliable below 5%. One bin of every tally is designated for the tally fluctuation charts at the end of the output file. This bin is also used for the weight window generator. It also is subject to ten statistical checks for tally convergence, including calculation of the variance of the variance (VOV). The VOV can be printed for all bins in a tally by using the DBCN card.

1. Fna Tally Cards

Seven basic neutron tally types, six basic photon tally types, and four basic electron tally types are available in MCNP as standard tallies. All are normalized to be per source particle unless changed by the user with a TALLYX subroutine or normed by weight in a criticality (KCODE) calculation.

Mnemonic	Tally Description	Fn units	*Fn units
F1:N or F1:P or F1:E	Current integrated over a surface	particles	MeV
F2:N or F2:P or F2:E	Flux averaged over a surface	particles/cm^2	MeV/cm^2
F4:N or F4:P or F4:E	Flux averaged over a cell	particles/cm^2	MeV/cm^2
F5a:N or F5a:P	Flux at a point or ring detector	particles/cm^2	MeV/cm^2
FIP5:N or FIP5:P	Array of point detectors for pinhole flux image	particles/cm^2	MeV/cm^2
FIR5:N or FIR5:P	Array of point detectors for planar radiograph flux image	particles/cm^2	MeV/cm^2
FIC5:N or FIC5:P	Array of point detectors for cylindrical radiograph flux image	particles/cm^2	MeV/cm^2
F6:N or F6:N,P or F6:P	Energy deposition averaged over a cell	MeV/g	jerks/g
F7:N	Fission energy deposition averaged over a cell	MeV/g	jerks/g
F8:P or F8:E or F8:P,E	Energy distribution of pulses created in a detector	pulses	MeV
+F8:E	Charge deposition	charge	N/A

The tallies are identified by tally type and particle type as follows. Tallies are given the numbers 1, 2, 4, 5, 6, 7, 8, or increments of 10 thereof, and are given the particle designator :N, :P, or :E (or :N,P only in the case of tally type 6 or :P,E only in the case of tally type 8). Thus you may have as many of any basic tally as you need, each with different energy bins or flagging or anything else. F4:N, F14:N, F104:N, and F234:N are all legitimate neutron cell flux tallies; they could all be for the same cell(s) but with different energy or multiplier bins, for example. Similarly F5:P, F15:P, and *F305:P are all photon point detector tallies. Having both an F1:N card and an F1:P card in the same INP file is not allowed. The tally number may not exceed three digits.

Tally types 1, 2, 4, and 5 are normally weight tallies (particles in the above table); however, if the Fn card is flagged with an asterisk (for example, *F1:N), energy times weight will be tallied. The asterisk flagging can also be used on tally types 6 and 7 to change the units from MeV/g to

jerks/g (1 jerk = 1 GJ = 10^9 J). The asterisk on a tally type 8 converts from a pulse height tally to an energy deposition tally. All of the units are shown in the above table.

Tally type 8 can also be flagged with a plus (+) to convert it from an energy deposition tally (flagged with an asterisk) to a charge deposition tally. The tally is the negative particle weight for electrons and the positive weight for positrons. The +F8 tally can be checked against an F1:E type surface tally. See page 3–88 for an example.

Only the F2 surface flux tally requires the surface area. The area calculated is the total area of the surface that may bound several cells, not a portion of the surface that bounds only a particular cell. If you need only the segment of a surface, you might segment the full surface with the FSn card (see page 3–106) and use the SDn card (see page 3–108) to enter the appropriate values. You can also redefine the geometry as another solution to the problem. The detector total is restricted to 20. The tally total is limited to 100. Note that a single type 5 tally may create more than one detector.

1. Surface and Cell Tallies (tally types 1, 2, 4, 6, and 7)

Simple Form: F*n*:*pl* S_1 ... S_k
General Form: F*n*:*pl* S_1 (S_2 ... S_3) (S_4 ... S_5) S_6 S_7 ...

n = tally number.
pl = N or P or N,P or E
S_i = problem number of surface or cell for tallying, or *T*.

Only surfaces bounding cells and listed in the cell card description can be used on F1 and F2 tallies. Tally 6 does not allow E. Tally 7 allows N only.

In the simple form above, MCNP creates *k* surface or cell bins for the requested tally, listing the results separately for each surface or cell. In the more general form, a bin is created for each surface or cell listed separately and for each collection of surfaces or cells enclosed within a set of parentheses. Entries within parentheses also can appear separately or in other combinations. Parentheses indicate that the tally is for the union of the items within the parentheses. For unnormalized tallies (tally type 1), the union of tallies is a sum, but for normalized tallies (types 2, 4, 6, and 7), the union results in an average. See page 3–88 for an explanation of the repeated structure and lattice tally format.

The symbol *T* entered on surface or cell Fn cards is shorthand for a region that is the union of all of the other entries on the card. A tally is made for the individual entries on the Fn card plus the union of all the entries.

If a tally label of the surfaces or cells in the output requires more than eleven characters, including spaces, MCNP defines an alphabetical or numerical designator for printing purposes. The designator [for example, G is (1 2 3 4 5 6)] is printed with the tally output. This labeling scheme is usually required for tallies over the union of a long list of surfaces or cells.

Example 1: F2:N 1 3 6 *T*

This card specifies four neutron flux tallies, one across each of the surfaces 1, 3, and 6 and one which is the average of the flux across all three of the surfaces.

Example 2: F1:P (1 2) (3 4 5) 6

This card provides three photon current tallies, one for the sum over surfaces 1 and 2; one for the sum over surfaces 3, 4, and 5; and one for surface 6 alone.

Example 3: F371:N (1 2 3) (1 4) *T*

This card provides three neutron current tallies, one for the sum over surfaces 1, 2, and 3; one for the sum over surfaces 1 and 4; and one for the sum over surfaces 1, 2, 3, and 4. The point of this example is that the *T* bin is not confused by the repetition of surface 1.

Another case for study is in the DEMO example in Chapter 5 on page 5–1.

2. Detector Tallies (tally type 5)

Form for point detectors: F*n*:*pl* *X Y Z* $\pm R_0$

n = tally number ending with 5.
pl = *N* for neutrons or *P* for photons.
X Y Z = location of the detector point.
$\pm R_0$ = radius of the sphere of exclusion:
in centimeters, if R_0 is entered as positive,
in mean free paths, if entered as negative. (A negative entry is illegal in a void.)

Form for ring detectors: F*na*:*pl* a_o *r* $\pm R_0$

n = tally number.
a = the letter *X*, *Y*, or *Z*.
pl = *N* for neutrons or *P* for photons.
a_o = distance along axis "a" where the ring plane intersects the axis.
r = radius of the ring in centimeters.
$\pm R_0$ = same meaning as for point detectors, but describes a sphere about the point selected on the ring.

Form for flux image radiographs: FIR*n*:*pl* or FIC*n*:*pl* X_1 Y_1 Z_1 R_0 X_2 Y_2 Z_2 F_1 F_2 F_3

FIR establishes a flux image on a rectangular radiograph planar grid (see Figure 2-11).
FIC establishes a flux image on a cylindrical radiograph grid (see Chapter 2 Figure 2-12).

n = the tally number ending with 5.
pl = N for neutrons or P for photons.
X_1 Y_1 Z_1 = a set of coordinates used with the entries on the FS*n* and C*n* cards to define the extent and spacing of the detector flux image grid. In the planar rectangular grid case (FIR), this point defines the center of the grid. In the

cylindrical grid case (FIC), this point defines the center of the cylinder on which the grid is established.

R_0 is not used (do not put image grid in scattering material). Enter zero as a placeholder.

X_2 Y_2 Z_2 = a set of reference coordinates that establishes the grid reference direction as being from (X_2 Y_2 Z_2) to (X_1 Y_1 Z_1). This direction is used as the outward normal to the detector image grid plane for the FIR case and as the axis of the cylinder for the FIC case.

F_1 = 0, both the source and scattered contributions will be scored on the grid.

< 0, only the scattered contributions will be scored. The scattered contributions can often be made on a much coarser image grid because there is much less structure to the scattered image. Use $F_1 < 0$ in this case. The NOTRN card can be used to obtain only the direct image with $F_1 = 0$.

F_2 for FIR = a radial restriction relative to the center of the grid to define a radial field of view on the grid (default is no radial restriction if 0).

F_2 for FIC = the radius of the cylindrical surface of the image grid (0 is FATAL error).

F_3 = 0, all flux contributions are directed to the center of each image grid bin.

≠ 0, all flux contributions are made with a random offset from the center of the image grid bin. This offset remains fixed and is used as the offset for the contributions to each of the remaining grid bins for the current source or scatter event.

Only one flux image detector is allowed on each FIC or FIR card. The point detector Russian roulette game is not used with FIC or FIR tallies. Consider use of the NOTRN card for only direct contributions, the second entry on the NPS card for limiting the direct FIR contributions, and the TALNP card to reduce size of the OUTP file for large-image grids.

Form for flux image by pinhole: FIP*n:pl* X_1 Y_1 Z_1 R_0 X_2 Y_2 Z_2 F_1 F_2 F_3

FIP establishes a flux image through a pinhole to a planar grid (see Chapter 2 Figure 2-13).

n = the tally number ending with 5.

pl = N for neutrons and P for photons.

X_1 Y_1 Z_1 = a set of coordinates of the pinhole center.

R_0 is not used (do not put image grid in scattering material). Enter zero as a placeholder.

X_2 Y_2 Z_2 = a set of reference coordinates that establishes the reference direction for the normal to the detector flux image grid from (X_2 Y_2 Z_2) to the pinhole at (X_1 Y_1 Z_1).

F_1 > 0, the radius of a cylindrical collimator, centered on and parallel to the reference direction, which establishes a radial field of view through the object and surrounding materials and onto the image grid (default is large when 0).

F_2 = 0, the tally is made using a perfect pinhole.

> 0, the radius of the pinhole perpendicular to the reference direction. The point within the pinhole through which the particle flux contribution will pass is picked randomly (uniformly in area) for each source and scatter event.

F_3 = the distance from the pinhole at (X_1 Y_1 Z_1) to the center of the detector grid along the direction established from (X_2 Y_2 Z_2) to (X_1 Y_1 Z_1). The image grid is perpendicular to this reference direction.

Only one pinhole image tally per FIP card is allowed. The point detector Russian roulette game is not used with the FIP tally. Consider use of the NOTRN card for only direct contributions and the TALNP card to reduce the size of the OUTP file for large-image grids. The image grid **SHOULD NOT** be in a scattering material because the point detector average flux neighborhood is not used for flux image tallies.

Form for defining an FIP, FIR, or FIC image grid: FS*n* and C*n* cards

The FIP and FIR rectangular grid dimensions on the image plane are established from entries on FS*n* and C*n* cards where the tally number *n* matches the flux image tally number for either the FIP*n* or FIR*n* card. The first entry on the FS*n* and C*n* cards sets the lower limit in cm of the first image bin for the s-axis and t-axis respectively. The other entries set the upper limit of each of the bins. These limits are set relative to the intersection of the reference direction and the grid plane, with an *s*-axis and *t*-axis, as shown in Chapter 2 Figures 2-11 and 2-13. The relationship of the *s*-axis, *t*-axis, and reference direction for the planar image grid is calculated by MCNP and follows the right-hand rule. Since the orientation of the *s*-axis and the *t*-axis is dependent on the reference direction in the geometry coordinate system, the MCNP tally output should be examined to see the direction cosines of these two planar image grid axes. These limits should be defined taking into account any image size change at the grid caused by magnification. The image grid SHOULD NOT be in a scattering material because the point detector average flux neighborhood is not used for flux image tallies.

Examples of these cards are as follows:

FS*n* –20. 99i 15. defines the values for the image grid *s*-axis (*n* ends with 5)
C*n* –25. 99i 10. defines the limits for the image grid *t*-axis (*n* ends with 5)

This sets up a 100 x 100 grid that extends from –20 cm to 15 cm along the *s*-axis, –25 cm to 10 cm along the *t*-axis, and has 10000 equal size bins. These bins need not be equal in size nor do they need to be symmetric about the reference direction, as shown above. If the reference direction is parallel to the *z*-axis of the geometry, then the *t*-axis of the grid is defined to be parallel to the *y*-axis of the geometry. The *s*-axis of the grid is defined as the cross product of a unit vector in the *t* direction and a unit vector in the reference direction. If the reference direction is not parallel to the *z*-axis, MCNP calculates the orthogonal axes. The *s* and *t* image axes direction cosines are printed in the OUTP file.

The FS*n* and C*n* cards have a different meaning for an FIC tally. The entries on the FS*n* card are the distances along the symmetry axis from (X_1, Y_1, Z_1). The entries on the C*n* card are the angles in degrees measured counterclockwise from the positive *t*-axis (see Chapter 2 Figure 2-12).

There is no limit to the number FS*n* and C*n* image grid bins that can be defined. Note, however, that it is easy to define a tally with a huge number of point detectors; for example, a 1000 by 1000 grid is the equivalent of 1 million point detectors, which could take a long time to run. FATAL

errors will result if the FS*n* and C*n* card bin specifications are not each monotonically increasing. The default tally fluctuation chart bin is the last FS*n* and C*n* bin in the total (direct plus scattered) detector tally. FS0 and C0 cards for these image tallies are not allowed. The T (total) and C (cumulative) options for the FS*n* and C*n* cards are not available for flux image tallies.

Default: None.

Use: You are encouraged to read about detectors in Chapter 2, beginning on page 2–91, before using them because they are very susceptible to unreliable results if used improperly. Remember that contributions to a detector are not made through a region of zero importance. Ring (rather than point) detectors should be used in all problems with axial symmetry. Flux image detectors should be located in a void because the constant flux neighborhood R_0 is not used (such a neighborhood would have to enclose the entire image grid). A detector located right on a surface probably will cause trouble. Detectors and DXTRAN can be used in problems with the $S(\alpha,\beta)$ thermal treatment, but the $S(\alpha,\beta)$ contributions are approximate (see Chapter 2 page 2–54). Detectors used with reflecting, white, or periodic surfaces give wrong answers (see Chapter 2 page 2–102). Consider using the PD*n* and DD*n* cards.

For more than one detector with the same *n* or *na* designation, sets of the above input parameters (quadruplets for F*n* or triplets for F*na*) are simply continued on the same Fn or F*na* card. FIC, FIP, and FIR image tallies are allowed only one image with the same *n* designation. If more than one detector of the same type (an F5:N and an F15:N, for example) are at the same location, the time-consuming contribution calculation upon collision is made only once and not independently for each detector, according to the rules in Chapter 2. Thus it is inexpensive to add more than one detector (each with a different response function, for example) at the same location as another.

The printout for detectors is normally in two parts: (1) the total of all contributions to the detector (as a function of any defined bins such as energy) and (2) the direct (or uncollided) contribution to the detector from the source. The direct contribution is always included in the total of all contributions. Adding the symbol ND at the end of a type 5 detector tally card inhibits the separate printing of the direct contribution for that tally. In coupled neutron/photon problems, the direct contribution in photon tallies is from photons created at neutron collisions.

Rules of Thumb for R_0: R_0 should be about 1/8 to 1/2 mean free path for particles of average energy at the sphere and zero in a void. Supplying R_0 in terms of mean free path will increase the variance and is not recommended unless you have no idea how to specify it in centimeters. R_0 must not encompass more than one material. MCNP cannot check this and the consequences may be wrong answers.

3. Pulse Height Tally (tally type 8)

Simple Form: F*n*:*pl* $S_1 \ldots S_k$
General Form: F*n*:*pl* $S_1 (S_2 \ldots S_3) (S_4 \ldots S_5) S_6 S_7 \ldots$

n = tally number.
pl = P, E or P,E

S_i = problem number of cell for tallying, or *T*.

The F8 tally provides the energy distribution of pulses created in a detector by radiation and is called a pulse height tally. See page 3–88 for an explanation of the repeated structure and lattice tally format. The F8 card is used to list the cell bins, just like an F4 tally. The union of tallies produces a tally sum, not an average. Cell, user, and energy bin cards are allowed. Flagging, segment, multiplier, time, and cosine bins are not allowed. The energy bins accumulate the energy deposited in a cell by all the tracks of a history rather than the energy of the scoring tracks. Both photons and electrons will be tallied if present, even if only E or only P is on the F8 card. In other words, the F8:P, F8:E, and F8:P,E are all equivalent tallies. An asterisk on the F8 card converts the tally from a pulse height tally to an energy deposition tally. A plus on the F8 card converts the tally from a pulse height tally to a charge deposition tally in units of electron charge.

Care must be taken when selecting energy bins for a pulse height tally. It is recommended that a zero bin and an epsilon bin be included such as

E8 0 1E–5 1E-3 1E-1 ...

The zero bin will catch nonanalog knock-on electron negative scores. The epsilon (1E–5) bin will catch scores from particles that travel through the cell without depositing energy. See Chapter 2 page 2–89.

The pulse height tally is a radical departure from other MCNP tallies. All other tallies are estimates of macroscopic variables, such as flux, whose values are determined by very large numbers of microscopic events. The pulse height tally records the energy or charge deposited in a cell by each source particle and its secondary particles. For other tallies it is not necessary to model microscopic events realistically as long as the expectation values of macroscopic variables are correct. For the pulse height tally, microscopic events must be modeled much more realistically.

The departures from microscopic realism in MCNP are everywhere. The number, energies, and directions of the secondary neutrons and photons from a neutron collision are sampled without any correlation between the particles and with no regard for the conservation of energy. Modeling the fluctuations in the number of fission neutrons is limited to choosing between the integer next larger and the integer next smaller than the average number of fission neutrons. The fluctuations in the energy loss rate of an electron are not correlated with the production of knock-ons and x rays. The variance reduction schemes in MCNP create unrealistic histories that nevertheless give correct results for macroscopic tallies.

Problems that give correct pulse height tallies are severely limited. CAUTION: The pulse height tally does not work well with neutrons because of the nonanalog nature of neutron transport that departs from microscopic realism at every turn. One can have a neutron source in a MODE N P or N P E problem, but only the photons and electrons can be tallied on the F8 card. The F8 tally can be used effectively in photon problems. Electron problems may give correct results as long as the tally cells are thick enough for the errors in the energy loss rate to average out. MCNP tries to detect conditions in a problem that would invalidate pulse height tallies, but it is not able to catch all of them. The user must ascertain that his problem does not violate the necessary conditions for obtaining correct answers.

Scoring the pulse height tally is done at the end of each history. In the absence of variance reduction, the scoring is reasonably easy to describe. For example, consider a unit weight source and an F8 tally in cell 7. Suppose that on a given particle history that there are K entries into cell 7 and L departures from cell 7. The tally energy associated with an F8 tally is the kinetic energy of the particle plus 1.022016 MeV if it is a positron. Particles can enter cell 7 either by crossing a boundary into cell 7 or entering cell 7 as a source event. Particles depart cell 7 either by capture in cell 7 or by crossing a boundary out of cell 7. Let E_i be the i^{th} tally energy of a particle entering cell 7 and let D_j be the j^{th} tally energy of a particle departing cell 7. The total energy deposited in cell 7 is:

$$T = \sum_{i=1}^{K} E_i - \sum_{j=1}^{L} D_j$$

Suppose the pulse height bins are specified on the E8 card as:

E8 T_1 T_2 T_3 T_4 T_5

If $T_{\{m-1\}} < T < T_m$, then MCNP will post a unit tally in the m^{th} bin. If the problem is analog but the source weight is w_s, then w_s would be posted in the m^{th} bin. If there is an asterisk on the F8 card, then MCNP tallies w_s*T in the m^{th} bin. If there is a plus on the F8 card, then MCNP posts the net charge change times the w_s into the m^{th} bin. That is, an entering electron or a departing positron constitute a charge change of -1, whereas a departing electron or an entering positron constitute a charge change of +1.

The scoring details are more complex with the planned (2003) pulse height tally variance reduction; the details are described in Ref. 2.

The +F8 charge deposition tally can be checked against an electron F1:E surface tally with the FT ELC option if the volume of the +F8 is exactly enclosed by the surfaces on the F1:E card. For example, if cell 1 is enclosed by spherical surface 2, then the following tallies give the same result provided the two F1 current tally bins (in – out) are properly subtracted.

```
+F8:E          and          F1:E   2
                            FT1   ELC  1
                            C1  0  1
```

Note that the meaning of the energy bins of a pulse height tally is entirely different from the meaning of the energy bins of the other tallies in MCNP. The normal meaning of energy bins is the energy of a scoring track. The meaning of the energy bins of a pulse height tally is the energy deposited in a cell bin by all the physically associated tracks of a history. (The deconvolution theory supplies the physical association of the tracks. See Ref. 2.)

Pulse Height Tally Variance Reduction

Variance reduction for F8 tallies is implemented, but there is not a lot of experience to guide the user. The theory for the F8 variance reduction in MCNP is described in Refs. 1 and 2. Experience

suggests that weight windows be used instead of geometry splitting for F8 tallies. Many of the variance reduction techniques that were designed for lowering the variance on the other tallies may be used with the F8 tally. Allowed variance reduction techniques are:

- Splitting/roulette (IMP card)
- Implicit capture and weight cutoff (CUT card)
- Weight window (WWN card)
- Forced collisions (FCL card)
- Exponential transform (EXT card)
- DXTRAN (DXT card)
- Weight roulette on DXTRAN particle (DD card)
- DXTRAN cell probabilities (DXC card)
- Source biasing (SB card)
- Energy splitting (ESPLT card)
- Time splitting (TSPLT card)

The roulette associated with splitting/roulette (IMP card) and weight windows (WWN card) may be less useful than for non-F8 tallies; the roulette may be turned off by adding "RR=off" on the VAR card. Although implicit capture and weight cutoff have been implemented, in most cases these games are turned by default if an F8 tally is in the problem. The only exception is if forced collisions are also used in the problem.

Note that the weight window generator was designed for non-F8 tallies; the generator should not be used for F8 tallies. The generator estimates the importance of a single particle at a phase-space point P. The generator cannot estimate the importance of a collection of K particles at phase-space points P1, P2, ... , PK. (To see what is involved with making a generator work with F8, see Ref. 3.) Instead, a useful window often can be generated using a tally such as an F4 tally in the same cell as the F8 tally.

Introduction to Pulse Height Variance Reduction Theory

The MCNP pulse height variance reduction theory is described in detail in references 1 and 2. Two simple examples are given in this manual to give the reader an idea of how MCNP does variance reduction with pulse height tallies. The essential idea is that MCNP's deconvolution method reconstructs physically possible random walks and assigns an appropriate tally weight based on how much the variance reduction has distorted the frequency of obtaining the walks. For example, if a random walk has been made twice as likely to occur in the simulation as it would naturally, then this random walk will be assigned at weight of 1/2 so that the expected tallies are preserved.

For the first example, suppose that there is a pair annihilation event and an exponential transform is applied to both .511 MeV branches. (Assume this is the only variance reduction used.) Because the exponential transform samples a nonanalog density, there will be a weight multiplication to

account for this. The left branch has a track weight of 1/5 indicating that the left branch's random walk was made 5 times as likely to occur as it would have without applying the exponential transform. Similarly, the right branch has a track weight of 1/3 indicating that the right branch's random walk was made 3 times as likely to occur as it would have without applying the exponential transform. Assuming that none of the Ei are in the same bin, the tally for the total current into the cell is tallied as:

1/5 in the energy bin around E5
1/5 in the energy bin around E7
1/3 in the energy bin around E1
1/3 in the energy bin around E3

and the total current leaving the cell is tallied as:

1/5 in the energy bin around E6
1/5 in the energy bin around E7
1/3 in the energy bin around E2
1/3 in the energy bin around E4

By contrast, as explained below, the F8 tally for this history is:

(1/5)(1/3) in the energy bin around E5-E6+E7-E7+E1-E2+E3-E4

Note that the F8 tally depends on the energy deposited collectively by both branches of the pair annihilation event. If the history above had been sampled without the exponential transforms, then the F8 tally would have been

1 in the energy bin around E5-E6+E7-E7+E1-E2+E3-E4.

Note that the physical walk contributes E5-E6+E7-E7+E1-E2+E3-E4 regardless of how often the walk is sampled. With the variance reduction applied here, the particular walk sampled occurred 5*3=15 times as often as it would in an analog calculation. Thus, the F8 tally credits the physical energy bin with a weight factor of 1/15, correcting for the fact that the annihilation pair has been made 15 times as likely to execute the walk that contributes E5-E6+E7-E7+E1-E2+E3-E4 as it should have. Note that it is a physical collection of particles that now carries the tally modification weight because it is the physical collection that tallies to the F8 tally rather than just the individual tracks as with other tallies in MCNP.

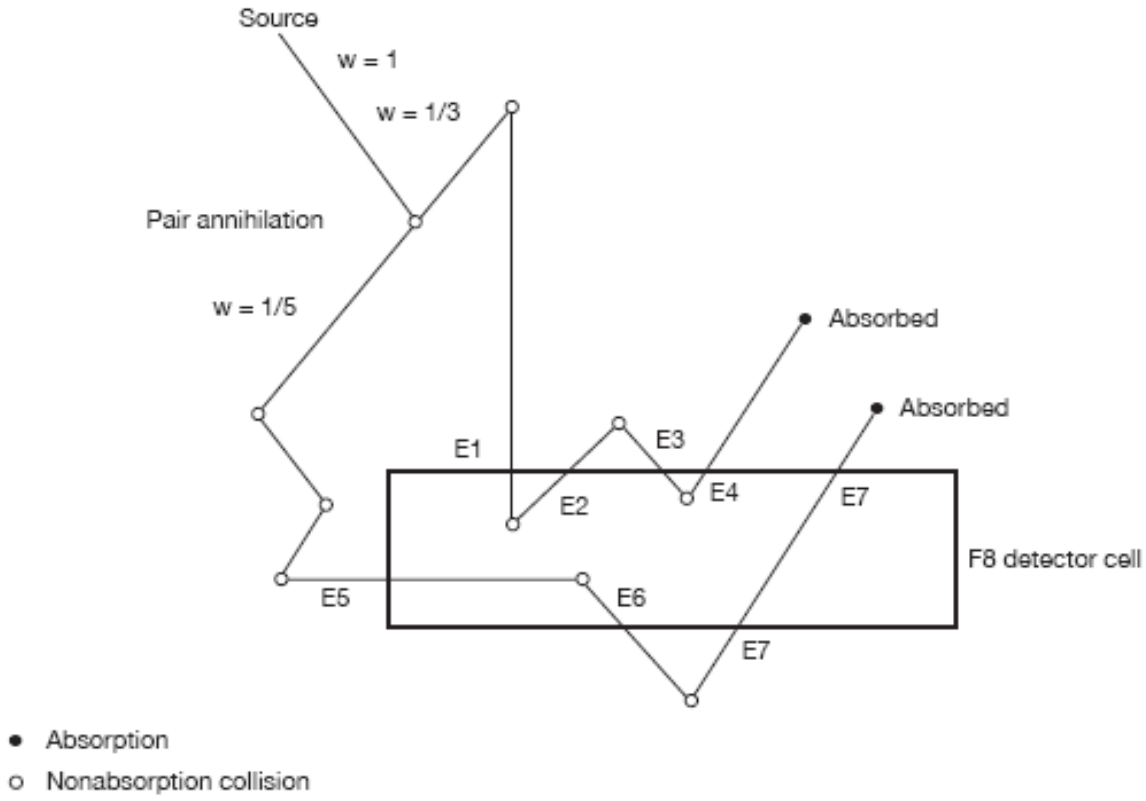


Figure 3-3. Example of exponential transform applied to both branches of a pair annihilation event.

The second example considers a 2:1 splitting event and no other variance reduction methods. Note that splitting is a mathematical artifice; only one physical particle exists after crossing the splitting surface. What the splitting does is give two (usually) different samples of the random walk after crossing the splitting surface. Both of these random walks do not physically occur at the same time. If the left split branch occurs then the right split branch does not and vice versa. Inasmuch as the splitting represents a doubling of the sampling frequency for either branch, the branches are each assigned a weight of 1/2. The energy bins associated with taking the left split branch or the right split branch are, respectively, E5-E6+E7-E7+E1-E8 or E5-E6+E7-E7+E1-E2+E3-E4. The pulse height tally is thus

1/2 in the energy bin around E5-E6+E7-E7+E1-E8
1/2 in the energy bin around E5-E6+E7-E7+E1-E2+E3-E4.

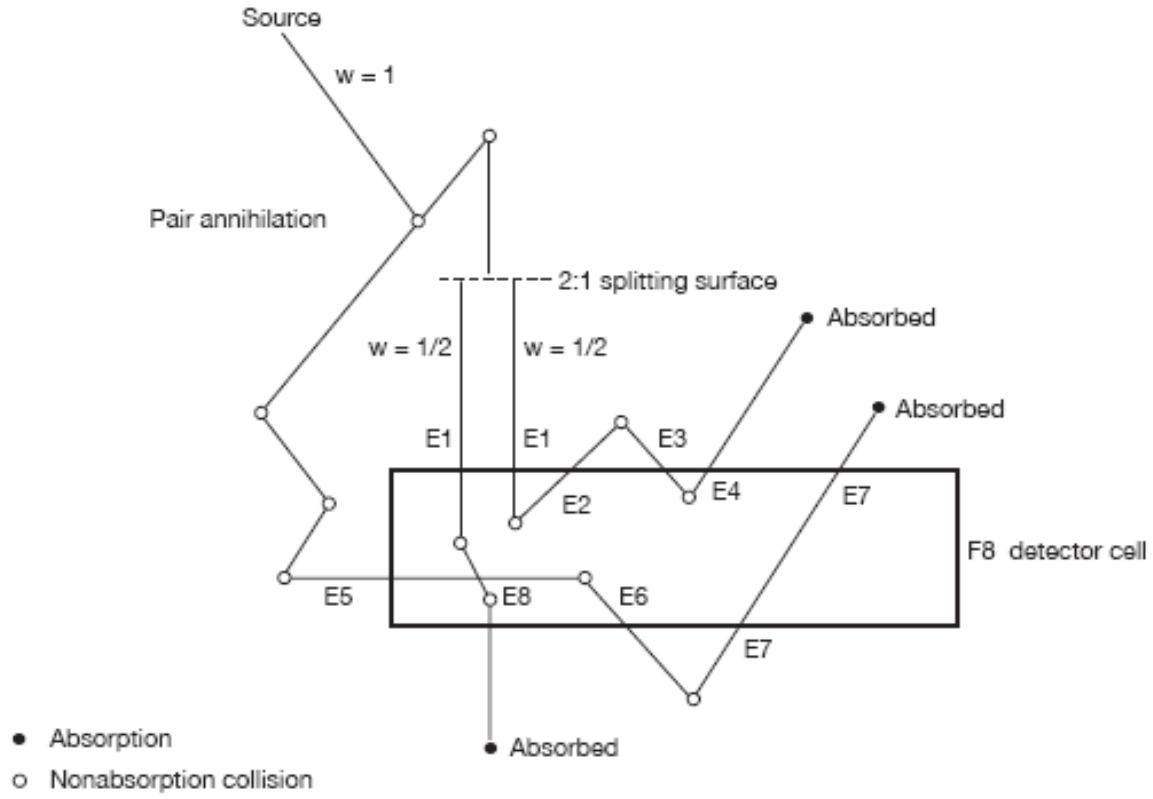


Figure 3-4. 2:1 Splitting example.

4. Surface, Cell, and Pulse Height Tallies for Repeated Structures and Lattices (tally types 1, 2, 4, 6, 7, and 8)

Simple Form: F*n*:*pl* $S_1 \ldots S_k$
General Form: F*n*:*pl* $S_1\ (S_2 \ldots S_3)\ ((S_4\ S_5) < (C_1\ C_2[I_1 \ldots I_2]) < (C_3\ C_4\ C_5)) \ldots$

n = tally number.
pl = N or P or N,P or E.
S_i = problem number of a surface or cell for tallying, U=#, or *T*.
C_i = problem number of a cell filled with a universe, or U=#.
\# = problem number of a universe used on a fill card.
I_i = index data for a lattice cell element, with three possible formats:

I_1 Indicating the I_1^{th} lattice element of cell C_2, as defined by the FILL array.
$I_1 : I_2$ $I_3 : I_4$ $I_5 : I_6$ Range of one or more lattice elements.

	Use the same format as on the FILL card.
I_1 I_2 I_3, I_4 I_5 I_6	Indicating lattice element (I_1, I_2, I_3), (I_4, I_5, I_6), etc. See LAT and FILL cards for indices explanation.

Use: Consider using the SPDTL card.

In the simple form, MCNP creates *k* surface or cell bins for the requested tally, listing the results separately for each surface or cell. In the more general form, a bin is created for each surface or cell listed separately and for each collection of surfaces or cells enclosed within a set of parentheses. A tally bin can involve a single tally level or multiple tally levels. Tallies involving repeated structure and lattice geometries can use either form.

If a tally label of the surface or cells in a given bin exceeds eleven characters, including spaces, an alphabetical or numerical designator is defined for printing purposes. The designator [G is (1 2 3 4 5 6)], for example, would be printed with the tally output. This labeling scheme is usually required for tallies over the union of a long list of surfaces or cells or with repeated structure tallies.

Some operators and nomenclature need to be introduced before the explanation of repeated structures and lattice tallies. The left arrow or less than symbol < is used to identify surfaces or cells within levels of repeated structures. See page 3–27 for an explanation of geometry levels. A tally bin that includes one or more left arrows implies multiple levels, called a chain. Multiple entries enclosed by parentheses at any level of a tally chain indicates the union of the items. Brackets [ ] immediately following a filled lattice cell identify one or more elements of that lattice. The input tally bin chain involving multiple levels MUST be enclosed by an outer set of parentheses.

F4:N (5 < 4 < 2 [1 0 0])

This example could specify an F4 tally in cell 5 when it is in cell 4, when cell 4 is in cell 2, which is a lattice, and only in lattice element [1,0,0]. While any cell (lattice, filled, or simple) can be entered as a tally cell (e.g., S_1 through S_5), only cells filled with a universe can be used in higher levels (e.g., C_1 through C_5.) See General Form, page 3–92.

Multiple bin format: In addition to multiple levels, multiple entries can be used in each level of the tally chain resulting in multiple output bins. Within the parentheses required around the tally bin chain, other sets of parentheses can be used to indicate the union of cells as in a simple tally description, resulting in fewer output tally bins.

$$((S_4\ S_5) < (C_1\ C_2\ [I_1 \ldots I_2]) < (C_3\ C_4\ C_5))$$

This example results in one output tally bin and will be the union of the tally in S_4 plus S_5 that fill C_1 or C_2 [elements $I_1 \ldots I_2$] and when C_1 or C_2 fills cells C_3, C_4, or C_5. Removing the first and third inner parentheses:

$$(S_4\ S_5 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_3\ C_4\ C_5)$$

results in the creation of 2*1*3=6 bins as follows:

$$(S_4 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_3), \quad (S_5 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_3),$$

$$(S_4 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_4), \quad (S_5 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_4),$$
$$(S_4 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_5), \quad (S_5 < (C_1\ C_2\ [I_1 \ldots I_2]) < C_5),$$

The repeated structure/lattice input tally bin format with levels that have multiple entries automatically creates multiple output tally bins. The total number of bins generated is the product of the number of entries at each level. If parentheses enclose all entries at a level, the number of entries at that level is one and results in the union of all those entries. See Chapter 4, page 4–48, for a CAUTION when tallying a union of overlapping regions. For unnormalized tallies (type 1, 8), the union is a sum. For normalized tallies (type 2, 4, 6, 7), the union is an average. A symbol *T* on the tally line creates an additional tally bin that is the union or total of all the other tally bins.

Brackets: Brackets [ ] enclose index data for lattice cell elements. Brackets make it possible to tally on a cell or surface only when it is within the specified lattice elements. The brackets must immediately follow a filled lattice cell. Listing a lattice cell without brackets will produce a tally when the tally cell or surface is in any element of the lattice, provided the tally cell or surface fills an entry at all other levels in the chain. The use of brackets is limited to levels after the first < in the tally specification.

To tally within lattice elements of a real world (level zero) lattice cell, use the special syntax that follows. Cell 3 contains material 1 and is bounded by four surfaces. The F4 card specifies a tally only in lattice element (0,0,0). This syntax is required because brackets can only follow a <.

```
3       1       −1.0    −1   2   3   4   lat=1
F4:N   (3 < 3 [0 0 0])
```

Universe format: The universe format, U=#, is a shorthand method of including all cells and lattice elements filled by universe #. This format can be used in any level of the tally chain. The following example illustrates valid shorthand U=# descriptions in the left column. The right column shows the tally after the shorthand has been expanded. Cells 4 and 5 are filled with universe 1.

	shorthand	expanded
F4:N	u=1	4 5
	(u=1)	(4 5)
	(u=1 < 2 < 3)	(4 5 < 2 < 3)
	((u = 1) < 2 < 3)	((4 5) < 2 < 3)
	(1 < u = 1 < 2 < 3)	(1 < 4 5 < 2 < 3)
	(1 < (u = 1) < 2 < 3)	(1 < (4 5) < 2 < 3)

In complex geometries, the U=# format should be used sparingly, especially with the multiple bin format. If 100 cells are filled by universe 1 and 10 cells are filled by universe 2, then the tally

```
F4:N    (u = 1 < u = 2)
```

will create 1000 output tally bins. However,

```
F4:N    ((u = 1) < (u = 2))
```

will create only one output tally bin.

Use of SDn card: When making tallies in repeated structure and lattice geometries, often a volume or area is required and MCNP will be unable to calculate it. Possibly the geometry causes the calculation to fail. A universe can be repeated a different number of times in different cells and the code has no way to determine this. There are two distinct options for entries on the SDn card relating to repeated structures and they cannot be mixed within a single tally.

The first option is to enter a value for each first level entry on the related F card. If the entry on the F card is the union of cells, the SD card value will be the volume of the union of the cells. The following examples illustrate Fn card tally descriptions in the left column. The right column shows the SDn card entries.

F4:N	(1 < 4 5 6 < 7 8)	SD4	V_1
	(1 2 3 < 4 5 6 < 7 8)		$V_1\ V_2\ V_3$
	(1 2 3 < (4 5 6) < (7 8))		$V_1\ V_2\ V_3$
	((1 2 3) < 4 5 6 < 7 8)		V_{123L}

V_i = volume of cell *i* and V_{123} = volume of the union of cells 1, 2, and 3. Even though the first line creates six tally bins, only one SD value is entered. This divisor is applied to all bins generated by the input tally bin. You do not need to know the number of bins generated by each input tally bin in order to use the SD card. The last line is the union of cells 1, 2, and 3 and only one divisor is entered on the SD card.

The second option is to enter a value for each bin generated by the Fn card.

F4:N	(1 < 4 5 6 < 7 8)	SD4	$V_1^1\ V_1^2\ V_1^3\ V_1^4\ V_1^5\ V_1^6$
	(1 2 3 < 4 5 6 < 7 8)		$V_1^1\ V_2^2\ V_3^3\ V_1^4\ V_2^5\ V_3^6\ V_1^7$ ... $V_1^{16}\ V_2^{17}\ V_3^{18}$
	(1 2 3 < (4 5 6) < (7 8))		$V_1\ V_2\ V_3$
	((1 2 3) < 4 5 6 < 7 8)		$V_{123}^1\ V_{123}^2\ V_{123}^3\ V_{123}^4\ V_{123}^5\ V_{123}^6$

V_1^j = volume of cell *i* for bin *j* and V_{123}^j = volume of the union of cells 1, 2, and 3 for bin *j*. If cell *i* is repeated the same number of times in all six bins generated by the first line above, then all six SD values for this input bin will be the same ($V_1^1 = V_1^2 = V_1^3 \ldots$). However, if cell 1 is repeated a different number of times in each bin, then different SD values should be entered. The volume is multiplied by the number of times it is repeated. In these cases, the total cell 1 volume for each generated bin will not be calculated. The bin generation order is explained previously in the Fn card section. For the first line above, the bin order is (1<4<7), (1<5<7), (1<6<7), (1<4<8), (1<5<8), and (1<6<8). The second line listed in the above sample generated 18 tally bins, and 18 SD values are required in the proper sequence. This option requires the knowledge of both the number and sequence of bins generated by each input tally bin.

2. FCn Tally Comment Card

Form: FCn any desired information

Default: No comment.

Use: Recommended for modified tally.

Anything entered after FCn will appear as the title heading of tally Fn. This card is particularly useful when tallies are modified in some way, so later readers of the output will be warned of modified or nonstandard tallies. The FCn card can be continued only by blanks in columns 1–5 on succeeding lines. The & continuation symbol is considered part of the comment, not as a continuation command.

3. En Tally Energy Card

Form: E*n* E_1 ... E_k

n = tally number.
E_i = upper bound (in MeV) of the i^{th} energy bin for tally *n*.

Default: If the En card is absent, there will be one bin over all energies unless this default has been changed by an E0 card.

Use: Required if the EMn card is used.

The entries on the En card must be entered in the order of increasing magnitude. If a particle has an energy greater than the last entry, it will not be tallied, but you will be warned that this has happened. If the last entry is greater than the upper energy limit E_{max} specified on the PHYS card, the last bin will be lowered to E_{max}. If there are several bins above E_{max}, the extra bins are eliminated.

An E0 (zero) card can be used to set up a default energy bin structure for all tallies. A specific En card will override the default structure for tally *n*.

MCNP automatically provides the total over all specified energy bins, but the total can be inhibited for a given tally by putting the symbol NT at the end of the En card for that tally. The symbol C at the end of the line causes the bin values to be cumulative and the last energy bin is also the total over all energy.

Example: E11 .1 1 20

This will separate an F11 current tally into four energy bins: (1) from the energy cutoff to 0.1 MeV, (2) from 0.1 to 1.0 MeV, (3) from 1.0 to 20.0 MeV, and (4) a total over all energy.

4. Tn Tally Time Card

Form: *Tn* T_1 ... T_k

n = tally number.
T_i = upper bound (in shakes) of the i^{th} time bin for tally *n*.

Default: If the Tn card is absent, there will be one bin over all times unless this default has been changed by a T0 card.

Use: Required if the TMn card is used. Consider the FQn card.

The times on the Tn card must be entered in order of increasing magnitude. If a particle has a time greater than the last entry on the Tn card, it will not be tallied, but you will be warned that this has happened. The last time bin entry should always be less than or equal to the time cutoff (see CUT card) except for point detectors. If time bins greater than the time cutoff are entered for tallies other than point detectors, the first bin limit over the cutoff will be lowered to the cutoff. All higher bins will be eliminated. For point detector tallies, time bins can exceed the time cutoff so that particles will score at detectors remote from the main body of the system. Setting the time cutoff lower than the last time bin will inhibit unproductive transport of slow neutrons in the system and will increase the efficiency of the problem.

A T0 (zero) card can be used to set up a default time bin structure for all tallies. A specific Tn card will override the default structure for tally *n*.

MCNP automatically provides the total over all specified time bins, but the total can be inhibited for a given tally by putting the symbol NT at the end of the Tn card for that tally. The symbol C at the end of the line causes the bin values to be cumulative and the last time bin is also the total over all time.

Example: T2 −1 1 1.0+37 NT

This will separate an F2 flux surface tally into three time bins: (1) from $-\infty$ to −1.0 shake, (2) from −1.0 shake to 1.0 shake, and (3) from 1.0 shake to 1.0e37 shakes, effectively infinity. No total bin will be printed in this example.

5. Cn Cosine Card (tally type 1 only)

Form: $Cn \quad C_1 \ldots C_k$

n = tally number.
C_i = upper cosine limit of the i^{th} angular bin for surface current tally n.
$C_1 > -1. \quad C_k = 1.$

Default: If the Cn card is absent, there will be one bin over all angles unless this default has been changed by a C0 card.

Use: Tally type 1. Required if the CMn card is used. Consider the FQn card.

The angular limits described by the Cn card are defined with respect to the positive normal to the surface at the particle point of entry. An FTn card with an FRV U V W option can be used to make the cosine bins relative to the vector u,v,w. The positive normal to the surface is always in the direction of a cell that has positive sense with respect to that surface. The cosines must be entered in increasing order, beginning with the cosine of the largest angle less than 180° to the normal and ending with the normal (cos=1). A lower bound of −1 is set in the code and should not be entered on the card. The last entry must always be 1.

A C0 (zero) card can be used to set up a default angular bin structure for all tallies. A specific Cn card will override the default structure for tally n. Note that the selection of a single cosine bin for an F1 tally gives the total and not the net current crossing a surface.

MCNP does not automatically provide the total over all specified cosine bins, but the total can be generated for a given tally by putting the symbol *T* at the end of the Cn card for that tally. The symbol C at the end of the line causes the bin values to be cumulative and the last cosine bin is also the total over all cosine bins.

Example: C1 −.866 −.5 0 .5 .866 1

This will tally currents within the angular limits (1) 180^o to 150^o, (2) 150^o to 120^o, (3) 120^o to 90^o, (4) 90^o to 60^o, (5) 60^o to 30^o, and (6) 30^o to 0^o with respect to the positive normal. No total will be provided.

As an example of the relation between a surface normal and sense for the C1 card, consider a source at the origin of a coordinate system and a plane (PY) intersecting the +*y* axis. An entry of 0 and 1 on the C1 card will tally all source particles transmitted through the plane in the 0 to 1 cosine bin (0^o to 90^o) and all particles scattered back across the plane in the −1 to 0 cosine bin (90^o to 180^o). A plane (PY) intersecting the −*y* axis will result in a tally of all source particles transmitted through the second plane in the −1 to 0 bin (90^o to 180^o) and all particles scattered back across the plane in the 0 to 1 bin (0^o to 90^o). Note that the positive normal direction for both planes is the same, the +*y* axis.

6. FQn Print Hierarchy Card

Form: FQ*n* A_1 A_2 ... A_8

n = tally number
A_i = F–cell, surface, or detector
D–direct or flagged
U–user
S–segment
M–multiplier
C–cosine
E–energy
T–time

Default: Order as given above.

Use: Recommended where appropriate.

The A_i's are the letters representing all eight possible types of tally bins. This card can be used to change the order in which the output is printed for the tallies. For a given tally, the default order is changed by entering a different ordering of the letters, space delimited. An example of this card is in the DEMO example in Chapter 5.

A subset of the letters can be used, in which case MCNP places them at the end of the FQn card and precedes them with the unspecified letters in the default order. The first letter is for the

outermost loop of the nest in the tally printout coding. The last two sets of bins make a table: the next to last set goes vertically; the last set of bins goes horizontally in the table.

Note that the default order is a table in E and T; any other bins in a tally will be listed vertically down the output page. Thus if you have a tally with only cell, user, and energy bins, the print for that tally will be a hard-to-read vertical list. Specifying U E as the only entries or last two entries on the FQn card will produce the same output, but in an easy-to-read table.

An FQ0 (zero) card can be used to change the default order for all tallies. A specific FQn card will then override that order for tally number *n*.

An example of this card is in the DEMO example in Chapter 5.

7. FMn Tally Multiplier Card

Form: FM*n* *(bin set 1)* *(bin set 2)* ... *T*

n = tally number
(bin set i) = ((multiplier set 1) (multiplier set 2) ... (attenuator set))
T = absent for no total over bins
= present for total over all bins
C = cumulative tally bins

attenuator set = C -1 m_1 px_1 m_2 px_2 ...
multiplier set *i* = C m (reaction list 1) (reaction list 2) ...
special multiplier set *i* = C $-k$

C = multiplicative constant
−1 = flag indicating attenuator rather than multiplier set
m = material number identified on an Mm card
px = density times thickness of attenuating material;
atom density if positive, mass density if negative
k = special multiplier option;
(reaction list *i*) = sums and products of ENDF or
special reaction numbers, described below.

Parentheses:

1. If a given multiplier set contains only one reaction list, the parentheses surrounding the reaction list can be omitted. Parentheses within a reaction list are forbidden.
2. If a given bin set consists of more than a single multiplier or attenuator set, each multiplier or attenuator set must be surrounded by parentheses, and the combination must also be surrounded by parentheses.
3. If the FMn card consists only of a single bin set, and that bin set consists only of a single multiplier or attenuator bin, surrounding parentheses can be omitted.

Default: If the *C* entry is negative (for type 4 tally only), *C* is replaced by $|C|$ times the atom density of the cell where the tally is made.

Use: Optional. Use the attenuators only when they are thin. Use only the multiplicative

constant for tally types 6 and 7. Disallowed for tally type 8.

Use: With mesh tallies: Only one multiplier set and reaction list per mesh tally is permitted. A combination of a multiplier set and attenuator set is not allowed. If m = 0 for a multiplier set, the reaction cross sections for the material in which the particle is traveling are used.

The FMn card is used to calculate any quantity of the form

$$C\int \varphi(E)R_m(E)dE,$$

where $\varphi(E)$ is the energy-dependent fluence (particles/cm^2) and *R(E)* is an operator of additive and/or multiplicative response functions from the MCNP cross-section libraries or specially designated quantities. Note that some MCNP cross-section library reaction numbers are different from ENDF/B reaction numbers. See Table 3.5 below. The constant *C* is any arbitrary scalar quantity that can be used for normalization. The material number *m* must appear on an Mm card, but need not be used in a geometrical cell of the problem.

A reaction list consists of one or more reaction numbers delimited by spaces and/or colons. A space between reaction numbers means multiply the reactions. A colon means add the reactions. The hierarchy of operation is multiply first and then add. One bin is created for each reaction list. Thus, if R_1, R_2, and R_3 are three reaction numbers, the form $R_1\ R_2 : R_3$ represents one reaction list (one bin) calling for reaction R_3 to be added to the product of reactions R_1 and R_2. No parentheses are allowed within the reaction list. The product of R_1 with the sum of R_2 and R_3 would be represented by the form $R_1\ R_2 : R_1\ R_3$ rather than by the form $R_1\ (R_2 : R_3)$. The latter form would produce two bins with quite a different meaning (see Examples 1 and 2 on page 3–102).

The reaction cross sections are *microscopic* (with units of barns) and not macroscopic. Thus, if the constant *C* is the atomic density (in atoms per barn · cm), the results will include the normalization "per cm^3." The examples in Chapter 4 (see page 4–39) illustrate the normalization.

Any number of ENDF/B or special reactions can be used in a multiplier set as long as they are present in the MCNP cross-section libraries, or in special libraries of dosimetry data. If neither a material nor any reactions are given, the tally is multiplied by the constant *C*.

A multiplier set that has only two entries, *C* k, has special meaning. If k= –1, the tally is multiplied by 1/weight and the tally is the number of tracks (or collisions for the F5 tally.) If k= –2, the tally is multiplied by 1/velocity and the tally is the neutron population integrated over time, or the prompt removal lifetime. See Chapter 2 page 2–177, Chapter 4 example 3 page 4–40, and the KCODE problem on page 5–63 in Chapter 5.

In addition to most of the approximately one hundred standard ENDF reaction numbers available (for example, R = 1, 2, 16, representing σ_{tot}, σ_{el}, $\sigma_{n,2n}$), the following nonstandard special R numbers may be used:

Table 3.5: ENDF/B Reaction Numbers

Type	Reaction Numbers
Neutrons	−1 total cross section without thermal
	−2 absorption cross section
	−3 elastic cross section without thermal
	−4 average heating number (MeV/collision)
	−5 gamma-ray production cross section, barns
	−6 total fission cross section
	−7 fission ν
	−8 fission Q (MeV/fission)
Photons	−1 incoherent scattering cross section
	−2 coherent scattering cross section
	−3 photoelectric cross section
	−4 pair production cross section
	−5 total cross section
	−6 photon heating number
Multigroup	−1 total cross section
	−2 fission cross section
	−3 nubar data
	−4 fission chi data
	−5 absorption cross section
	−6 stopping powers
	−7 momentum transfers

A list of many of the ENDF reaction numbers can be found in Appendix G. The total and elastic cross sections, R = 1 and R = 2, are adjusted for temperature dependence. All other reactions are interpolated directly from the library data tables. Note that for tritium production, the R number differs from one nuclide to another. Note also that tally types 6 and 7 already include reactions, so the FMn card makes little sense for n = 6 or 7. Generally only the constant-multiplier feature should be used for these tally types. Photon production reactions can be specified according to the MTRP prescription in Table F.6 in Appendix F.

An attenuator set of the form C -1 m px, where m is the material number and px is the product of density and thickness, allows the tally to be modified by the factor $e^{-\sigma_{tot} px}$ representing an exponential line-of-sight attenuator. This capability makes it possible to have attenuators without actually modeling them in the problem geometry. CAUTION: The assumption is made that the attenuator is thin, so that simple exponential attenuation without buildup from scattering is valid.

The attenuator set can include more than one layer:

$$C \quad -1 \; m_1 \; px_1 \; m_2 \; px_2$$

in which case the factor is $e^{-\sigma_1 px_1 - \sigma_2 px_2}$. The attenuator set can also be part of a bin set, for example,

$$((C_1 \;\; m_1 \;\; R_1)\,(C_2 \;\; m_2 \;\; R_2)\,(C_3 \;\; -1 \;\; m_3 \;\; px_3))$$

in which case the attenuation factor is applied to every bin created by the multiplier sets. Note that both the inner and the outer parentheses are required for this application. This combination of attenuator sets and reaction multipliers cannot be used with a mesh tally.

Tallies are posted in all multiplier bins for each score. MCNP does not automatically provide the total over all specified multiplier bins for a particular tally. The total is available for a tally, however, by putting the symbol *T* at the end of the FMn card for that tally.

In perturbed problems (see PERT card, page 3–156), the perturbation keyword RXN can affect the cross sections used with the FM card tally multipliers. If a tally in a cell is dependent on a cross section that is perturbed, then $R_{ij'} \neq 0$ and a correction is made to the $R_{1j'} = 0$ case (see Chapter 2 page 2–195). For this required $R_{1j'}$ correction to be made, the user must ensure that the R reactions on the FM card are the same as the RXN reactions on the PERT card AND that the FM card multiplicative constant C is negative, indicating multiplication by the atom density to get macroscopic cross sections. For example, if R = –6 for fission on the FM card, you should not use RXN=18 for fission on the PERT card. If $C > 0$, the cross sections are not macroscopic; it is assumed that there is no tally dependence on a perturbed cross section, $R_{1j'} = 0$, and no correction is made. The same $R_{ij'} \neq 0$ correction is automatically made for the F6 tally and the KCODE k_{eff} calculation, and for an F7 tally if the perturbation reaction is fission because these three tallies all have implicit associated FM cards.

Example 1: FMn C m $R_1\ R_2 : R_1\ R_3$

Example 2: FMn C m $R_1\ (R_2 : R_3)$

These two examples reiterate that parentheses cannot be used for algebraic hierarchy within a reaction list. The first example produces a single bin with the product of reaction R_1 with the sum of reactions R_2 and R_3. The second case creates two bins, the first of which is reaction R_1 alone; the second is the sum of R_2 and R_3, without reference to R_1.

Example 3:
F2:N 1 2 3 4
FM2 (C_1) (C_2) (C_3) (C_4) T

Example 4:
F12:N 1 2 3 4
FM12 C_1

Example 5:
F22:N (1 2 3) 4 T
FM22 (C_1) (C_2) (C_3) (C_4)

These three examples illustrate the syntax when only the constant-multiplier feature is used. All parentheses are required in these examples. Tally 2 creates 20 bins: the flux across each of surfaces 1, 2, 3, and 4 with each multiplied by each constant C_1, C_2, C_3, C_4, and the sum of the four constants. Tally 12 creates 4 bins: the flux across each of surfaces 1, 2, 3, and 4 with each multiplied by the constant C_1. Tally 22 creates 12 bins: the flux across surface 1 plus surface 2 plus surface 3,

the flux across surface 4, and the flux across all four surfaces with each multiplied by each constant C_1, C_2, C_3, and C_4. An FQn card with an entry of F M or M F would print these bins of the tallies in an easy-to-read table rather than strung out vertically down the output page.

Several more examples of the FMn card are in Chapter 4 beginning on page 4–39. The DEMO example in Chapter 5 (see page 5–1) also illustrates the general form of the card.

Using MCNP tallies, there are two ways to obtain the energy deposited in a material in terms of rads (1 rad = 100 ergs/g). When the actual material of interest is present in the MCNP model, the simplest way is to use the heating tally with units MeV/g in conjunction with C=1.602E–08 on the companion FMn card, where C=(1.602E–06 ergs/MeV)/(100 ergs/g). When the material is not present in the model, rads can be obtained from type 1, 2, 4, and 5 tallies by using an FMn card where C is equal to the factor above times $N_o\eta \times 10^{-24}/A$, where N_o is Avogadro's number and η and A are the number of atoms/molecule and the atomic weight, respectively, of the material of interest. This value of C equals ρ_a/ρ_g as discussed in Chapter 2 on page 2–89. The implicit assumption when the material is not present is that it does not affect the radiation transport significantly. In the reaction list on the FM card, you must enter –4 1 for neutron heating and –5 –6 for photon heating. See page 2–89 in Chapter 2 and page 4–39 in Chapter 4 for examples. For both F4 and F6, if a heating number from the data library is negative, it is set to zero by the code.

8. DEn Dose Energy Card
DFn Dose Function Card

Form: DEn A E_1 ... E_k
DFn B F_1 ... F_k

n = tally number.
E_i = an energy (in MeV).
F_i = the corresponding value of the dose function.
A = LOG or LIN interpolation method for energy table.
B = LOG or LIN interpolation method for dose function table.

Defaults: If A or B is missing, LOG is chosen for that table.

Use: Tally comment is recommended.

This feature allows you to enter a pointwise response function (such as flux-to-dose conversion factors) as a function of energy to modify a regular tally. Both cards must have the same number of numerical entries and they must be monotonically increasing in energy. Particle energies outside the energy range defined on these cards use either the highest or lowest value.

By default MCNP uses log-log interpolation between the points rather than a histogram function as is done for the EMn card. The energy points specified on the DEn card do not have to equal the tally energy bins specified with the En card for the Fn tally. Unlike EMn card use, there can be many points on the DEn and DFn cards, but the response can be tallied in only a few energy bins such as one unbounded energy bin.

If *n* is zero on these two cards, the function will be applied to all tallies that do not have DEn and DFn cards specifically associated with them.

LIN or LOG can be chosen independently for either table. Thus any combination of interpolation (log-log, linear-linear, linear-log, or log-linear) is possible. The default log-log interpolation is appropriate for the ANSI/ANS flux-to-dose rate conversion factors (they are listed in Appendix H); kermas for air, water, and tissue; and energy absorption coefficients.

Example: DE5 $E_1\ E_2\ E_3\ E_4 \ldots E_k$
DF5 LIN $F_1\ F_2\ F_3\ F_4 \ldots F_k$

This example will cause a point detector tally to be modified according to the dose function F(E) using logarithmic interpolation on the energy table and linear interpolation on the dose function table.

9. EMn Energy Multiplier Card

Form: EM*n* $M_1 \ldots M_k$

n = tally number.
M_i = multiplier to be applied to the i^{th} energy bin.

Default: None.

Use: Requires an En card. Tally comment is recommended.

This card can be used with any tally (specified by *n*) to scale the usual current, flux, etc. by a response function. There should be one entry for each energy entry on the corresponding En card. When a tally is being recorded within a certain energy bin, the regular contribution is multiplied by the entry on the EMn card corresponding to that bin. For example, a dose rate can be tallied with the appropriate response function entries. Tallies can also be changed to be per unit energy if the entries are $1/\Delta E$ for each bin. Note that this card modifies the tally by an energy-dependent function that has the form of a histogram and not a continuous function. It also requires the tally to have as many energy bins as there are histograms on the EMn card. If neither of these two effects is desired, see the DEn and DFn cards.

A set of energy multipliers can be specified on an EM0 (zero) card that will be used for all tallies for which there is not a specific EMn card.

10. TMn Time Multiplier Card

Form: TM*n* $M_1 \ldots M_k$

n = tally number.
M_i = multiplier to be applied to the i^{th} time bin.

Default: None.

Use: Requires a Tn card. Tally comment is recommended.

This card is just like the EMn card except that the entries multiply time bins rather than energy bins. The Tn and TMn cards must have the same number of entries. Note that this card modifies the tally by a time-dependent function that has the form of a histogram and not a continuous function.

A set of time multipliers can be specified on a TM0 (zero) card that will be used for all tallies for which there is not a specific TMn card.

For example, if the entries are $1/\Delta T$, where ΔT is the width of the corresponding time bin, the tally will be changed to be per unit time with the units of $1/\Delta T$.

11. CMn Cosine Multiplier Card (tally type 1 only)

Form: CM*n* $M_1 \ldots M_k$

n = tally number.
M_i = multiplier to be applied to the i^{th} cosine bin.

Default: None.

Use: Tally type 1. Requires a Cn card. Tally comment is recommended.

This card is just like the EMn and TMn cards except that the entries multiply cosine bins. The number of entries on the CMn card must be the same as on the Cn card. Note that this card modifies the tally by an angular-dependent function that has the form of a histogram and not a continuous function.

A set of cosine multipliers can be specified on a CM0 (zero) card that will be used for all type 1 tallies for which there is not a specific CMn card.

For example, if you want the directionally dependent F1 tally results to be per steradian, the i^{th} entry on the CM1 card is

$$\frac{1}{2\pi(\cos\theta_i - \cos\theta_{i-1})}$$

where θ_o is 180^o.

12. CFn Cell-Flagging Card (tally types 1, 2, 4, 6, 7)

Form: CF*n* $C_1 \ldots C_k$

n = tally number.
C_i = problem cell numbers whose tally contributions are to be flagged.

Default: None.

Use: Not used with detectors or pulse height tallies. Consider the FQn card.

Particle tracks can be “flagged” when they leave designated cells and the contributions of these flagged tracks to a tally are listed separately in addition to the normal total tally. This method can determine the tally contribution from tracks that have passed through an area of interest.

Cell flagging cannot be used for detector tallies. The same purpose can be accomplished with an FTn card with the ICD option.

The cell flag is turned on only upon leaving a cell. A source particle born in a flagged cell does not turn the flag on until it leaves the cell.

In MODE N P, the flagged neutron tallies are those caused by either neutrons leaving the flagged cell or photons leaving the flagged cell that later produce a photoneutron that is tallied. Likewise, flagged photon tallies can be caused by either a photon leaving a flagged cell or a neutron leaving a flagged cell, which leads to a photon that is tallied.

```
Example:   F4:N    6    10  13
           CF4     3     4
```

In this example the flag is turned on when a neutron leaves cell 3 or 4. The print of Tally 4 is doubled. The first print is the total track length tally in cells 6, 10, and 13. The second print is the tally in these cells for only those neutrons that have left cell 3 or 4 at some time before making their contribution to the cell 6, 10, or 13 tally.

13. SFn Surface-Flagging Card (tally types 1, 2, 4, 6, 7)

Form: SFn S_1 ... S_k

n = tally number.
S_i = problem surface numbers whose tally contributions are to be flagged.

Default: None.

Use: Not used with detectors. Consider the FQn card.

This feature is identical to cell flagging except that particles turn the flag on when they cross the specified surfaces. Thus a second tally print is given for only those particles that have crossed one or more of the surfaces specified on the SFn card.

Surface flagging cannot be used for detector tallies but an FTn card with the ICD option will do the same thing.

The situation for tallies in MODE N P is like that for the CFn card: a neutron or photon can be flagged either because it has crossed a flagged surface or because it was created by a particle that crossed a flagged surface.

Both a CFn and an SFn card can be used for the same tally. The tally is flagged if the track leaves one or more of the specified cells or crosses one or more of the surfaces. Only one flagged output for a tally is produced from the combined CFn and SFn card use.

14. FSn Tally Segment Card (tally types 1, 2, 4, 6, 7)

Form: FSn S_1 ... S_k

n = tally number.

S_i = signed problem number of a segmenting surface.

Default: No segmenting.

Use: Not used with detectors. May require the SDn card. Consider the FQn card.

This card allows you to subdivide a cell or a surface into segments for tallying purposes, the advantage being that it is then not necessary to specify the problem geometry with extra cells just for tallying. The segmenting surfaces specified on the FSn card are listed with the regular problem surfaces, but they need not be part of the actual geometry and hence do not complicate the cell/surface relationships.

If k surfaces are entered on the FSn card, $k + 1$ surface or volume segments are created. Tally n is subdivided into $k + 1$ segment bins according to the order and sense of the segmenting surfaces listed on the FSn card. If the symbol T is on the FSn card, there will be an additional total bin. The symbol C at the end of the FS card causes the bin values to be cumulative. Segmenting is done according to the following scheme:

Fn:N S (or C)
FSn S_1 ... S_k T (optional)

Tally n over surface S (or in cell C) will be subdivided into the following bins:

1 the portion with the same sense with respect to surface S_1 as the sign given to S_1,
2 the portion with the same sense with respect to surface S_2 as the sign given to S_2 but excluding that already scored in a previously listed segment,
k the portion with the same sense with respect to surface S_k as the sign given to S_k but excluding that already scored in a previously listed segment,
k+1 everything else,
k+2 entire surface or cell if T is present on FSn card.

If the symbol T is absent from the FSn card, the $(k+2)^{th}$ bin is missing and MCNP calculates the tally only for each segment (including the "everything else" segment). If multiple entries are on the Fn card, each cell or surface in the tally is segmented according to the above rules. For tally types 1 or 2, the segmenting surfaces divide a problem surface into segments for the current or flux tallies. The segmenting surfaces divide a problem cell into segments for tally types 4, 6, or 7. For normalized tallies, the segment areas (for type 2), volumes (for type 4), or masses (for types 6 and 7) may have to be provided. See the discussion under the SDn card.

Example 1:
```
F2:N   1
FS2    -3  -4
```

This example subdivides surface 1 into three sections and calculates the neutron flux across each of them. There are three prints for the F2 tally: (1) the flux across that part of surface 1 that has negative sense with respect to surface 3, (2) the flux across that part of surface 1 that has negative sense with respect to surface 4 but that has not already been scored (and so must have positive sense with respect to surface 3), (3) everything else (that is, the flux across surface 1 with positive sense with respect to both surfaces 3 and 4).

It is possible to get a zero score in some tally segments if the segmenting surfaces and their senses are not properly specified. In Example 1 above, if all tallies that are positive with respect to surface 3 are also all positive with respect to surface 4, the second segment bin will have no scores.

Example 2:
```
F2:N    1
FS2     –3   4
```

The order and sense of the surfaces on the FS2 card are important. This example produces the same numbers as does Example 1 but changes the order of the printed flux. Bins two and three are interchanged.

Example 3:
```
F1:N    1  2  T
FS1     –3    T
```

This example produces three current tallies: (1) across surface 1, (2) across surface 2, and (3) the sum across surfaces 1 and 2. Each tally will be subdivided into three parts: (1) that with a negative sense with respect to surface 3, (2) that with a positive sense with respect to surface 3, and (3) a total independent of surface 3.

Several additional examples of the FSn card are in Chapter 4 beginning on page 4–42.

15. SDn Segment Divisor Card (tally types 1, 2, 4, 6, 7)

Form: SD*n* $(D_{11}\ \ D_{12}...\ D_{1m})\ (D_{21}\ \ D_{22}\ ...\ D_{2m})...\ (D_{k1}\ \ D_{k2}\ ...\ D_{km})$

n = tally number. *n* cannot be zero.
k = number of cells or surfaces on Fn card, including *T* if present.
m = number of segmenting bins on the FSn card, including the remainder segment, and the total segment if FSn has a *T*.
D_{ij} = area, volume, or mass of j^{th} segment of the i^{th} surface or cell bin for tally *n*.

The parentheses are optional.

Hierarchy for obtaining volume, area, or mass:
1. For cell or surface without segmenting (tally types 2, 4, 6, and 7):
   a. nonzero entry on SDn card,
   b. nonzero entry on VOL or AREA card,
   c. volume, area or mass calculated by MCNP,
   d. FATAL error.
2. For cell or surface with segmenting (tally types 2, 4, 6, and 7):
   a. nonzero entry on SDn card,
   b. volume, area or mass calculated by MCNP
   c. FATAL error.
3. For surface in a type 1 tally:
   a. nonzero entry on SDn card,
   b. no divisor.

Default: See paragraph below.

Use: Not used with detectors. May be required with the FSn card. Can be used without the FSn card.

For segmented cell volumes or surface areas defined by the FSn card that are not automatically calculated by MCNP, the user can provide volumes, areas, or masses on this segment divisor card to be used by tally *n*. This card is similar to the VOL and AREA cards but is used for specific tallies, whereas the VOL and AREA cards are used for the entire problem geometry. For tally type 2 the entry is area, for tally type 4 the entry is volume, and for tally types 6 and 7 the entries are masses. Tally type 1 (the current tally) is not normally divided by anything, but with the SD1 card the user can introduce any desired divisor, for example, area to calculate the surface current density.

Example F4:N 1 2 3 *T*
SD4 1 1 1 1

Note that the SDn card can be used to define tally divisors even if the tally is not segmented. In this example the tally calculates the flux in the three cells plus the union of the three cells. The VOL card can be used to set the volume divisor of the three cells (to unity, for example), but it cannot do anything about the divisor for the union. Its divisor is the sum of the volumes (whether MCNP-calculated or user-entered) of the three cells. But the divisors for all four of the cell bins can be set to unity by means of the SDn card. These entries override entries on the VOL and AREA cards. See page 3–95 for use with repeated structure tallies.

16. FUn TALLYX Input Card

Form: FU*n* X_1 X_2 ... X_k
or: FU*n* *blank*

n = tally number.
X_i = input parameter establishing user bin *i*.

Default: If the FU card is absent, subroutine TALLYX is not called.

Use: Used with a user-supplied TALLYX subroutine or FTn card.

This card is used with a user-supplied tally modification subroutine TALLYX and some cases of the FTn card. If the FUn card has no input parameters, TALLYX will be called but no user bins will be created. The *k* entries on the FUn card serve three purposes: (1) each entry establishes a separate user tally bin for tally *n*, (2) each entry can be used as an input parameter for TALLYX to define the user bin it establishes, and (3) the entries appear in the output as labels for the user bins. IPTAL(3,1,ITAL) is the pointer to the location in the TDS array of the word preceding the location of the data entries from the FUn card. Thus if the FUn card has the form shown above,

TDS(L+1) = X_1
TDS(L+2) = X_2
⋮
TDS(L+k) = X_k

where L = IPTAL(3,1,ITAL)
k = IPTAL(3,4,ITAL) – 1
= IPTAL(3,3,ITAL) – 1
n = JPTAL(1,ITAL)
ITAL = program number of the tally

MCNP automatically provides the total over all specified user bins. The total can be inhibited for a tally by putting the symbol NT at the end of the FUn card for that tally as follows:

FUn X_1 X_2 ... X_k NT

and there is one change in the preceding list of variables:

k = IPTAL(3,4,ITAL) – 1
= IPTAL(3,3,ITAL)

The symbol C at the end of the FU card causes the bin values to be cumulative, in which case

IPTAL(3,3,ITAL) = IPTAL(3,4,ITAL)
IPTAL(3,6,ITAL) = 1.

The discussion of the IPTAL and JPTAL arrays in Appendix E (see page E–31) and the following description of TALLYX may be useful.

17. Subroutine TALLYX User-supplied Subroutine

Use: Called for tally n only if an FUn card is in the INP file.

TALLYX is called whenever a tally with an associated FUn card but no FTn card is scored. The locations of the calls to TALLYX are such that TALLYX is the very last thing to modify a score before it is posted in the tally. TALLYX calls can be initiated by more than one FUn card for different values of *n*; a branch must be constructed inside the subroutine based on which tally Fn is calling TALLYX, where *n* = JPTAL(1,ITAL). TALLYX has the following form:

```
subroutine tallyx(t,ib)
   ! t is the input and output tally score value.
   ! ib controls scoring. see the user's manual.
   use mcnp_global
   use mcnp_debug

   implicit none
   integer :: ib
   real(dknd) :: t

   ! Add User-Supplied FORTRAN Statements here

   return
end subroutine tallyx
```

The quantity *T* (first argument of TALLYX) that is scored in a standard tally can be multiplied or replaced by anything. The modified score *T* is then put into one of the *k* user bins established by the FUn card. In TALLYX(T,IB) the second argument IB is defined to allow for more than one pass through TALLYX per tally score. By default, IB=0, which means make one pass through the MCNP coding where user bin tally scores are posted. If the user sets IB<0 in TALLYX, no score will be made. If the user sets IB>0, passes through the user bin loop including TALLYX will be made until IB is reset to zero. This scheme allows for tally modification and posting in more than one user bin. The variable IBU is the variable designating the particular user bin established by the FUn card. Its value is 1 before the first pass through the user bin loop. The indices of the current user, segment, cosine, energy, and time bins (IBU, IBS, IBC, IBE, and IBT, respectively) and the flag JBD that indicates flagged- or direct-versus-not are in COMMON storage for optional modification by TALLYX. Note that the index of the multiplier bin is not available and cannot be modified. NTX is a variable from the module TSKCOM. It is set equal to NX just before the CALL TALLYX in TALLYD, TALLY, and TALPH. The variable NX is set to unity just before the start of the user bins loop and is incremented after the CALL TALLYX, so NTX contains the number of the TALLYX call. An example of using NTX to tally in every user bin before leaving the user bin loop follows:

```
subroutine tallyx(t,ib)
   use mcnp_global
   use mcnp_debug

   implicit none
   integer :: ib
   real(dknd) :: t

   t = whatever_you_want
   ibu = ntx
   ib = 1
   if (ntx > iptal(3,4,ital)-1) ib=0

   return
end subroutine tallyx
```

If IBU is out of range, no score is made and a count of out-of-range scores is incremented. If excessive loops through TALLYX are made, MCNP assumes IB has been incorrectly set and terminates the job with a BAD TROUBLE error (excessive means greater than the product of the numbers of bins of all kinds in the tally). Several examples of the FUn card and TALLYX are in Chapter 4 beginning on page 4–49. The procedure for implementing a TALLYX subroutine is the same as for the user-provided SOURCE subroutine.

18. TFn Tally Fluctuation Card

Form: TF*n* $I_1 \ldots I_8$

n = tally number. *n* cannot be zero.
I_i = bin number for bin type *i*. $1 \le I_i \le last$
last= IPTAL(LIPT+i,3,ITAL)
= total number of bins in one of the eight bin types.

Default: 1 1 *last* *last* 1 *last* *last* *last*

1. first cell, surface, or detector on Fn card
2. total rather than flagged or uncollided flux
3. last user bin
4. last segment bin
5. first multiplier bin on FMn card
6. last cosine bin
7. last energy bin
8. last time bin.

Use: Whenever one or more tally bins are more important than the default bin
Particularly useful in conjunction with the weight window generator.

At the end of the output, one chart for each tally is printed to give an indication of tally fluctuations; that is, how well the tally has converged. The tally mean, relative error, variance of the variance, Pareto slope (see Chapter 2 page 2–127), and figure of merit ($FOM = 1/(\sigma^2 t)$, where σ is the relative error printed with the tally and t is computer time in minutes) are printed as functions of the number of histories run. The *FOM* should be roughly constant. The TF card determines for which bin in tally *n* the fluctuations are printed. It also determines which tally bin is optimized by the weight window generator (WWE and WWG cards).

The TFn card allows you to change the default bin for a given tally and specify for which tally bin the chart and all the statistical analysis output will be printed. The eight entries on the card correspond (in order) to the list of bin indices for the eight dimensions of the tally bins array. The order is fixed and not affected by an FQn card.

The mean printed in a chart will correspond to some number in the regular tally print. If you have more than one surface listed on an F2 card, for example, the chart will be for the first surface only; charts can be obtained for all surfaces by having a separate tally for each surface.

You may find the *J* feature useful to jump over *last* entries. Remember that totals are calculated for energy, time, and user bins (unless inhibited by using NT), so that *last* for eight energy bins is 9. If one segmenting surface divides a cell or surface into two segments, *last* in that case is 2, unless *T* is used on the FS card, in which case *last* is 3. If there are no user bins or cosine bins, for example, *last* is 1 for each; *last* is never less than 1.

Example: Suppose an F2 tally has four surface entries, is divided into two segments (the segment plus everything else) by one segmenting surface, and has eight energy bins. By default, one chart will be produced for the first surface listed, for the part outside the segment, and totaled over energy. If you wish a chart for the fifth energy bin of the third surface in the first segment, you would use TF2 3 2J 1 2J 5.

19. DDn Detector Diagnostics Card

Form: DD*n* k_1 m_1 k_2 m_2 ...

n = 1 for neutron DXTRAN spheres
= 2 for photon DXTRAN spheres

= tally number for specific detector tally
k_i = criterion for playing Russian roulette for detector i
m_i = criterion for printing large contributions

Defaults: If k_i is not specified on a DDn card, k_i on the DD card is used. If that is not specified, k_1 on the DD card is used. If that is not specified, $k_i = 0.1$ is used. A similar sequence of defaults defines m_i, with a final default of $m_i = 1000$.

Use: Optional. Remember that Russian roulette will be played for detectors and DXTRAN unless specifically turned off by use of the DD card. Consider also using the PDn or DXC cards.

This card (1) using a Russian roulette game, can speed up calculations significantly by limiting small contributions that are less than some fraction k of the average contribution per history to detectors or DXTRAN spheres, and (2) can provide more information about the origin of large contributions or the lack of a sufficient number of collisions close to the detector or DXTRAN sphere. The information provided about large contributions can be useful for setting cell importances or source-biasing parameters.

For a given detector or DXTRAN sphere, the Russian roulette criterion works as follows:

1. If k_i is positive, all contributions to the detector or sphere are made for the first 200 histories. Then the average contribution per history is computed (and will be updated from time to time throughout the problem). Thereafter, any contribution to the detector or sphere larger than k_i times this average contribution will always be made, but any contribution smaller than k_i times the average will be subject to the Russian roulette game. (k_i is not allowed to be greater than 1.)
2. If k_i is negative, contributions larger than $|k_i|$ will always be made, and contributions smaller than $|k_i|$ will be subject to Russian roulette. This rule applies to all histories from the beginning of the problem, and the 200th history has no significance.
3. If k_i is zero, no Russian roulette game will be played for the detector or sphere.

Probably, $k = 0.5$ is suitable for most problems; the nonzero default value 0.1 means that the game is *always played unless explicitly turned off by the user.*

The second entry, m_i, determines the condition for printing diagnostics for large contributions. If the entry is zero, there is no diagnostic print. If the entry is positive, two possibilities exist.

1. If the corresponding k_i is positive or zero, no diagnostic prints will be made for the first 200 histories. Thereafter, the first 100 contributions larger than m_i times the average tally per history will be printed.
2. If the corresponding k_i is negative, the first 100 contributions larger than m_i times $|k_i|$ will be printed.

Remember that when k_i is positive, the Russian roulette game is played on the basis of the estimated average contribution per history. Because the estimate improves from time to time, the game is based on different values for different histories. This can make debugging a problem more complicated, and the variance estimate does not quite obey the Central Limit Theorem.

A procedure worth considering is to determine the average contribution per history in a preliminary run and then to use some fraction of the negative of this value in subsequent longer runs. The Russian roulette game is played without regard to particle time or energy; thus time and energy bins for which the ultimate tally is small may lose a disproportionate share of scores by the roulette game.

The DD card eliminates tracks with DXTRAN but only contributions with detectors.

Example:	DXT:N	x_1 y_1 z_1 RI_1 RO_1
		x_2 y_2 z_2 RI_2 RO_2
		x_3 y_3 z_3 RI_3 RO_3
	DXT:P	x_4 y_4 z_4 RI_4 RO_4
	F15X:P	a_1 r_1 R_1
		a_2 r_2 R_2
	DD	.2 100 .15 2000
	DD1	−1.1E25 3000 J J J 3000
	DD15	.4 10

Detector/sphere	k	m
sphere 1	−1.1E25	3000
sphere 2	.15	2000
sphere 3	.2	3000
sphere 4	.2	100
detector 1	.4	10
detector 2	.15	2000

Another example of the DD card and a description of its output is in Chapter 5 (see page 5–60). For a more detailed discussion of the Russian roulette game, see page 2–105 in Chapter 2.

20. DXT DXTRAN Card

Form: DXT:*N* x_1 y_1 z_1 RI_1 RO_1 x_2 y_2 z_2 RI_2 RO_2 ... DWC_1 DWC_2 $DPWT$

n	=	*N* for neutrons, *P* for photons, not available for electrons.
$x_i\, y_i\, z_i$	=	coordinates of the point at the center of the i^{th} pair of spheres
RI_i	=	radius of the i^{th} inner sphere in cm
RO_i	=	radius of the i^{th} outer sphere in cm
DWC_1	=	upper weight cutoff in the spheres
DWC_2	=	lower weight cutoff in the spheres
$DPWT$	=	minimum photon weight. Entered on DXT:N card only.

Defaults: Zero for DWC_1, DWC_2, and $DPWT$.

Use: Optional. Consider using the DXC:N, DXC:P, or DD cards when using DXTRAN.

DXTRAN is used to improve the particle sample in the vicinity of a tally (see page 2–160 in Chapter 2). It should not be misconstrued as a tally itself, such as a detector; it is used in

conjunction with tallies as a variance reduction technique. DXTRAN spheres must not overlap. The inner sphere should normally cover the tally region if possible. Specifying a tally cell or surface partly inside and partly outside a DXTRAN sphere usually will make the mean of the tally erratic and the variance huge.

The technique is most effective when the geometry inside the spheres is very simple and can be costly if the inside geometry is complicated, involving several surfaces. The inner sphere is intended to surround the region of interest. The outer sphere should surround neighboring regions that may scatter into the region of interest. In MCNP, the relative importance of the two regions is five. That is, the probability density for scattering toward the inner sphere region is five times as high as the probability density for scattering between the inner and outer spheres. The weight factor is 1/5 for particles scattered toward the inner sphere.

Rule of Thumb for RI and RO: The inner radius RI should be at least as large as the tally region, and RO–RI should be about one mean free path for particles of average energy at the spheres. DXTRAN can be used around detectors, but the combination may be very sensitive to reliable sampling.

There can be up to ten sets of X Y Z RI RO on each DXT card. There is only one set of DWC_1 and DWC_2 entries for each particle type. This pair is entered after conclusion of the other data and (with DXT:N) before the one value of DPWT. The weight cutoffs apply to DXTRAN particle tracks inside the outer radii and have default values of zero. The DXTRAN photon weight cutoffs have no effect unless the simple physics is used, with one exception: upon leaving the sphere, track weights (regardless of what physics is used) are checked against the cutoffs of the CUT:P card. The DXTRAN weight cutoffs DWC and DWC_2 are ignored when mesh-based weight windows are used.

The minimum photon weight limit *DPWT* on the DXT:N card parallels almost exactly the minimum photon weight entries on the PWT card. One slight difference is that in Russian roulette during photon production inside DXTRAN spheres, the factor for relating current cell importance to source cell importance is not applied. Thus, the user must have some knowledge of the weight distribution of the DXTRAN particles (from a short run with the DD card, for example) inside the DXTRAN sphere, so the lower weight limit for photon production may be intelligently specified. As in the case of the PWT entries, a negative entry will make the minimum photon weight relative to the source particle starting weight. The default value is zero, which means photon production will occur at each neutron DXTRAN particle collision in a material with nonzero photon production cross section inside the DXTRAN sphere.

DXTRAN can be used in a problem with the $S(\alpha,\beta)$ thermal treatment, but contributions to the DXTRAN spheres are approximate. DXTRAN should not be used with reflecting surfaces, white boundaries, or periodic boundaries (see Chapter 2 page 2–102). DXTRAN is incompatible with a monodirectional source because direct contributions from the source are ignored.

If more than one set of DXTRAN spheres is used in the same problem, they can “talk” to each other in the sense that collisions of DXTRAN particles in one set of spheres cause contributions to another set of spheres. The contributions to the second set have, in general, extremely low weights but can be numerous with an associated large increase in computer time. In this case the DXTRAN

weight cutoffs probably will be required to kill the very-low-weight particles. The DD card can give you an indication of the weight distribution of DXTRAN particles.

21. FTn Special Treatments for Tallies

Form: FT*n* ID_1 $P_{1,1}$ $P_{1,2}$ $P_{1,3}$ ... ID_2 $P_{2,1}$ $P_{2,2}$ $P_{2,3}$ ...

n = tally number.
ID_i = the alphabetic keyword identifier for a special treatment:
FRV–fixed arbitrary reference direction for tally 1 cosine binning.
GEB–Gaussian energy broadening.
TMC–time convolution.
INC–identify the number of collisions.
ICD–identify the cell from which each detector score is made.
SCX–identify the sampled index of a specified source distribution.
SCD–identify which of the specified source distributions was used.
PTT–put different multigroup particle types in different user bins.
ELC–electron current tally.
$P_{i,j}$ = parameters for that special treatment, either a number, a parenthesis or a colon.

Default: If the FT card is absent, there is no special treatment for tally n.

Use: Optional; as needed.

The syntax and meaning of the $P_{i,j}$ is different for each ID_i. A special treatment may cause a set of user bins or possibly a set of some other kind of bins to be created. The information in the $P_{i,j}$ allows the number and kind of those bins to be inferred easily. More than one special treatment can be specified by a given tally except for combinations of INC, ICD, SCX,SCD, PTT and ELC. Only one of these special treatments can be used by a tally at one time because all require user bins, making them mutually exclusive.

A description of the special treatments available follows with an explanation of the allowed parameters for each.

FRV V_1 V_2 V_3
The V_i are the xyz components of vector V, not necessarily normalized. If the FRV special treatment is in effect for a type 1 tally, the direction V is used in place of the vector normal to the surface as the reference direction for getting the cosine for binning.

GEB a b c
The parameters specify the full width at half maximum of the observed energy broadening in a physical radiation detector: fwhm = $a + b\sqrt{E + cE^2}$, where E is the energy of the particle. The units of a, b, and c are MeV, $MeV^{1/2}$, and none, respectively. The energy actually scored is sampled from the Gaussian with that fwhm. See Chapter 2.

TMC a b
All particles should be started at time zero. The tally scores are made as if the source was actually a square pulse starting at time a and ending at time b.

INC
No parameters follow the keyword but an FUn card is required. Its bin boundaries are the number of collisions that have occurred in the track since the creation of the current type of particle, whether at the source or at a collision where some other type of particle created it. If the INC special treatment is in effect, the call to TALLYX that the presence of the FUn card would normally trigger does not occur. Instead IBU is set by calling JBIN with the number of collisions as the argument. To capture all particles, the last FU bin value should be a very large number.

ICD
No parameters follow the keyword but an FUn card is required. Its bins are the names of some or all of the cells in the problem. If the cell from which a detector score is about to be made is not in the list on the FUn card, the score is not made. TALLYX is not called. The selection of the user bin is done in TALLYD.

SCX k
The parameter k is the name of one of the source distributions and is the k that appears on the SIk card. One user bin is created for each bin of source distribution k plus a total bin. The scores for tally n are then binned according to which bin of source distribution k the source particle came from. The score of the total bin is the score you would see for tally n without the special treatment, if source distribution k is not a dependent distribution. CAUTION: For a dependent distribution, the score in the total bin is the subtotal portion of the score from dependent distribution k.

SCD
No parameters follow the keyword but an FUn card is required. Its bins are a list of source distribution numbers from SIk cards. The scores for tally n are then binned according to which distribution listed on the FUn card was sampled. This feature might be used to identify which of several source nuclides emitted the source particle. In this case, the source distributions listed on the FUn card would presumably be energy distributions. Each energy distribution is the correct energy distribution for some nuclide known to the user and the probability of that distribution being sampled from is proportional to the activity of that nuclide in the source. The user might want to include an FCn card that tells to what nuclide each energy distribution number corresponds. CAUTION: If more than one of the source distributions listed on the FU card is used for a given history, only the *first* one used will score.

PTT
No parameters follow the keyword but an FUn card is required. Its bins are a list of atomic weights in units of MeV of particles masquerading as neutrons in a multigroup data library. The scores for tally n are then binned according to the particle type as differentiated from the masses in the multigroup data library. For example, .511 0 would be for electrons and photons masquerading as neutrons.

ELC c

The single parameter c of ELC specifies how the charge on an electron is to affect the scoring of an F1 tally. Normally, an electron F1 tally gives particle current without regard for the charges of the particles. There are 3 possible values for c:

c=1 to cause negative electrons to make negative scores,
c=2 to put positrons and negative electrons into separate user bins, and
c=3 for the effect of both c=1 and c=2.

If c=2 or 3, three user bins, positrons, electrons and total are created.

22. FMESH Superimposed Mesh Tally

Form: FMESH*n*:pl fmesh variable=specification

n = tally number (only type 4 tallies are permitted)
pl = N or P or E

Default: See Table 3.6.

Use: Optional

The FMESH card allows the user to define a mesh tally superimposed over the problem geometry. Results are written to a separate output file, with the default name MESHTAL. By default, the mesh tally calculates the track length estimate of the particle flux, averaged over a mesh cell, in units of particles/cm^2. If an asterisk precedes the FMESH card, energy time particle weight will be tallied, in units of MeV/cm^2.

The equal sign is optional. Keywords can be entered in any order. Special input features I, M, and R can be used except with GEOM, FACTOR, OUT, and TR. Table 3.6 summarizes the mesh tally keywords and lists their defaults. The default geometry is rectangular, the default ORIGIN point is (0,0,0), and the default OUT format is columnar. For a cylindrical mesh, the default cylindrical axis is parallel to the MCNP geometry *z*-axis, and the half plane defining $\theta=0$ is the MCNP geometry positive *x*-axis. The mesh tallies can be used in combination with the DE, DF, FC, and FM cards.

Table 3.6: Superimposed Mesh Tally Keywords

Keyword	Meaning	Default
GEOM	Mesh geometry, either Cartesian (“xyz” or “rec”) or cylindrical (“rzt” or “cyl”). Default is Cartesian coordinates.	xyz
ORIGIN	*x, y,* and *z* coordinates in MCNP cell geometry of the origin (bottom center for cylindrical or bottom, left, behind for rectangular) of the mesh.	0., 0., 0.
AXS	Vector giving the direction of the axis of the cylindrical mesh.	0., 0., 1.
VEC	Vector defining, along with AXS, the plane for $\theta=0$	1., 0., 0.
IMESH	Locations of the coarse meshes in the *x* direction for rectangular geometry or in the *r* direction for cylindrical geometry	None

Table 3.6: Superimposed Mesh Tally Keywords

Keyword	Meaning	Default
IINTS	Number of fine meshes within corresponding coarse meshes in the *x* direction for rectangular geometry or in the *r* direction for cylindrical geometry	1
JMESH	Locations of the coarse meshes in the *y* direction for rectangular geometry or in the *z* direction for cylindrical geometry	None
JINTS	Number of fine meshes within corresponding coarse meshes in the *y* direction for rectangular geometry or in the *z* direction for cylindrical geometry	1
KMESH	Locations of the coarse meshes in the *z* direction for rectangular geometry or in the θ direction (in revolutions) for cylindrical geometry	None
KINTS	Number of fine meshes within corresponding coarse meshes in the *z* direction for rectangular geometry or in the θ direction for cylindrical geometry	1
EMESH	Values of the coarse meshes in energy, in MeV	0., $E_{pl,max}$
EINTS	Number of fine meshes within the corresponding coarse meshes in energy	1
FACTOR	Multiplicative factor for each mesh	1.
OUT	Output format, either in column (“col”, “cf”) format or as a series of 2D matrices, (“ij”, “ik”, “jk”). If “cf” is chosen, the volume and the tally results multiplied by the volume are also printed.	col
TR	Number of the transformation to be applied to the mesh	None

The location of the n^{th} coarse mesh in the *u* direction (r_{un} in what follows) is given in terms of the most positive surface in the *u* direction. For a rectangular mesh, the coarse mesh locations r_{xn}, r_{yn}, r_{zn}, are given as planes perpendicular to the *x*, *y*, and *z* axis, respectively, in the MCNP cell geometry coordinate system; thus the ORIGIN point (x_0, y_0, z_0) is the most negative point of the mesh tally. For a cylindrical mesh, ORIGIN defines the bottom center point of the mesh. The z-coordinate is then measured from the cylindrical mesh origin. For both types of geometry, the lowest energy value is 0 MeV. The coarse mesh locations and energy values must increase monotonically (beginning with the ORIGIN point). The fine meshes are evenly distributed within the n^{th} coarse mesh in the *u* direction.

For a cylindrical mesh, the AXS and VEC vectors need not be orthogonal but they must not be parallel; the one half-plane that contains them and the ORIGIN point will define θ = 0. The AXS vector will remain fixed. The length of the AXS or VEC vectors must not be zero. The *z* coordinate is specified in the cylinder geometry coordinate system. The θ coarse mesh locations are given in revolutions and the last one must be 1.

At least one coarse mesh per coordinate direction must be specified using IMESH, JMESH, and KMESH keywords. The code uses a default value of 1 fine mesh per coarse mesh if the IINTS,

JINTS, or KINTS keywords are omitted. If the IINTS, JINTS, or KINTS keywords are present, the number of entries must match the number of entries on the IMESH, JMESH, and KMESH keywords, respectively. Entries on the IINTS, JINTS, and KINTS keywords must be greater than zero.

Any mesh can be transformed using TR followed by a transformation number.

The output format is specified using the OUT keyword. The default value is "col", which produces output in a columnar format, listing the coordinates of the center of the bin, along with the tally results and relative errors. If the value of OUT is set to "cf", then in addition to the coordinates and results, the volume of the mesh cell and the tally times the volume of the cell is listed. A second format for the output is specified by "ij", "ik", or "jk", for which the tally results are printed as a series of two 2-dimensional matrices, with i = x or r, j = y or z, and k = z or θ, depending on the coordinate system chosen. The first matrix contains the tally results, and the second matrix the relative errors. The rows and columns are labeled by the mid-points of the corresponding mesh bins. These pairs of matrices will be printed for each mesh bin in the third coordinate.

```
Example:   FMESH4:n   GEOM=cyl   ORIGIN= –100 0 0
                      IMESH=5 10 IINTS=5 2
                      JMESH= 100 200 JINTS 10 5
                      KMESH .5 1 KINTS=1 2
                      AXS= 1 0 0 VEC=0 1 0 OUT=ij
```

This example describes a cylindrical mesh tally along the x-axis, with base at $x = -100$ and $\theta = 0$ along the $+y$-axis. The tally is divided into 5 bins from $r = 0$ to $r = 5$, 2 bins from $r = 5$ to $r = 10$, 10 bins from $x = -100$ to 0, 5 bins from $x = 0$ to $x = 100$, 1 bin from $\theta = 0^o$ to $\theta = 180^o$, and 2 bins from $\theta = 180^o$ to 360^o.

23. SPDTL Lattice Speed Tally Enhancement

Form: SPDTL *x*

x = *force* or *off* (one entry is required)

Default: The lattice speed tally enhancement will be enabled by default if strict criteria are met.

Use: Optional.

The data card SPDTL, with the keyword *force* or *off*, will allow the user to force or prevent, respectively, the use of the lattice speed tally enhancement. This allows the user to run a short test case with and without the enhancements and verify they are appropriate if the two runs yield the same tally results. Using SPDTL *force* will also print comments about lattice speed tally enhancement conflicts with other cards.

The lattice speed tally enhancements will greatly reduce the runtime of certain problems, namely large lattices used for voxel phantoms. This enhancement will only work under certain conditions, which MCNP will try to detect. If any of the following criteria are not met, then the lattice speed

tally enhancement will not be used unless the SPDTL *force* card is used. Using the SPDTL *force* card to run the lattice speed tally enhancement is discouraged, since it may result in a program crash, tally values that are all zeros, or silent wrong answers.

Criteria that must be met for MCNP to automatically (and appropriately) use the lattice speed tally enhancement:

a) A hexagonal lattice must be present in the geometry.
b) All F4 tallies contain a hexahedral lattice.
c) None of the following cards are used: DXT, DXC, F1, F2, *F4, F6, F7, F8, +F8, PERT, WWG, WWGE.
d) None of the following cards are used to modify an F4 tally: FT, E, EM, T, TM, CF, SF, FS, C.
e) All F4 tallies have an associated FM4 card that contains only a single digit multiplier.
f) All F4 tallies have associated DE DF cards.

The following criteria are not checked by MCNP. It is up to the user to make sure the input deck meets these criteria:

g) Nested lattices are not tallied over.
h) The entries for a cell's fill card do not include that cell's own universe number.
i) The full lattice index range is given on every lattice on each F4 tally card.

For more information, see Ref. 4.

F. Material Specification

The cards in this section specify the isotopic composition of the materials in the cells. This, in turn, determines which cross-section evaluations will be used.

Mnemonic	Card Type	Page
Mn	Material	3–122
MPNn	Photonuclear Nuclide Selector	3–124
DRXS	Discrete Reaction Cross Section	3–125
TOTNU	Total Fission	3–126
NONU	Fission Turnoff	3–126
AWTAB	Atomic Weight	3–127
XSn	Cross-Section File	3–127
VOID	Material Void	3–128
PIKMT	Photon–Production Bias	3–128
MGOPT	Multigroup Adjoint Transport Option	3–129

1. Mn Material Card

Form: M*n* $ZAID_1$ $fraction_1$ $ZAID_2$ $fraction_2$ ... keyword=value ...

n corresponds to the material number on the cell cards

$ZAID_i$ = either a full ZZZAAA.nnX or partial ZZZAAA element or nuclide identifier for constituent *i,* where ZZZ is the atomic number, AAA is the atomic mass, *nn* is the library identifier, and X is the class of data

$fraction_i$ = atomic fraction (or weight fraction if entered as a negative number) of constituent *i* in the material.

keyword = value, where = sign is optional. Keywords are:

GAS = *m* flag for density–effect correction to electron stopping power.
m = 0 calculation appropriate for material in the condensed (solid or liquid) state used.
m = 1 calculation appropriate for material in the gaseous state used.

ESTEP = *n* causes the number of electron substeps per energy step to be increased to *n* for the material. If *n* is smaller than the built–in default found for this material, the entry is ignored. Both the default value and the ESTEP value actually used are printed in Table 85.

NLIB = *id* changes the default neutron table identifier to the string *id*.

PLIB = *id* changes the default photoatomic table identifier to *id*.

PNLIB = *id* changes the default photonuclear table identifier to *id*.

ELIB = *id* changes the default electron table identifier to *id*.

COND = *id* sets conduction state of a material only for el03 evaluation.
< 0 nonconductor
= 0 (default) nonconductor if at least one nonconducting component; otherwise a conductor
> 0 conductor if at least one conducting component.

Default: None for ZAID fraction; GAS=0; ESTEP internally set; NLIB, PLIB, PNLIB and ELIB=first match in XSDIR; COND=0.

Use: Optional, but required if you want materials in cells.

Transport Table Selection

Each material must be defined as a set of components and their corresponding material fraction. A component consists of a nuclide identifier (ZA) and an optional library identifier (ID). Nuclide is the generic term for either a "generic" element or an isotope. This is usually specified as an integer value ZZZAAA where ZZZ is the atomic number and AAA is the atomic mass number or zero for a natural element. When discussing nuclear data (e.g. in selecting neutron or photonuclear transport tables), nuclides should be given as isotope descriptions. This reflects the isotopic nature of nuclear data.

However, it should be noted that some older nuclear data sets contain "natural" elemental nuclear data that combines data for all the naturally occurring isotopes in an element into one data set. When discussing atomic data (e.g. in selecting electron or photoatomic transport tables), nuclides should be given as elemental descriptions, i.e. use AAA=000. ALWAYS specify a material with the most descriptive nuclides possible. If a material is best described using isotopic nuclide identifiers, the appropriate atomic data will be selected by using ZZZ000 obtained from the specified ZZZAAA value.

The optional library identifier (ID) may be specified in one of two ways. If a component is specified using the full ZAID identifier, the requested table will always be chosen. For example, a component given as 74184.60c will always choose the ENDF60 W-184 transport table for neutron interactions. Similarly, a component given as 74184.24u will always choose the LA150 W-184 table for photonuclear interactions. An interesting feature of the code, a component given as 74184.02p will always choose the MCPLIB02 W (74000.02p) table for photoatomic interactions (elemental atomic data drops the AAA specifier). As is implied by these examples, only one unique table (i.e. fully specified ZAID) can be prescribed for each material component. Other tables for that component will be chosen according to the xLIB keyword option or as the first table matching the nuclide identifier and containing the appropriate transport data. The NLIB, PLIB, PNLIB and ELIB options allow the user to specify the default ID for neutron, photoatomic, photonuclear and electron tables, respectively, excepting that a component with a fully specified ZAID of the appropriate class of data will always take precedence over the xLIB specified default library.

Examining an example material card will hopefully clarify how this occurs. Consider the material card:

Example: M1 6012.50c 1 8016.01p 2 nlib=60c pnlib=24u plib=02p

This material will choose the neutron transport tables 6012.50c and 8016.60c. The component 6012.50c is a fully specified neutron transport table that takes precedence over the NLIB default ID specifier. The 02p portion of the component 8016.02p is ignored because it specifies the wrong class of table; therefore the NLIB default ID 60c is used to choose the 8016.60c neutron transport table.

Similarly, the material will choose the photoatomic transport tables 6000.02p and 8000.01p by ignoring the mass number (AAA), using the PLIB specified ID 02p for carbon and the component specified 01p for oxygen. Since neither component ID is appropriate for choosing photonuclear tables, the material chooses 6012.24u and 8016.24u based on the PNLIB default ID 24u. Since no ID is specified for electron tables in either the component description or using the ELIB option, the first appropriate electron table is chosen from the XSDIR (6000.03e and 8000.03e assuming the currently distributed XSDIR).

MCNP is a table based physics code, i.e. the code cannot run if data are needed for a requested set of collision physics and the necessary tables do not exist for a given material component. Since photoatomic and electron transport tables exist for almost all elements, ensuring that a table exists is usually not a concern. Because neutron and photonuclear tables are usually isotopic and may not cover the same set of isotopes, it can be difficult to specify a material composition that represents the best neutron and photonuclear physics for that material. Currently, the recommended solution

for this issue is to choose the best isotopic neutron composition when specifying the components on the material card. If photonuclear physics is on, one can then use the MPN card (described below) to select the best set of photonuclear tables.

Material Component Fractions

Each component is followed by its material fraction. Positive numbers indicate atom fraction and negative numbers indicate mass fraction. Atom and mass fractions cannot be mixed on the same material card. The code will renormalize the material fractions if they do not sum to one. For example, the example material card above specifies carbon dioxide at 1 atom of carbon to 2 atoms of oxygen which would be renormalized to ~33.3 atom percent of carbon and ~66.7 atom percent oxygen. It is best to specify atom fractions as the code will convert mass fractions to atom fractions using the (possibly outdated) value of the atomic weight ratio from the transport table.

2. MPNn Photonuclear Nuclide Selector

Form: MPN*n* ZA_1 ZA_2 ... ZA_i ...

ZA_i = Identifying number of the form ZZAAA, where ZZ is the atomic number and AAA the mass number

Default: None.

Use: Optional. Applies only to photonuclear cross sections.

The MPNn card corresponds to the Mn card of the same n value and allows the user to specify a different set of nuclides for each component on the material card for use in selecting photonuclear tables. This card is optional. If used it must have a corresponding Mn card and the number of integer entries on the MPNn card must match the number of components on the Mn card. This option is provided to facilitate the selection of the best set of photonuclear and neutron tables when the set of tables available for photonuclear and neutron interactions differ. Consider the following example:

Example 1:	M2	74182 .263	74183 .143	74184 .3067	74186 .286
	MPN2	74184	74184	74184	74184

The example material card defines material 2 (M2) as "natural" tungsten using the best description of tungsten given the available neutron tables. Note that the atom fraction sums to 0.9987; the missing 0.0013 atom fraction would go to W-180 but there is not a neutron table available for 74180. Leaving this out, the code will redistribute the missing fraction among the remaining four isotopes. This represents the "best" available description of natural tungsten based on the availability of neutron tables for specific nuclides and the code will choose specific tables based on the first nuclide match within the XSDIR. Likewise, if there is only one photonuclear table for any tungsten isotope (74184 in the example above), then the photonuclear nuclide selector allows that nuclide (and therefore the associated, available table) to be attached to each component of the material. To reiterate, the ability to select different nuclide identifiers for photonuclear table selection than are used for neutron table selection is advantageous in that it allows the best description of the material by the tables that are available.

```
Example 2:   M3      1001 2      8016 1
             MPN3    0           8016
```

The example for the material M3 above shows another capability offered by the MPN card. Given a material card definition for water (ignoring the minor isotopes), there is not a photonuclear table available for nuclide 1001 (hydrogen-1). Any component of a material may be given the photonuclear nuclide identifier of zero, in which case NO photonuclear collisions will occur with that component of the material. This allows a problem to be run (i.e. it can always find the "null" table) with the photonuclear tables that are available.

```
Example 3:   M4      83209 1
             MPN4    82207
```

The last major use of the MPN card is to substitute existing photonuclear tables for components for which no table is available. In the example material card M4 above, bismuth-209 is defined as the "true" material. If a bismuth-209 photonuclear table is unavailable, the photonuclear nuclide selector card allows a lead-207 (or a table for ANY other nuclide) to be substituted.

All material definitions that ignore or substitute collision tables for one nuclide in place of the true nuclide should be viewed as suspect. It is up to the user to perform adequate sensitivity studies to determine if the calculated answer is "good enough."

3. DRXS Discrete Reaction Cross-Section Card

Form: DRXS $ZAID_1$ $ZAID_2$ ... $ZAID_i$ ...
or *blank*

$ZAID_i$ = Identifying number of the form ZZAAA.nn, where ZZ is the atomic number, AAA the mass number, and *nn* the neutron library identifier.

Default: Continuous-energy cross-section treatment if DRXS is absent.

Use: Optional. Applies only to neutron cross sections.

Nuclides listed on the optional DRXS card are given a discrete energy treatment instead of the regular fully continuous-energy cross-section treatment if the necessary discrete data are available. Check the list in Appendix G for availability. If the DRXS card is present but has no entries after the mnemonic, discrete cross sections will be used for every nuclide, if available.

All discrete reaction libraries are based on a 262 energy group structure. Groups below 1 eV make the discrete treatment appropriate for thermal neutron problems near room temperature. All discrete reaction libraries have photon production data given in expanded format.

It is not recommended that this card be used unless you are transporting neutrons in an energy region where resonances and hence self-shielding are of little importance. However, if the problem under consideration meets this criterion, using the DRXS card can reduce computer storage requirements and enhance timesharing.

Use of these discrete cross sections will not result in the calculation being what is commonly referred to as a multigroup Monte Carlo calculation because the only change is that the cross sections are represented in a histogram form rather than a continuous-energy form. The angular treatment used for scattering, energy sampling after scattering, etc., is performed using identical procedures and data as in the continuous-energy treatment. The user wanting to make a truly multigroup Monte Carlo calculation should use the MGOPT card multigroup capability.

4. TOTNU Total Fission Card

Form: TOTNU NO
or *blank*

Default: If the TOTNU card is absent, prompt $\bar{\upsilon}$ is used for non-KCODE calculations and total $\bar{\upsilon}$ is used for KCODE calculations.

Use: All steady-state problems should use this card.

In a non-KCODE problem, prompt $\bar{\upsilon}$ is used for all fissionable nuclides for which prompt $\bar{\upsilon}$ values are available if the TOTNU card is absent. If a TOTNU card is present but has no entry after it, total $\bar{\upsilon}$, sampling both prompt and delayed $\bar{\upsilon}$, will be used for those fissionable nuclides for which prompt and delayed values are available. A TOTNU card with NO as the entry is the same as if the card were absent, that is, prompt $\bar{\upsilon}$ is used.

In a KCODE calculation, total $\bar{\upsilon}$, including both prompt and delayed $\bar{\upsilon}$ as available, is used for all fissionable nuclides if the TOTNU card is absent. If a TOTNU card is present but has no entry after it, total $\bar{\upsilon}$, using both prompt and delayed $\bar{\upsilon}$, is again used. A TOTNU card with NO as the entry causes prompt $\bar{\upsilon}$ to be used for all fissionable nuclides for which prompt values are available.

The nuclide list of Appendix G indicates data available for each fissionable nuclide. The MCNP neutron cross-section summary print from XACT will show whether prompt or total was used.

5. NONU Fission Turnoff Card

Form: NONU a_1 a_2 ... a_i ... a_{mxa}
or *blank*

a_i = 0 fission in cell i treated as capture; gammas produced
= 1 fission in cell i treated as real; gammas produced
= 2 fission in cell i treated as capture; gammas not produced
mxa = number of cells in the problem

Default: If the NONU card is absent, fission is treated as real fission.

Use: Optional, as needed.

This card turns off fission in a cell. The fission is then treated as simple capture and is accounted for on the loss side of the problem summary as the “Loss to fission” entry. If the NONU card is not used, all cells are given their regular treatment of real fission, that is, the same as if all entries were

one. If the NONU card is present but blank, all a_i's are assumed to be zero and fission in all cells is treated like capture. The NONU card cannot be added to a continue-run.

A value of 2 treats fission as capture and, in addition, no fission gamma rays are produced. This option should be used with KCODE fission source problems written to surface source files. Suppressing the creation of new fission neutrons and photons is important because they are already accounted for in the source.

Sometimes it is desirable to run a problem with a fixed source in a multiplying medium. For example, an operating reactor power distribution could be specified as a function of position in the core either by an SDEF source description or by writing the fission source from a KCODE calculation to a WSSA file with a CEL option on an SSW card. The non-KCODE calculation would be impossible to run because of the criticality of the system and because fission neutrons have already been accounted for. Using the NONU card in the non-KCODE mode allows this problem to run correctly by treating fission as simple capture.

6. AWTAB Atomic Weight Card

Form: AWTAB $ZAID_1$ AW_1 $ZAID_2$ AW_2 ...

$ZAID_i$ = *ZAID* used on the Mm material card excluding the X for class of data specification.
AW_i = atomic weight ratios.

Default: If the AWTAB card is absent, the atomic weight ratios from the cross-section directory file XSDIR and cross-section tables are used.

Use: Optional, as needed.

Entries on this card override the existing atomic weight ratios as contained in both the cross-section directory file XSDIR and the cross-section tables. The AWTAB card is needed when atomic weights are not available in an XSDIR file. Also, for fission products, ZAID=50120.35, the atomic weight of tin ($^{120}_{50}Sn$) will be used, so the following AWTAB card is needed:

AWTAB 50120.35 116.490609

Warning: Using atomic weight ratios different from the ones in the cross-section tables in a neutron problem can lead to negative neutron energies that will cause the problem to terminate prematurely.

7. XSn Cross-Section File Card

Form: XS*n*

n = 1 to 999

Default: None

Use: Optional, as an alternative to the directory part of the XSDIR file.

The XSn card can be used to load cross-section evaluations not listed in the XSDIR file directory. You can use XSn cards in addition to the XSDIR file. Each XSn card describes one cross-section

table. The entries for the XSn card are identical to those in XSDIR except that the + is not used for continuation. A detailed description of the required entries is provided in Appendix F beginning on page F–2.

8. VOID Material Void Card

Form: VOID no entries
or: VOID C_1 C_2 ... C_i

C_i = cell number

Default: None.

Use: Debugging geometry and calculating volumes.

The first form is used when calculating volumes stochastically (see Chapter 2 page 2–190) and when checking for geometry errors (see page 3–8). When the VOID card is blank, the material number and density is set to zero for all cells, FM cards are turned off, heating tallies are turned into flux tallies, and, if there is no NPS card, the effect of an NPS 100000 card is created. If there is a TALLYX subroutine, it may need to be changed, too.

The second form is used to selectively void cells instead of setting the material number and density to zero by hand on cell cards. It is a convenience if you want to check whether the presence of some object in your geometry makes any significant difference in the answers.

9. PIKMT Photon–Production Bias Card

Form: PIKMT Z_1 $IPIK_1$ $MT_{1,1}$ $PMT_{1,1}$ ... $MT_{1,\,IPIK_1}$ $PMT_{1,\,IPIK_1}$
Z_n $IPIK_n$ $MT_{n,1}$ $PMT_{n,1}$ ... $MT_{n,\,IPIK_n}$ $PMT_{n,\,IPIK_n}$

Z_i = the ZAID of the i^{th} entry. Full or partial ZAIDs can be specified; that is, 29000 is equivalent to 29000.50.

$IPIK_i$ = the parameter that controls the biasing for $ZAID_i$.
0 = no biasing for $ZAID_i$; photons from $ZAID_i$ are produced with the normal sampling technique.
−1 = no photons are produced from $ZAID_i$.
> 0 = there is biasing for $ZAID_i$. The value of $IPIK_i$ is the number of partial photon-production reactions to be sampled.

$MT_{i,j}$ and $PMT_{i,j}$ are only required for ZAIDs with $IPIK_i > 0$, where $IPIK_i$ pairs of entries of MTs and PMTs are necessary. The MTs are the identifiers for the partial photon-production reactions to be sampled. The PMTs control, to a certain extent, the frequency with which the specified MTs are sampled. The entries need not be normalized. For a ZAID with a positive value of IPIK, any reaction that is not identified with its MT on the PIKMT card will not be sampled.

Default: If the PIKMT card is absent, there is no biasing of neutron-induced photons. If PIKMT is present, any ZAID not listed has a default value of $IPIK_i = -1$.

Use: Optional; see caveats below.

For several classes of coupled neutron-photon calculations, the desired result is the intensity of a small subset of the entire photon energy spectrum. Two examples are discrete-energy (line) photons and the high-energy tail of a continuum spectrum. In such cases, it may be profitable to bias the spectrum of neutron-induced photons to produce only those that are of interest.

1. Warning: Use of the PIKMT card can cause nonzero probability events to be completely excluded and the biasing game may not necessarily be a fair one. While neutron tallies will be unaffected (within statistics), the only reliable photon tallies will be those with energy bins immediately around the energies of the discrete photons produced.
2. Users need information about the MT identifiers of the reactions that produce discrete-energy photons. Many web sites provide information about MT identifiers of reactions that produce discrete photons. Use the words "MT identifiers" "reactions" and "discrete energy photons" as the search phrase with a search engine such as www.google.com to find more sources of information.
3. The feature is also useful for biasing the neutron-induced photon spectrum to produce very high energy photons (for example, $E_\gamma \geq 10\ MeV$). Without biasing, these high-energy photons are produced very infrequently; therefore, it is difficult to extract reliable statistical information about them. An energy cutoff can be used to terminate a track when it falls below the energy range of interest. Los Alamos users interested in using the PIKMT card for this application should see X-5 regarding an internal code (NIPE) that is useful for optimizing such problems.

Example:
```
PIKMT  26000.55  1   102001  1   7014  0
       29000  2   3001  2   3002  1
       8016  −1
```

This example results in normal sampling of all photon-production reactions for ^{14}N. All photons from neutron collisions with Fe are from the reaction with MT identifier 102001. Two photon-production reactions with Cu are allowed. Because of the PMT parameters, the reaction with MT identifier 3001 is sampled twice as frequently relative to the reaction with MT identifier 3002. No photons are produced from ^{16}O or from any other isotopes in the problem that are not listed on the PIKMT card.

10. MGOPT Multigroup Adjoint Transport Option

Form: MGOPT MCAL IGM IPLT ISB ICW FNW RIM

MCAL = F for forward problem
A for adjoint problem

IGM = the total number of energy groups for all kinds of particles in the problem. A negative total indicates a special electron-photon problem.

IPLT = indicator of how weight windows are to be used.
= 0 means that IMP values set cell importances. Weight windows, if any, are ignored for cell importance splitting and Russian roulette.
= 1 means that weight windows must be provided and are transformed into energy-dependent cell importances. A zero weight-window lower bound produces an importance equal to

the lowest nonzero importance for that energy group.
= 2 means that weight windows do what they normally do (see page 3–45).

ISB = Controls adjoint biasing for adjoint problems only (MCAL=A).
= 0 means collisions are biased by infinite-medium fluxes.
= 1 means collisions are biased by functions derived from weight windows, which must be supplied.
= 2 means collisions are not biased.

ICW = name of the reference cell for generated weight windows.
= 0 means weight windows are not generated.
≠ 0 requires volumes be supplied or calculated for all cells of nonzero importance.

FNW = normalization value for generated weight windows. The value of the weight-window lower bound in the most important energy group in cell ICW is set to FNW.

RIM = compression limit for generated weight windows. Before generated weight windows are printed out, the weight windows in each group are separately checked to see that the ratio of the highest to the lowest is less than RIM. If not, they are compressed.

Default: IPLT=0, ISB=0, ICW=0, FNW=1, RIM=1000. MCAL and IGM must be specified.

Use: Required for multigroup calculation.

MCAL and IGM are required parameters. The others are optional. "J" is not an acceptable value for any of the parameters.

At this time, the standard MCNP multigroup neutron cross sections are given in 30 groups and photons are given in 12 groups. Thus, an existing continuous-energy input file can be converted to a multigroup input file simply by adding one of the following cards:

```
MGOPT   F  30    $MODE N
MGOPT   F  42    $MODE N P
MGOPT   F  12    $MODE P
```

A negative IGM value allows a single cross-section table to include data for more than one sort of particle. This feature applies currently to electron/photon multigroup calculations only. A problem with 50 electron groups followed by 30 photon groups in one table would have IGM = −80. Also all tables must have the same group structure. A negative IGM value will use the energy variable on the source or tally card as a group index unless it is associated with a distribution. For an energy distribution on the source card, there should be IGM increasing integer entries for each group on the SI card. On a tally energy card, if there are less than IGM entries, they will be taken as energies in MeV; otherwise, the bins will be according to group index. The particles can be separated in tallies by using the PTT option on the FTn tally card.

An input file for an adjoint problem can have both an IMP card and weight window cards (IPLT=0 ISB=1). The entries on the weight window cards are not weight windows in the normal sense but biasing functions. If IPLT=1 the values on a weight window card become energy-dependent cell importances. Until now, importances have been energy independent.

See Appendix G for a more complete discussion of multigroup libraries.

G. Energy and Thermal Treatment Specification

The following cards control energy and other physics aspects of MCNP. All energies are in units of MeV and all times are in shakes.

1. PHYS Energy Physics Cutoff Card

a) Neutrons

Form: PHYS:N EMAX EMCNF IUNR DNB FISNU

EMAX = upper limit for neutron energy, MeV.
EMCNF = energy boundary above which neutrons are treated with implicit capture and below which they are treated with analog capture.
IUNR = 0/1 on/off unresolved resonance range probability tables.
DNB = number of delayed neutrons produced from fission
–1/0/>0 natural sampling/no delayed neutrons produced/DNB delayed neutrons per fission.
DNB > 0 not allowed in KCODE calculation.
FISNU = method for sampling the number of neutrons from fission.
< 0 negative of the Gaussian width to be used for sampling fission neutron multiplicities for all fissionable isotopes.
= 0 sample fission neutron multiplicity using bounded integers.
= 1 use reevaluated Gaussian width by isotope for multiplicities.
= 2 use original Terrell Gaussian widths by isotope for multiplicities.
≠ 0 not allowed in a KCODE or adjoint multigroup calculation.

Default: EMAX = very large; EMCNF = 0.0 MeV; IUNR = 0; DNB = –1; FISNU = 0

Use: Optional.

EMAX is the upper limit for neutron energy. All neutron cross-section data above EMAX are expunged. If EMAX is not specified, there is no upper energy expunging of cross-section data to save computer storage space. The physics of MCNP is such that if a neutron energy is greater than the maximum energy in a table (typically 20 MeV), the cross section for the maximum energy is

used with no extrapolation. If a particle is born above EMAX, either by source or collision, it is rejected and the particle energy is resampled.

EMCNF controls the type of capture. Any neutron with energy greater than EMCNF will receive the implicit capture treatment; below EMCNF, it will receive analog capture. This parameter is analogous to EMCPF on the PHYS:P card and is useful in eliminating low-energy histories when using a thermal treatment. Substantial computer time may be saved in a region of low absorption (especially if the region is heterogeneous and bounded by a reflecting surface) simply by reducing the number of tracks. EMCNF should be set to operate when a neutron enters a thermal regime, typically a few kT. However, analog capture may undesirably kill important particles before they are tallied or before they participate in physics important to the problem.

If EMCNF = EMAX, analog capture is used regardless of the value of WC1 on the CUT card. If WC1 = 0, analog capture is used regardless of the value of EMCNF.

IUNR controls the treatment of cross sections in the unresolved energy range. The probability table treatment (IUNR=0) should be left on for better physics but can be turned off (IUNR=1) to measure the effect of the probability table treatment or to speed calculations when unresolved resonances are unimportant.

DNB controls the number of delayed neutrons produced from fission and can be used only when TOTNU is specified for fissionable nuclides for which delayed and prompt ν values are available. If DNB is not specified, the number of delayed neutrons produced per fission is determined from the ratio of delayed ν to total ν. The nuclide list of Appendix G indicates data available for each fissionable nuclide.

FISNU controls how the number of neutrons emitted from a fission is sampled for both continuous energy and forward multigroup problems. The default FISNU = 0 samples from the bounding integers for $\bar{\nu}$, e.g., if $\bar{\nu}$ for a fission is 2.6, then 40% of the samples select two neutrons and 60% select three neutrons. If FISNU >0, then an isotope-dependent Gaussian width is used to sample the number of fission neutrons from 0 to a maximum number (typically 7 or 8). If FISNU <0, then –FISNU is used as the constant Gaussian width value for all isotopes. If FISNU is going to be used, a FISNU = 1 is recommended. All Gaussian samplings are unbiased. The sampled fission neutron multiplicities and factorial moments are listed in Print Table 115. The nonzero FISNU options are not allowed in criticality or adjoint calculations in order to preserve the original integer method where so much important validation work has been done. The FM card option for multiplying by $\bar{\nu}$ (–7) uses the exact $\bar{\nu}$ (and not the sampled number of fission neutrons) to reduce the variance of the result. See Chapter 2, Section IV.C.5.e on page 2–50 for a discussion of the sampling of neutron emission from fission.

b) Photons

Form: PHYS:P EMCPF IDES NOCOH ISPN NODOP

EMCPF = upper energy limit for detailed photon physics treatment, MeV.
IDES = 0 photons will produce electrons in MODE E problems or bremsstrahlung photons with the thick target bremsstrahlung model.

	=	1	photons will not produce electrons as above.
NOCOH	=	0	coherent scattering occurs.
	=	1	coherent scattering will not occur.
ISPN	=	-1	analog photonuclear collision sampling.
	=	0	no photonuclear collisions.
	=	1	biased photonuclear collision sampling.
NODOP	=	0	Doppler energy broadening occurs.
	=	1	Doppler energy broadening will not occur.

Default: EMCPF = 100 MeV; IDES = 0; NOCOH = 0; ISPN=0; NODOP = 0.

Use: Optional.

Photons with energy greater than EMCPF will be tracked using the simple physics treatment. If WC1 = 0 on the CUT:P card, analog capture is used in the energy region above EMCPF. Otherwise capture is simulated by weight reduction with Russian roulette on weight cutoff. Photons with energy less than EMCPF will be treated with the more detailed physics that always includes analog capture. For a detailed discussion of the simple and detailed photon physics treatments, see Chapter 2 beginning on page 2–57.

The simple physics treatment, intended primarily for higher energy photons, considers the following physical processes: photoelectric effect without fluorescence, Compton scattering, and pair production. The highly forward peaked coherent Thomson scattering is ignored.

In the detailed physics treatment, photoelectric absorption can result in fluorescent emission, the Thomson and Klein-Nishina differential cross sections are modified by appropriate form factors and Compton profiles taking electron binding effects into account, and coherent scattering is included.

To turn off the production of secondary electrons generated by photons, the switch IDES can be set, either on the PHYS:P or on the PHYS:E card. If either of these cards sets IDES = 1, photons will NOT produce electrons, even if IDES = 0 is set on the other. In a photon-only problem, turning off secondary electrons causes the thick-target bremsstrahlung model to be bypassed. This option should be exercised only with great care because it alters the physics of the electron-photon cascade and will give erroneously low photon results when bremsstrahlung and electron transport are significant.

NOCOH is a switch to allow coherent scattering to be turned off for photons with energies below EMCPF. Thus, coherent scattering can be suppressed within the detailed physics treatment without losing the other advantages of the detailed model. When NOCOH = 1, the cross section for coherent scattering will be set to zero. This approximation can be useful in problems with bad point detector variances.

ISPN is a switch to allow photonuclear collisions to be turned on/off and, if on, to indicate whether to bias the photonuclear collisions. Note that photonuclear physics is considered separately from simple or detailed photoatomic physics. The default is not to include photonuclear collisions. This is due to sparsely available data and will hopefully change in the future. If turned on, a

photonuclear table must be provided for each material component (see the discussion of the Mn and MPn cards). ISPN = -1 will turn analog photonuclear collision sampling on. This will sample one photon interaction per collision, i.e. natural selection of photoatomic events or photonuclear events. ISPN = 1 will turn biased photonuclear collision sampling on. In this mode, the photon will be split at each collision, each of the two parts undergoing a photoatomic or photonuclear event with their weights updated accordingly.

NODOP is a switch to turn off Doppler energy broadening for photons. This feature is automatically turned off when using simple physics. Turning this feature off with the detailed physics treatment results in a comment printed to the screen. Photon data libraries without Compton profile data also results in warning messages.

c) Electrons

Form: PHYS:E EMAX IDES IPHOT IBAD ISTRG BNUM XNUM RNOK ENUM NUMB

EMAX	=		upper limit for electron energy in MeV.
IDES	=		0/1 = photons will/will not produce electrons.
IPHOT	=		0/1 = electrons will/will not produce photons.
IBAD	=	0	full bremsstrahlung tabular angular distribution.
	=	1	simple bremsstrahlung angular distribution approximation.
ISTRG	=	0	sampled straggling for electron energy loss.
	=	1	expected-value for electron energy loss.
BNUM	<	0	only applicable for el03 evaluation. See below for details.
	=	0	bremsstrahlung photons will not be produced
	>	0	produce BNUM times the analog number of bremsstrahlung photons. Radiative energy loss uses the bremsstrahlung energy of the first sampled photon.
XNUM	>	0	produce XNUM times the analog number of electron-induced x–rays.
	=	0	x-ray photons will not be produced by electrons.
RNOK	>	0	produce RNOK times the analog number of knock-on electrons.
	=	0	knock-on electrons will not be produced.
ENUM	>	0	produce ENUM times the analog number of photon-induced secondary electrons.
	=	0	photon-induced secondary electrons will not be produced.
NUMB	>	0	produce bremsstrahlung on each substep
	=	0	nominal bremsstrahlung production

Defaults: EMAX = 100 MeV; IDES, IPHOT, IBAD, ISTRG = 0;
BNUM, XNUM, RNOK, ENUM = 1., NUMB = 0

Use: Optional.

EMAX is the upper electron energy limit in MeV. Electron cross sections and related data are generated on a logarithmic energy grid from EMAX down to an energy at least as low as the global energy cutoff for electrons. Setting the value of EMAX too high results in longer processing times

and larger storage requirements for electron data. EMAX should be set to the highest electron energy encountered in your problem.

IDES is a switch to turn off electron production by photons. The default (IDES = 0) is for photons to create electrons in all photon-electron problems and for photons to produce bremsstrahlung photons using the thick-target bremsstrahlung approximation in photon problems run without electrons. In either case the electron default cross-section library will be read, which requires considerable processing time. Electron transport is also very slow. However, the neglect of electron transport and bremsstrahlung production will cause erroneously low photon results when these effects are important. IDES = 1 turns off electron production, but it does not turn off the pair-production-produced annihilation photons. See ENUM.

IPHOT is a switch to turn off photon production by electrons. Because photon transport is fast relative to electron transport and is usually required for an accurate physical model, the default (IPHOT = 0, which leaves photon production on) is recommended.

IBAD is a switch to turn on the simple approximate bremsstrahlung angular distribution treatment and turn off the full, more detailed model. The electron-photon transport can be simulated with either the simple or the full treatment, but bremsstrahlung photon contributions to detectors and DXTRAN can use only the simple treatment. The full detailed physics model is more accurate and just as fast as the simple approximate treatment for the generation of transported photons, and is therefore the default (IBAD = 0), even though it is unavailable for bremsstrahlung photon contributions to detectors and DXTRAN spheres. Setting IBAD = 1 causes the simple treatment to be used for bremsstrahlung photon generation as well as for bremsstrahlung contributions to detectors and DXTRAN spheres.

ISTRG is a switch to control the electron continuous-energy slowing down treatment. If ISTRG = 1, the expected value for each collision is used; if ISTRG = 0 (default), the more realistic sampled value is used. The option of using the expected value is useful for some comparisons to deterministic electron transport calculations.

BNUM, XNUM, RNOK, and ENUM are biasing parameters for specific classes of electron- or photon-production processes. For each parameter the default is 1.0, which invokes an analog treatment for the associated process. Other values allow biasing of the sampling of the processes. The processes associated with the four parameters follow.

BNUM is used to control the sampling of bremsstrahlung photons produced along electron substeps. The default value (BNUM = 1) results in the analog number of bremsstrahlung tracks being sampled. If BNUM > 0, the number of bremsstrahlung photons produced is BNUM times the number that would be produced in the analog case. If the number of tracks is increased, an appropriate weight reduction is made; if the biasing reduces the number of tracks, the weight is increased. If BNUM = 0, the production of bremsstrahlung photons is turned off. In the el1 treatment, BNUM > 0 produces BNUM times the number of analog identical photons with appropriately modified weights. In the el03 treatment, BNUM > 0 produces BNUM times the number of analog photons, each sampled independently for energy and angle with appropriately modified weights. Such a scheme is similar to the one used in ITS3.0 and recommended by Bielajew, et al.[5] In either case, radiative energy loss uses the bremsstrahlung energy of the first

sampled photon. BNUM < 0 (only for el03) produces |BNUM| times the number of analog photons, each sampled independently for energy and angle with appropriately modified weights. However, the radiative energy loss uses the average energy of all the bremsstrahlung photons sampled. Such a scheme conserves energy more closely but becomes more like a continuous-slowing-down approximation energy-loss model.

XNUM is used to control the sampling of x-ray photons produced along electron substeps. The default value (XNUM = 1) results in the analog number of tracks being sampled. If XNUM > 0, the number of photons produced is XNUM times the number that would be produced in the analog case, and an appropriate weight adjustment is made. If XNUM = 0, the production of x-ray photons by electrons is turned off.

RNOK is used to control the number of knock-on electrons produced in electron interactions. The default value (RNOK = 1) results in the analog number of tracks being sampled. If RNOK > 0, the number of knock-on electrons produced is RNOK times the analog number, and an appropriate weight adjustment is made. If RNOK = 0, the production of knock-on electrons is turned off.

ENUM is used to control the generation of photon-induced secondary electrons. The default value (ENUM = 1) results in an analog treatment. If ENUM > 0, ENUM times the analog number of secondaries will be produced, and an appropriate weight adjustment is made. If ENUM = 0, the generation of secondary electrons by photons will be turned off. ENUM = 0 differs from IDES = 1. If ENUM = 0, pair production is totally turned off. If IDES = 1, the pair production–produced annihilation photons are still produced.

NUMB generates bremsstrahlung on each electron substep. Only a real event, one that has been sampled to have a bremsstrahlung interaction, causes energy loss. The weights of the bremsstrahlung photons are multiplied by the probability of interaction in a substep. If two or more photons are produced in a real event, the weight of the second or more photons is the unadjusted value because there is no Poisson sampling, except for real events.

In any of these biasing schemes, increasing the population of photons also increases the population of electrons because the additional photon tracks create photoelectrons, Compton recoil electrons, pair production electrons, etc. Similarly, increasing the number of electrons will propagate an increase in the population of subsequent generations of the cascade. Because electron transport is slow, a judicious use of ENUM < 1 may often be appropriate. When BNUM is set by the user, ENUM=1/BNUM in the el03 treatment unless the user sets ENUM. When NUMB>0, ENUM=1% by default.

The use of the switches, or of zero values for the biasing parameters, to turn off various processes goes beyond biasing, and actually changes the physics of the simulation. Therefore such actions should be taken with extreme care. These options are provided primarily for purposes of debugging, code development, and special-purpose studies of the cascade transport process.

2. TMP Free-Gas Thermal Temperature Card

Form: TMP*n* T_{1n} T_{2n} ... T_{in} ... T_{In}

n = index of time on the THTME card.
T_{in} = temperature of i^{th} cell at time n, in MeV.
I = number of cells in the problem.

Default: 2.53×10^{-8} MeV, room temperature.

Use: Optional. Required when THTME card is used. Need for low-energy neutron transport at other than room temperature. A FATAL error occurs if a zero temperature is specified for a nonvoid cell.

The TMP cards provide MCNP with the time-dependent cell thermal temperatures that are necessary for the free-gas thermal treatment of low-energy neutron transport described in Chapter 2 (see page 2–28). This treatment becomes important when the neutron energy is less than about four times the temperature of heavy nuclei or less than about 400 times the temperature of light nuclei. Thus the TMP cards should be used when parts of the problem are not at room temperature and neutrons are transported with energies within a factor of 400 from the thermal temperature.

Thermal temperatures are entered as a function of time with a maximum of 99 entries allowed. These times are entered on a thermal time (THTME) card. The thermal temperatures at time t_1 are listed, cell by cell, on the TMP1 card; the cell thermal temperatures at time t_2 are listed on the TMP2 card, etc. Cell thermal temperatures at times between two entries are determined by linear interpolation. Times before the first time value or after the last time value use the thermal temperature(s) at the nearest time entry. If no THTME card is present, a single TMP card with the index n omitted may be used, and the values on it will be used at all times.

Cell temperatures impact elastic scattering cross sections and collision kinematics (see Chapter 2 page 2–28 for a more comprehensive description). It should be noted, however, that the temperatures given on the TMP card affect only elastic scattering cross sections and have no effect on, for example, absorption cross sections or thermal scattering kernels. Furthermore, while the temperature effect on smoothly varying scattering cross sections (such as free-gas thermal scattering) is treated correctly, resonances in scattering cross sections are not broadened accurately. However, because the default value for free-gas thermal scattering is room temperature, values do need to be given on TMP cards whenever cells are at other temperatures.

We use kT to denote the thermal temperature of a cell and use units of MeV. The following formulas can be used to provide the values of kT for temperatures in degrees Kelvin, Celsius, Rankine, and Fahrenheit.

$$\begin{aligned} kT(\text{MeV}) &= 8.617 \times 10^{-11} T, \text{ where } T \text{ is in degrees K} \\ &= 8.617 \times 10^{-11} (T + 273.15) \text{ where } T \text{ is in degrees C} \\ &= 4.787 \times 10^{-11} T \text{ where } T \text{ is in degrees R} \\ &= 4.787 \times 10^{-11} (T + 459.67) \text{ where } T \text{ is in degrees F} \end{aligned}$$

3. THTME Thermal Times Card

Form: THTME $t_1\ t_2 \ldots t_n \ldots t_N$

t_n = time in shakes at which thermal temperatures are specified on the TMP card.
N = total number of thermal times specified.

Default: Zero; temperature is not time dependent.

Use: Optional. Use with TMP card.

The THTME card specifies the times at which the thermal temperatures on the TMPn cards are provided. The temperatures on the TMP1 card are at time t_1 on the THTME card, the temperatures on the TMP2 card are at time t_2 on the THTME card, etc. The times must be monotonically increasing: $t_n < t_{n+1}$. For each entry on the THTME card there must be a TMPn card.

4. MTm *S*(α,β) Material Card

Form: MT*m* X_1 X_2 ...

m = material number on Mm card
X_i = *S*(α,β) identifier corresponding to a particular component on the Mm card.

Default: None.

Use: Optional, as needed.

For any material defined on an Mn card, a particular component of that material (represented by a ZAID number) can be associated through an MTm card with an *S*(α,β) data set if that data set exists. The *S*(α,β) data for that ZAID are used in every cell in which that material is specified. For a particular ZAID in a material, the free-gas treatment can be used down to the energy where *S*(α,β) data are available. At that point, the *S*(α,β) treatment automatically overrides the free-gas treatment (that is, there is no mixing of the two treatments for the same ZAID in the same material at a given energy). Typically the free-gas model is used for a particular ZAID of a material down to 4 eV and then the *S*(α,β) treatment will take over. In general, *S*(α,β) effects are most significant below 2 eV.

The *S*(α,β) treatment is invoked by identifiers on MTm cards. The *m* refers to the material *m* defined on a regular Mm card. The appearance of an MTm card will cause the loading of the corresponding *S*(α,β) data from the thermal data file. The currently available *S*(α,β) identifiers for the MTm card are listed in Appendix G. *S*(α,β) contributions to detectors or DXTRAN spheres are approximate.

Examples:

```
M1      1001  2    8016  1    $ light water
MT1     LWTR.07

M14     1001  2    6012  1    $ polyethylene
MT14    POLY.03

M8      6012  1               $ graphite
MT8     GRPH.01
```

H. Problem Cutoff Cards

The following cards can be used in an initiate-run or a continue-run input file to specify parameters for some of the ways to terminate tracks in MCNP.

Mnemonic	Card Type	Page
CUT	Cutoffs	3–139
ELPT	Cell–by–Cell Energy Cutoff	3–140
NOTRN	Direct-Only Neutral Particle Point Detector Contributions	3–141
NPS	History Cutoff	3–141
CTME	Computer Time Cutoff	3–142

1. CUT Cutoffs Card

Form: CUT:*n* *T* *E* *WC1* *WC2* *SWTM*

n = *N* for neutrons, *P* for photons, *E* for electrons.
T = time cutoff in shakes, 1 shake=10^{-8} sec.
E = lower energy cutoff in MeV.
WC1 and *WC2* = weight cutoffs.
SWTM = minimum source weight.

Default: See below.

Use: Optional, as needed.

Defaults

Neutron default: *T*=very large, *E*=0.0 MeV, *WC1* = –0.50, *WC2* = –0.25,
SWTM=minimum source weight if the general source is used.

If a neutron's time becomes greater than *T*, its transport is stopped and it is killed. Even though MCNP is time dependent, neutron decay is not considered. Any neutron with energy lower than *E* is killed.

If a neutron's weight *WGT* falls below *WC2* times the ratio *R* of the source cell importance to the current cell importance, then with probability $WGT/(WC1 * R)$, the neutron survives and is assigned $WGT = WC1 * R$. If negative values are entered for the weight cutoffs, the values

$$|WC1| * W_s \text{ and } |WC2| * W_s$$

will be used for *WC1* and *WC2*, respectively, where W_s is the minimum weight assigned to a source neutron from an MCNP general source. These negative entries are recommended for most problems. If only *WC1* is specified, then $WC2 = 0.5 * WC1$. See Chapter 2 page 2–148 for a discussion of weight cutoffs.

In a coupled neutron/photon problem, photons are generated before the neutron weight cutoff game is played.

If *WC1* is set to zero, capture is treated explicitly by analog rather than implicitly by reducing the neutrons's weight according to the capture probability. If *EMCNF* = E_{max} on the PHYS card, analog capture is used regardless of the value of *WC1* except for neutrons leaving a DXTRAN sphere.

SWTM (source weight minimum) can be used to make the weight cutoffs relative to the minimum starting weight of a source particle for user source as is done automatically for the general source. The entry will in general be the minimum starting weight of all source particles, including the effects of energy and direction biasing. The entry is also effective for the general source. Then *SWTM* is multiplied by the W entry on the SDEF card but is unaffected by any directional or energy biasing. This entry is ignored for a KCODE calculation.

Photon default: *T*=neutron cutoff, *E*=0.001 MeV, *WC1* = –0.50, *WC2* = –0.25,
SWTM=minimum source weight if the general source is used.

The CUT:P weight cutoffs are analogous to the CUT:N card except that they are used only for energies above the EMCPF entry on the PHYS:P card (see page 3–133). If WC1=0, analog capture is specified for photons of energy greater than EMCPF, just as it is for neutrons. For energies below EMCPF, analog capture is the only choice with one exception: photons leaving a DXTRAN sphere. Their weight is always checked against the CUT:P weight cutoff upon exiting. If only *WC1* is specified, then *WC2* = 0.5 ∗ *WC1*.

In a coupled neutron/photon problem, the photon weight cutoffs are the same as the neutron weight cutoffs unless overridden by a CUT:P card. Again, the photon weight cutoffs have no effect at energies below EMPCF (except with DXTRAN as noted above).

MCNP allows only analog capture below 0.001 MeV. Because the photoelectric cross section is virtually 100% of the total cross section below that energy for all isotopes, tracks will be quickly captured and terminated.

Electron default: *T*=neutron cutoff, *E*=0.001 MeV, *WC1* = 0, *WC2* = 0,
SWTM=minimum source weight if the general source is used.

The CUT:E weight cutoff entries have the same meaning as the neutron entries have.

2. ELPT Cell-by-cell Energy Cutoff

Form: ELPT:*n* x_1 x_2 ... x_i ... x_I

n = *N* for neutrons, *P* for photons, *E* for electrons.
x_i = lower energy cutoff of cell i
I = number of cells in the problem.

Default: Maximum of ELPT or CUT.

Use: For cell-dependent energy cutoff.

A separate lower energy cutoff can be specified for each cell in the problem. The higher of either the value on the ELPT:n card or the global value E on the CUT:n card applies.

3. NOTRN Direct-Only Neutral Particle Point Detector Contributions

When the NOTRN card appears in the INP file, no transport of the neutral particle source particles takes place. Only the direct neutral particle source contributions to all point detector tallies are made. This card is especially useful for doing a faster calculation to generate the direct tally. NOTRN is not legal in a continue run.

Also new with imaging is the option to turn off the printing of all of the tally bin values in the OUTP file.

4. NPS History Cutoff Card

Form: NPS N NPSMG

N = total number of histories to be run in the problem.

NPSMG = number of histories for which source contributions are to be made to the pixels of the FIR image grid. When the number of source histories exceeds NPSMG, the usual time-consuming process of determining the attenuation of the FIR direct contributions is avoided by adding the average of previous direct contributions into each of the appropriate direct image tally bins. Depending on the computer time required to calculate the direct image in a particular problem, NPSMG may save substantial computer time. For example, a monoenergetic isotropic point source or a monoenergetic monodirectional surface source requires only one history to completely determine the direct image. Thus, NPSMG = 1 is sufficient in this case. Changing both entries on the NPS card is allowed in a continue run.

Default: None.

Use: As needed to terminate the calculation. In a criticality calculation, the NPS card has no meaning and a warning error message is issued if it is used. 8 byte integer values allowed for N and NPSMG.

The single entry *N* on this card is used to terminate the Monte Carlo calculation after *N* histories have been transported—unless the calculation is terminated earlier for some other reason such as computer time cutoff.

In a continue-run, NPS is the total number of particles including runs before the continue-run; it is cumulative. However, a negative NPS entry means to print an output file at the time of the last history run and then stop.

In a surface source problem, either more or less than all of the particle histories on the RSSA surface source file will be run, depending on the value N entered on the NPS card. If $N < NP1$, where $NP1$ is the number of original histories, Russian roulette with weight adjustment will be played with each history in the file, using a survival probability of $N/NP1$. If $N > NP1$, the histories will be split $N/NP1$ to 1, and the fractional part is taken care of by sampling. This can be done equally well for nonspherical sources by cell importance splitting. With a spherical source, each multiple occurrence of the history is sampled for a different starting location on the source sphere, possibly improving the spatial statistics of the results. In either case, the use of the NPS card will not provide additional information about the original source distributions or the transport to the recording surface crossing.

5. CTME Computer Time Cutoff Card

Form: CTME*x*

x = maximum amount of computer time (in minutes) to be spent in the Monte Carlo calculation.

Default: None

Use: As needed

For a continue-run job the time on the CTME card is the time relative to the start of the continue-run; it is not cumulative. If the job is parallel, CTME is compared to ctm, total computation time for all processors, and the cutoff will be delayed to the next rendezvous to assure consistent data.

Five normal ways to terminate an MCNP calculation are the NPS card, the CTME card, the job time limit, the end of a surface source file, and the number of cycles on a KCODE card. If more than one is in effect, the one encountered first will control termination of the MCNP calculation. MCNP checks the computer time remaining in a running problem and will terminate the job itself, leaving enough time to wrap up and terminate gracefully.

I. User Data Arrays

Two arrays, IDUM and RDUM, are in MCNP variable COMMON and are available to the user. They are included in the dumps on the RUNTPE file and can therefore be used for any purpose, including accumulating information over the entire course of a problem through several continue-runs. Each array is dimensioned to hold a maximum of 50 entries and each array can be filled by cards in the input file. IDUM is an integer array and RDUM is a floating point array.

1. IDUM Integer Array Card

Form: IDUM $I_1 \ldots I_n$, where $1 \le n \le 50$

I = an integer number.

Default: All array values zero.

Use: Useful only in user-modified versions of MCNP.

Entries (up to 50) fill the IDUM array with integer numbers. If floating point numbers are entered, they will be truncated and converted to integers.

2. RDUM Floating Point Array Card

Form: RDUM R_1 ... R_n, where $1 \le n \le 50$

R = real number.

Default: All array values zero.

Use: Useful only in user-modified versions of MCNP.

Entries (up to 50) fill the RDUM array with floating-point numbers.

J. Peripheral Cards

The following cards offer a variety of conveniences:

1. PRDMP Print and Dump Cycle Card

Form: PRDMP NDP NDM MCT NDMP DMMP

NDP = increment for printing tallies
NDM = increment for dumping to RUNTPE file
MCT = flag to write MCTAL file and for OUTP comparisons
NDMP = maximum number of dumps on RUNTPE file

DMMP =	Sequential MCNP	Multiprocessing MCNP
	TFC entries every	TFC entries and rendezvous every
	< 0 1000 particles	1000 particles
	= 0 1000 particles	10 during the run (see discussion below)
	> 0 DMMP particles	DMMP particles

Default: Print only after the calculation has successfully ended. Dump every 60 minutes and at the end of the problem. Do not write a MCTAL file. Write all dumps to the RUNTPE file. DMMP=0 (see table above).

Use: Recommended, especially for complex problems. 8 byte integer values allowed for NDP, NDM, DMMP.

The PRDMP card allows the user to control the interval at which tallies are printed to the OUTP file and information is dumped to the RUNTPE file. Positive entries mean that after every NDP history the summary and tallies are printed to the output file, and after every NDM history a dump is written to the run file. A negative entry changes the unit from histories to minutes of computer time. In a criticality calculation, positive entries for NDP and NDM on the PRDMP card are interpreted as the number of cycles rather than the number of particles started. Printing and dumping are done only at the ends of cycles. For a parallel run, setting NDP and NDM in terms of particles or cycles is recommended. If NDP or NDM is set to time on a parallel job, it will be time used by one processor, approximately elapsed wall time. The scheduled print or dump will be delayed to the next rendezvous or cycle to assure consistent data.

If the third entry MCT on the PRDMP card is nonzero, a MCTAL file is written at the problem end. The MCTAL file is an ASCII file of tallies that can be subsequently plotted with the MCNP MCPLOT option (see description in Appendix B). The MCTAL file is also a convenient way to store tally information in a format that is stable for use in the user's own auxiliary programs. For example, if the user is on a system that cannot use the MCNP MCPLOT option, the MCTAL file can be manipulated into whatever format is required by the user's own local plotting algorithms. If MCT = –1, references to code name, version number, problem ID, figure of merit, and anything else having to do with running time are omitted from MCTAL and OUTP so that tracking runs (identical random walks) yield identical MCTAL and OUTP files. MCT = –2 turns off additional prints in OUTP to assist in comparing multitasking output.

The PRDMP card also allows the user to control the size of the RUNTPE file by specifying the maximum number of dumps, NDMP, to be written. The RUNTPE file will contain the last NDMPs that were written. For example, if NDMP = 4, after dump 20 is written only dumps 17, 18, 19, and 20 will be on the RUNTPE file. In all cases, the fixed data and cross-section data at the front of the RUNTPE file are preserved.

The fifth entry DMMP has several possible meanings. For sequential MCNP, a value of DMMP ≤ 0 results in TFC entries every 1000 particles initially. This value doubles to 2000 after 20 TFC entries. A positive value of DMMP produces TFC entries every DMMP particles initially. For distributed memory multiprocessing, DMMP < 0 produces TFC entries and task rendezvous every 1000 particles initially, the same as does the sequential version. DMMP=0, the default value, produces ten TFC entries and task rendezvous, rounded to the nearest 1000 particles, based on other cutoffs such as NPS, CTME, etc. This selection optimizes speedup in conjunction with TFC entries. If detectors/DXTRAN are used with default Russian roulette criteria (DD card default), the DMMP=0 entry is changed by MCNP to < 0, ensuring tracking with the sequential version (i.e., TFC entries and rendezvous every 1000 particles). As with the sequential version, DMMP > 0 produces TFC entries and task rendezvous every DMMP particles, even with detectors/DXTRAN with default Russian roulette criteria. Setting DMMP to a large positive number

minimizes communication time and maximizes speedup. However, the TFC may not have many entries, possibly only one, if DMMP=NPS.

2. LOST Lost Particle Card

Form: LOST LOST(1) LOST(2)

LOST(1) = number of particles which can be lost before the job terminates with BAD TROUBLE.
LOST(2) = maximum number of debug prints that will be made for lost particles.

Defaults: 10 lost particles and 10 debug prints.

Use: Discouraged. Losing more than 10 particles is rarely justifiable.

The word "lost" means that a particle gets to an ill-defined section of the geometry and does not know where to go next. This card should be used cautiously: you should know why the particles are being lost, and the number lost should be statistically insignificant out of the total sample. Even if only one of many particles gets lost, there could be something seriously wrong with the geometry specification. Geometry plots in the area where the particles are being lost can be extremely useful in isolating the reason that particles are being lost. See page 3–8.

3. RAND Random Number Generation Card

Form: RAND *keword1*=value *keyword2*=value .....

Keywords: GEN{1} SEED{19073486328125} STRIDE{152917} HIST{1}

GEN = type of pseudorandom number generator to be used by MCNP
1 MCNP Lehmer 48-bit congruential generator (period = 7.0×10^{13} numbers)
2 L'Ecuyer 63-bit generator number 1 (period = 9.2×10^{18} numbers)
3 L'Ecuyer 63-bit generator number 2 (period = 9.2×10^{18} numbers)
4 L'Ecuyer 63-bit generator number 3 (period = 9.2×10^{18} numbers)
SEED = initial random number generator seed (must end with an odd digit)
STRIDE= number of random numbers between source particles
HIST = n advance generator to start first history with history n random number. 8 byte integer values allowed for SEED, STRIDE, HIST.

i^{th} source particle always starts with the same random number; this correlated source sampling enables faster evaluation of small problem differences where the problems have identical source distributions.

Random number generators will not repeat when the period is exceeded, but longer periods are preferred. Next default MCNP generator will be GEN = 2.

RAND entries take precedence over DBCN(1), DBCN(8), and DBCN(13).

CAUTION: When trying to duplicate a particle history by setting the starting random number with either *seed*= or *hist*=, the random number sequence may be altered by a default Russian roulette game on contributions to detectors or DXTRAN spheres. If a problem has detectors or DXTRAN, the only ways to reproduce histories with *seed*= or *hist*= are: (a) turn off the Russian roulette game on the DD card by setting k = 0; (b) play the roulette game with a fixed criterion by setting k < 0 on the DD card; or (c) reproduce a history with NPS < 200.

4. DBCN Debug Information Card

Form: DBCN X_1 X_2 X_3 ... X_{20}

X_1	=	See "RAND seed= "
X_2	=	debug print interval
X_3 and X_4	=	history number limits for event log printing
X_5	=	maximum number of events in the event log to print per history Default = 600
X_6	=	unused
X_7	=	1 produces a detailed print from the volume and surface area calculations
X_8	=	See "RAND hist= "
X_9	=	closeness of coincident repeated structures surfaces Default = 1.E-4
X_{10}	=	unused
X_{11}	=	1 causes collision lines to print in lost particle event log
X_{12}	=	expected number of random numbers
X_{13}	=	See "RAND stride= "
X_{14}	=	See "RAND gen= "
X_{15}	=	1 prints the shifted confidence interval and the variance of the variance for all tally bins
X_{16}	=	scale the score grid for the accumulation of the empirical $f(x)$ in print tables 161 and 162
X_{17}	=	0 default angular treatment for partial substeps to generation sites of secondary particles > 0 alternate angular treatment for secondary generation < 0 MCNP4A treatment of electron angles at secondary generation sites
X_{18}	=	0 default "MCNP–style" Landau straggling sampling logic (bin-centered treatment) 1 "ITS–style" Landau straggling sampling logic (nearest-group-boundary treatment) 2 detailed Landau straggling sampling logic (energy- and step-specific treatment)
$X_{19\text{-}30}$	=	unused

Default: See below

Use: Optional.
8 byte integer values allowed for all entries.

The entries on this card are used primarily for debugging problems and the code itself. The first 12 can be changed in a continue run which is useful for diagnosing troubles that occur late in a long-running problem.

1. This option should not be used. Use "RAND seed= " instead.
2. X_2 is used to print out information about every X_2^{nd} particle. The information consists of: (a) the particle history number, (b) the total number of neutron, photon, and electron collisions, (c) the total number of random numbers generated, and (d) the random number at the beginning of the history. This information is printed at the beginning of the history and is preceded by the letters DBCN in the output to aid in a pattern search.

3. & 4. Event log printing is done for histories X_3 through X_4, inclusively. The information includes a step-by-step account of each history, such as where and how a particle is born, which surface it crosses and which cell it enters, what happens to it in a cell, etc. See X_{11}.

5. X_5 is the maximum number of events the event log will print per history. The default is 600.
6. Unused.
7. $X_7 = 1$ will cause a detailed print from the volume and surface area calculations and is useful only to MCNP code developers.
8. This option should not be used. Use "RAND hist= " instead.
9. X_9 defines the distance allowed between coincident repeated structure surfaces for them still to be considered coincident. The default is 1.E–4. A value of 1.E–30 reproduces the earlier treatment where coincident repeated structure surfaces was not allowed. X_9 should not have to be changed unless geometries have dimensions greater than 1.E5 or unless surfaces at different levels are intended to be closer than 2.E–4.
10. Unused.
11. $X_{11} = 1$ causes collision lines to print in the lost particle event log.
12. X_{12} is the expected number of random numbers for this calculation. Entering X_{12} will cause the last line of the output file to print X_{12} and the actual number of random numbers used so that a quick comparison can be made to see if two problems tracked each other.
13. This option should not be used. Use "RAND stride= " instead.
14. This option should not be used. Use "RAND gen= " instead.
15. A nonzero X_{15}^{th} entry causes the shifted confidence interval and the variance of the variance (VOV) to be calculated and printed for all tally bins. An extra line of tally output is created for each tally that contains nonzero information. The shifted confidence interval center is followed by the estimated VOV. If the tally mean and relative error (RE) are all zeros, the VOV line is not printed because it is all zero also. Changing X_{15} from nonzero to zero in a CONTINUE run will cause the VOV information not to be printed. X_{15} cannot be changed from zero to nonzero in a CONTINUE run.
16. MCNP uses a logarithmically spaced history score grid in print table 161 for $f(x)$, producing a straight line for $f(x)$ on a log–log plot for $1/x^n$ behavior, covering 60 decades of unnormalized tally magnitudes from 1E–30 to 1E30. This range can be multiplied by the X_{16}^{th} entry when the range is not sufficient. A negative entry means that negative

history scores will be accrued in the score grid $f(-x)$ and the absolute value of X_{16} will be used as the score grid multiplier. Positive history scores will then be lumped into the lowest bin with this option. This scaling can be done only in the original problem, not in a CONTINUE run.

17. If X_{17} is 0, the default angular treatment for partial substeps to generation sites of secondary particles is invoked. This treatment accounts for the probability of the delta function first, then interpolates in the cosine of the deflection angle. It does not preserve the plane in which the deflection angle will lie at the end of the full substep.
If $X_{17} > 0$, an angular treatment for secondary generation is invoked as follows. The cosine of the electron angle is interpolated and the end-of-substep plane is preserved, but the changing probability of the delta function along the substep is ignored. This option is preserved for further testing of angular algorithms because results have been known to be sensitive to these details.
If $X_{17} < 0$, the MCNP4A treatment of electron angles at secondary generation sites is invoked.
18. See the discussion beginning on page 2–74.

5. FILES File Creation Card

Form: FILES *unit no.* *filename* *access* *form* *record length*

unit no.	=	1 to 99
filename	=	name of the file
access	=	sequential or direct
form	=	formatted or unformatted
record length	=	record length in a direct access file

Defaults: *unit no* = none; *filename* = none; *access* = sequential;
form = formatted if access = sequential, unformatted if access = direct;
record length = not required if access = sequential, no default if access = direct.

Use: When a user-modified version of MCNP needs files whose characteristics may vary from run to run. Not legal in a continue-run.

If this card is present, the first two entries are required and must not conflict with existing MCNP units and files. The words "sequential," "direct," "formatted," and "unformatted" can be abbreviated. If more than one file is on the FILES card, the defaults are not much help but the abbreviations will keep it brief. The maximum number of files allowed is six, unless the dimension of the KUFIL array in Fixed COMMON storage is increased.

```
Example 1:  FILES  21   ANDY  S  F  0  22   MIKE  D  U  512
```

If the filename is DUMN1 or DUMN2, the user can optionally use the execution line message to designate a file whose name might be different from run to run, for instance in a continue-run.

```
Example 2:  FILES 17  DUMN1
            MCNPINP=TEST3   DUMN1=POST3
```

CAUTION: The names of any user files in a continue-run will be the same as in the initial run. The names are not automatically sequenced if a file of the same name already exists; therefore, a second output file from a continue-run will overwrite and replace the content of an existing file of the same name. If you are using the FILES card for an input file and do a continue-run, you will have to provide the coding for keeping track of the record number and then positioning the correct starting location on the file when you continue or MCNP will start reading the file at the beginning.

6. PRINT Output Print Tables

Form: PRINT x

x = no entry gives the full output print
x = x_1 x_2 ... prints basic output plus the tables specified by the table numbers x_1, x_2, ...
x = $-x_1$ $-x_2$ ... prints full output except the tables specified by x_1, x_2, ...

Default: No PRINT card in the INP file or no PRINT option on the execution line will result in a reduced output print.

Use: Optional.

The following output will be printed automatically, as applicable:

- a listing of the input file,
- the problem summary of particle creation and loss,
- KCODE cycle summaries,
- tallies,
- tally fluctuation charts, and
- the tables listed below marked basic and default.

You will always get the information indicated by the first five bullets listed above and the tables labelled “basic” in Table 3.7 on the next page. They *cannot* be turned off. Tables marked “default” will be printed automatically but they *can* be turned off with the PRINT card.

To get all optional print tables applicable to your problem (indicated in Table 3.7 below as blank type) use the PRINT card in the INP file or the PRINT option on the execute line. The execute line takes precedence over the input card. Absence of a PRINT card or a PRINT option produces only the tables marked “basic,” “default,” and “shorten.” Entries are allowed only on the PRINT card, not following the PRINT option. Entries on the PRINT card can be in any order.

The PRINT card entries are table numbers of optional and default tables, and control turning the table off or on. If all the entries are positive, you will get the “basic” tables plus the tables requested on the PRINT card. If any entry is negative, you will get all tables applicable to your problem *except* those turned off by the negative entries.

The table number appears in the upper right-hand corner of the table, providing a convenient pattern when scanning the output file with an editor. The pattern is PRINT TABLE n, where n is always preceded by one space and is a two- or three-digit number. The table numbers, titles, and type are summarized in Table 3.7 below. Tables that cannot be controlled by the PRINT card are

marked as type "basic." Tables that are automatically printed but *can* be turned off are marked as type "default." Tables with no type (blank) can be turned off and on with the PRINT card or option.

Tables 160, 161, and 162 are different from the other tables. If you turn off table 160, tables 161 and 162 will not appear either. If table 160 is printed, they will all be printed. They are all automatically printed if there is no PRINT card or if there is a blank PRINT card. If a PRINT card has a positive entry, tables 160, 161, and 162 will not appear unless table 160 is explicitly requested. If the entry is negative, they will appear unless table 160 is explicitly turned off.

Table 175 cannot be turned off completely, but the output can be greatly shortened to every 100 cycles plus the last five cycles. PRINT −175 and PRINT 110 both will produce the short version of Table 175.

Table 128, the repeated structure universe map, is special. If table 128 is not turned on in an initial run, it CANNOT be turned on in a subsequent continue-run because the (often large) storage arrays have not been set up. Table 128 is the only print table that affects storage. The information in the other tables is always stored, whether or not it is printed. A warning will be printed in a repeated structures problem if you do not request the universe map/lattice activity table in the original run.

The PRINT control can be used in a continue-run to recover all or any applicable print tables, even if they were not requested in the original run. A continue file with NPS −1 and PRINT will create the output file for the initial run starting with the Problem Summary (located after table 110). Table 128 can never be printed if it was not requested in the original run.

Table 3.7: Table of PRINT Tables

Table Number	Type	Description
10		Source coefficients and distribution
20		Weight window information
30		Tally description
32		Mesh tally description
35		Coincident detectors
40		Material composition
50		Cell volumes and masses, surface areas
60	basic	Cell importances
62	basic	Forced collision and exponential transform
70		Surface coefficients
72	basic	Cell temperatures
80		ESPLT/TSPLT Importance Ratios
85		Electron range and straggling tables multigroup: flux values for biasing adjoint calculations
86		Electron bremsstrahlung and secondary production
90		KCODE source data
98		Physical constants and compile options
100	basic	Cross-section tables
102		Assignment of S(α,β) data to nuclides
110		First 50 starting histories

Table 3.7: Table of PRINT Tables

Table Number	Type	Description
120		Analysis of the quality of your importance function
126	basic	Particle activity in each cell
128		Universe map
130		Neutron/photon/electron weight balance
140		Neutron/photon nuclide activity
150		DXTRAN diagnostics
160	default	TFC bin tally analysis
161	default	$f(x)$ tally density plot
162	default	Cumulative $f(x)$ and tally density plot
170		Source distribution frequency tables, surface source
175	shorten	Estimated k_{eff} results by cycle
178		Estimated k_{eff} results by batch size
190	basic	Weight window generator summary
198		Weight windows from multigroup fluxes
200	basic	Weight window generated windows

Example 1: PRINT 110 40 150

The output file will contain the "basic" tables plus tables 40, 110, and 150, not 160, 161, 162 (the "default" tables), and the shortened version of 175.

Example 2: PRINT 170 –70 –110

The output file will contain all the "basic" tables, all the "default" tables, the long version of table 175, and all the optional tables applicable to your problem, except tables 70, 110, and 170.

7. TALNP Control of Tally Output

The TALNP card with no entries turns off the bin prints for all tallies in the problem. If there are entries, it turns off the bin prints for the tally numbers that are listed. If after the run is complete and one would like to see these numbers, the printing of the bin values can be restored with the TALNP card in an INP file used in a continue-run and the tally numbers entered on the TALNP card as negative numbers. A single entry of zero in a continue run restores the prints of all tally bins.

8. MPLOT Plot Tally While Problem is Running

Form: MPLOT MCPLOT keyword=parameter

Default: None.

Use: Optional.
8 byte integer values allowed for FREQ.

This card specifies a plot of intermediate tally results that is to be produced periodically during the run. The entries are MCPLOT commands for one picture. The = sign is optional. During the run,

as determined by the FREQ n entry, MCRUN will call MCPLOT to display the current status of one or more of the tallies in the problem. If a FREQ n command is not included on the MPLOT card, n will be set to 5000. The following commands cannot appear on the MPLOT card: RMCTAL, RUNTPE, DUMP, and END. All of the commands on the MPLOT card are executed for each displayed picture, so coplots of more than one bin or tally are possible. No output is sent to COMOUT. MCPLOT will not take plot requests from the terminal and returns to MCRUN after each plot is displayed. See Appendix B page B–15 for a complete list of MCPLOT commands available.

Another way to plot intermediate tally results is to use the TTY interrupt <ctrl–c>IMCPLOT or <ctrl–c>IM that allows interactive plotting during the run. At the end of the history that is running when the interrupt occurs, MCRUN will call MCPLOT, which will take plot requests from the terminal. No output is sent to the COMOUT file. The following commands cannot be used: RMCTAL, RUNTPE, DUMP and END.

9. PTRAC Particle Track Output Card

Form: PTRAC keyword=parameter(s) keyword=parameter(s)

Default: See Table 3.8.

Use: Optional.

This card generates an output file, default name PTRAC, of user-filtered particle events. The name PTRAC can be changed on the execution line or within the message block. Using this card without any keywords causes all particle events to be written to the PTRAC file.

CAUTION: An extremely large file likely will be created unless NPS is small. Use of one or more keywords listed in Table 3.8 will reduce significantly the PTRAC file size. In Table 3.8 the keywords are arranged into three categories: output control keywords, event filter keywords, and history filter keywords. The output control keywords provide user control of the PTRAC file and I/O. The event filter keywords filter particle events on an event-by-event basis. That is, if the history meets the filter criteria, all filtered events for that history are written to file PTRAC. The PTRAC card keywords can be entered in any order and, in most cases, the corresponding parameter values can appear in any order (exceptions are noted below.) The PTRAC card is not legal in a continue-run input file because a change in the PTRAC input would require a readjustment in dynamically allocated storage.

When multiple keywords are entered on the PTRAC card, the filter criteria for each keyword must be satisfied to obtain an output event. For example:

PTRAC FILTER=8,9,erg EVENT=sur NPS=1,50 TYPE=e CELL=3,4

will write only surface crossing events for 8–9 MeV electrons generated by histories 1–50 that have entered cells 3 or 4.

Table 3.8: PTRAC Keywords, Parameter Values, and Defaults

Keyword	Parameter Values	Default	Entries
Output Control Keywords			
BUFFER	Integer > 0	100	1
FILE	asc, bin	bin	1
MAX	8 byte integer ≠ 0	10000	1
MEPH	Integer > 0	*	1
WRITE	pos, all	pos	1
Event Filter Keywords			
EVENT	src, bnk, sur, col, ter	*	1–5
FILTER	Real, Integer, Mnemonic	*	2–72
TYPE	N,P,E	*	1–3
History Filter Keywords			
NPS	8 byte integer > 0	*	1–2
CELL	Integer > 0	*	Unlimited
SURFACE	Integer > 0	*	Unlimited
TALLY	Integer ≠ 0	*	Unlimited
VALUE	Real, Integer	*	Unlimited

BUFFER Determines the amount of storage available for filtered events. A small value results in increased I/O and a decrease in required memory, whereas a large value minimizes I/O and increases memory requirements.

FILE Controls file type. One of the following values can be entered:
asc–generates an ASCII output file.
bin–generates a binary output file. This is the default.

MAX Sets the maximum number of events to write to the PTRAC file. A negative value terminates MCNP when this value is reached.

MEPH Determines the maximum number of events per history to write to the PTRAC file.
Default: write all events.

WRITE Controls what particle parameters are written to the PTRAC file.
pos–only x, y, z location with related cell and material numbers.
all–additionally, u, v, w direction cosines, energy, weight, and time.
If the size of the PTRAC file is a concern and the additional parameters are not needed, the default value of “pos” is recommended.

EVENT Specifies the type of events written to PTRAC. One or more of the following parameter values can be entered:
src–initial source events
bnk–bank events
sur–surface events
col–collision events
ter–termination events

The bank events include secondary sources, e.g., photons produced by neutrons, as well as particles created by variance reduction techniques, e.g., DXTRAN and energy splitting. See Appendix I page I–5 for a complete list.

FILTER Specifies additional MCNP variables for filtering. The parameter values consist of one or two numerical entries and a variable mnemonic that corresponds to a variable in the PBLCOM common block. See Table 3.9 for available mnemonics. A single numerical entry requires an exact value.
EXAMPLE: FILTER=2,icl writes only those events that occur in cell 2.
Two numerical entries represent a range.
EXAMPLE: FILTER=0,10,x writes only those events in which the particle's *x*-coordinate is between 0 and 10 cm. When a range is specified, the first entry must be less than or equal to the second. Multiple sets of numerical entries and mnemonics are also allowed.
EXAMPLE: FILTER=0.0,10.0,x 0,1,u 1.0,2,erg writes only those events in which the particle's *x*-coordinate is between 0 and 10 cm and the particle's *x*-axis cosine in between 0 and 1 and the particle's energy is between 1 and 2 MeV.
Default: No additional filtering.

TYPE Filters events based on particle type. One or more of the following parameter values can be entered:
n–neutron events; p–photon events; e–electron events
EXAMPLE: TYPE=p,e writes only photon and electron events.
Default: Events for all particle types are written.

NPS Sets the range of particle histories for which events will be output. A single value produces filtered events only for the specified history.
EXAMPLE: NPS=10 writes events only for particle number 10.
Two entries indicate a range and will produce filtered events for all histories within that range. The first entry must be less than or equal to the second.
EXAMPLE: NPS=10,20 writes events for particles 10 through 20.
Default: Events for all histories.

CELL, SURFACE, TALLY The cell, surface, or tally numbers entered after these keywords are used for history filtering. If any track of the history enters listed cells or crosses listed surfaces or contributes to the TFC bin of listed tallies, all filtered events for the history are written to the PTRAC file. See page 3–111 for specification of the TFC bin.
EXAMPLE: CELL=1,2 writes all filtered events for those histories that enter cell 1 or 2.
EXAMPLE: TALLY=4 writes all filtered events for those histories that contribute to tally 4 (see VALUE keyword for filter criteria). The number of entries following CELL, SURFACE, and TALLY is unlimited. A negative TALLY entry indicates that the corresponding VALUE entry is a multiplier rather than an absolute value.
Default: No history filtering.

VALUE Specifies the tally cutoff above which history events will be written.

The number of entries must match those of the TALLY keyword.
EXAMPLE: Tally=4 VALUE=2.0 writes all filtered events of any history that contributes 2.0 or more to the TFC bin of tally 4. A negative TALLY value indicates that the corresponding VALUE entry is a multiplier.
EXAMPLE: TALLY=–4 VALUE=2.0 writes all filtered events of any history that contributes more than $2.0*T_a$ to tally 4, where T_a is the average tally of the TFC bin. The values for T_a are updated every DMMP histories. Typically, DMMP=1000. See the PRDMP card, page 3–143. Filtering based on the T_a values will occur only when they become nonzero. Thus, when using a multiplier, PTRAC events may not be written for several thousand particles, or at all, if scores are seldom or never made to the TFC bin of the specified tally. In such cases, it is best to enter an absolute value.
EXAMPLE: TALLY=4 VALUE=0.0 writes all filtered events of every history that scores to tally 4.
Default: A multiplier of 10.0 for each tally associated with the TALLY keyword

Table 3.9: Mnemonic Values for the FILTER Keyword

Mnemonic	MCNP Variable	Description
X	XXX	*X*-coordinate of particle position (cm)
Y	YYY	*Y*-coordinate of particle position (cm)
Z	ZZZ	*Z*-coordinate of particle position (cm)
U	UUU	Particle *X*-axis direction cosine
V	VVV	Particle *Y*-axis direction cosine
W	WWW	Particle *Z*-axis direction cosine
ERG	ERG	Particle energy (MeV)
WGT	WGT	Particle weight
TME	TME	Time at the particle position (shakes)
VEL	VEL	Speed of the particle (cm/shake)
IMP1	FIML(1)	Neutron cell importance
IMP2	FIML(2)	Photon cell importance
IMP3	FIML(3)	Electron cell importance
SPARE1	SPARE(1)	Spare banked variable
SPARE2	SPARE(2)	Spare banked variable
SPARE3	SPARE(3)	Spare banked variable
ICL	ICL	Problem number of current cell
JSU	JSU	Problem number of current surface
IDX	IDX	Number of current DXTRAN sphere
NCP	NCP	Count of collisions for current branch
LEV	LEV	Geometry level of particle location
III	III	1st lattice index of particle location
JJJ	JJJ	2nd lattice index of particle location
KKK	KKK	3rd lattice index of particle location

10. PERTn Perturbation Card

Form: PERT*n*:*pl* keyword=parameter(s) keyword=parameter(s)

n = unique, arbitrary perturbation number.
pl = N, P, or N,P. Not available for electrons.
keyword = See Table 3.10.

Default: Some keywords are required. See Table 3.10.

Use: Optional.

This card allows perturbations in cell material density, composition, or reaction cross-section data. The perturbation analysis uses the first- and second-order differential operator technique described in Chapter 2, page 2–197. Using this technique, the perturbation estimates are made without actually changing the input material specifications. Multiple perturbations can be applied in the same run, each specified by a separate PERT card. There is no limit to the number of perturbations because dynamic memory is used for perturbation storage. The entire tally output is repeated for each perturbation, giving the estimated differential change in the tally, or this change can be added to the unperturbed tally (see the METHOD keyword). For this reason, the number of tallies and perturbations should be kept to a minimum. A track length estimate of perturbations to k_{eff} is automatically estimated and printed for KCODE problems. The CELL keyword that identifies one or more perturbed problem cells is required. Also, either the MAT or RHO keyword must be specified.

Table 3.10: PERT Keywords, Parameter Values, and Defaults

Keyword	Parameter Values	Default	Entries
Basic Keywords			
CELL	Integer > 0	Required	Unlimited
MAT	Integer > 0	*	1
RHO	Real, integer	*	1
Advanced Keywords			
METHOD	±1, 2, 3	1	1
ERG	Real, Integer > 0	All Energies	2
RXN	Integer	1	Unlimited

CELL Indicates which cells are perturbed. At least one entry is required, and there is no limit to the number of entries. A comma or space delimiter is required between entries:

```
CELL=1,2,3,4
CELL=1  10i  12
```

MAT Specifies the perturbation material number, which must have a corresponding Mm card. Composition changes can only be made through the use of this keyword. If the RHO keyword is omitted, the MAT keyword is required. Note in the CAUTIONS listed below that certain composition changes are prohibited.

RHO Specifies the perturbed density of the cells listed after the CELL keyword. A positive entry indicates units of atoms/cm^3 and a negative entry indicates units of g/cm^3. If the MAT keyword is omitted, the RHO keyword is required.

METHOD Specifies the number of terms to include in the perturbation estimate.

1 – include first and second order (default)
2 – include only first order
3 – include only second order

A positive entry produces perturbation tallies that give the estimated differential change in the unperturbed tally (default). A negative entry adds this change to the unperturbed tally. The ability to produce first- and second-order terms separately enables the user to determine the significance of including the second-order estimator for subsequent runs. If the second-order results are a significant fraction (20-30%) of the total, then higher order (or other) terms are necessary to accurately predict the change in the unperturbed tally. In such cases, the magnitude of the perturbation should be reduced to satisfy this condition. Typically, this technique is accurate to within a few percent for up to 30% changes in the unperturbed tally. It is *strongly* recommended that the magnitude of the second order term be determined before the user continues with this capability.

ERG The two entries specify an energy range in which the perturbation is applied. The default range includes all energies. This keyword is usually used with the RXN keyword to perturb a specific cross section over a particular energy range.

RXN Entries must be ENDF/B reaction types that identify one or more specific reaction cross sections to perturb. A list of available ENDF/B reaction types is given in Appendix G. This keyword allows the user to perturb a single reaction cross section of a single nuclide in a material, all reaction types of a single nuclide, a single reaction for all nuclides in a material, and a set of cross sections for all nuclides in a material. The default reaction is the total cross section (RXN=1 for neutrons and multigroup, RXN=-5 for photons). Relevant nonstandard special R numbers on page 3–100 can be used. Those that cannot be used are –4, –5, –7, and –8 for neutrons; –6 for photons; and –3, –4, –6, and –7 for multigroup problems. If these irrelevant R numbers are used, the following FATAL error will be printed: “fatal error. reaction # illegal in perturbation #.”

RXN=2 elastic cross section
RXN=–2 absorption cross section

RXN reaction numbers must be consistent with FM card reaction numbers (see page 3–100) if the perturbation affects the tally cross section. RXN=–6 is most efficient for fission, although MT=18, MT=19, or MT=–2 (multigroup) also work for k_{eff} and F7 tallies.

CAUTIONS:

1. There is no limit to the number of perturbations, but they should be kept to a minimum as each perturbation can degrade performance by 10-20%.

2. It is not possible to take a region originally specified as void and put in a material with the perturbation technique. However, you can specify a region as containing a material and use the PERT card to make it void by setting RHO=0.

3. It is not possible to introduce a new nuclide into a material composition. However, you can set up the problem with a mixture of all nuclides of interest and use PERT cards to remove one or more nuclides (see the examples below).

4. The track length estimate of k_{eff} in KCODE criticality calculations assumes the fundamental eigenvector (fission distribution) is unchanged in the perturbed configuration.

5. Use CAUTION in selecting the multiplicative constant and reaction number on FM cards used with F4 tallies in perturbation problems. The track length correction term $R_{1j'}$ is made only if the multiplicative constant on the FM card is negative (indicating macroscopic cross sections with multiplication by the atom density of the cell). If the multiplicative constant on the FM card is positive, it is assumed that any FM card cross sections are independent of the perturbed cross sections. If there is a reaction (RXN) specified on the PERT card, the track length correction term R_{1j} is set only if the exact same reaction is specified on the FM card. For example, an entry of RXN=2 on the PERT card is not equivalent to the special elastic reaction −3 on the FM card (should either enter 2 and 2 or −3 and −3).

6. DXTRAN, F5 point detector tallies, and F8 pulse height tallies are not compatible with the PERT card. DXTRAN will give a FATAL error; F5 and F8 will give zero perturbations.

7. Large perturbations require higher than second order terms to avoid inaccurate tallies. Refer to the METHOD keyword for a more complete discussion.

8. If the relative concentrations of a perturbed material (MAT keyword) are changed, the cross-differential terms in the 2nd order perturbation term are neglected. The perturbation is the sum of the independent nuclide perturbations. If the 2nd order term (METHOD 3) is large relative to the 1st order term (METHOD 2), the perturbation implementation may be inadequate. See example 8 on page 3–160 for a complete discussion.

Examples of the PERT Card

Example 1: PERT1:n,p CELL=1 RHO=0.03

This perturbation specifies a density change to 0.03 atoms/cm^3 in cell 1. This change is applied to both neutron and photon interactions.

```
Example 2:   3    1   −1   −1  2  −3  4  −5  6      $ mat 1 at 1 g/cm3
             12   1   −1   −7  8  −9  10 −11 12     $ mat 1 at 1 g/cm3
```

```
  …
C  M1 material is semiheavy water
M1  1001  .334  1002  .333  8016  .333
C  M8 material is heavy water
M8                1002  .667  8016  .333
PERT2:n     CELL=3,12  MAT=8  RHO=–1.2
```

This perturbation changes the material composition of cells 3 and 12 from material 1 to material 8. The MAT keyword on the PERT card specifies the perturbation material. The material density was also changed from 1.0 to 1.2 g/cm^3 to change from water to heavy water.

Example 3:

```
PERT3:n,p   CELL=1 10i 12   RHO=0   METHOD=–1
```

This perturbation makes cells 1 through 12 void for both neutrons and photons. The estimated changes will be added to the unperturbed tallies.

Example 4:

```
60   13   –2.34   105  –106  –74  73  $ mat 13 at 2.34 g/cm3
 …
M13   1001 –.2  8016  –.2  13027  –.2  26000  –.2  29000  –.2
M15   1001 –.2  8016  –.2  13027  –.2  26000  –.2  29000  –.4
PERT1:p  CELL=60  MAT=15  RHO=–2.808  RXN=51  9i  61,91
         ERG=1,20
PERT2:p  CELL=60  RHO=–4.68  RXN=2
```

This example illustrates sensitivity analysis. The first PERT card generates estimated changes in tallies caused by a 100% increase in the Cu (n, n') cross section (ENDF/B reaction types 51–61 and 91) above 1 MeV. To effect a 100% increase, double the composition fraction (–.2 to –.4) and multiply the ratio of this increase by the original cell density (RHO=[1.2/1.0] ∗ –2.34 = –2.808 g/cm^3, where the composition fraction for material 13 is 1.0 and that for material 15 is 1.2.) A change must be made to RHO to maintain the other nuclides in their original amounts. Otherwise, after MCNP normalizes the M15 card, it would be as follows, which is different from the composition of the original material M13:

```
M15   1001  –.167  8016  –.167  13027  –.167  26000  –.167  29000  –.333
```

The second PERT card (PERT2:p) gives the estimated tally change for a 100% increase in the elastic (RXN=2) cross section of material 13. RHO=–2.34 ∗ 2 = –4.68 g/cm^3.

Example 5:

```
M4   6000.60C  .5   6000.50C  .5
M6   6000.60C   1
M8                  6000.50C   1
PERT1:n   CELL=3   MAT=6   METHOD=–1
PERT2:n   CELL=3   MAT=8   METHOD=–1
```

The perturbation capability can be used to determine the difference between one cross-section evaluation and another. The difference between these perturbation tallies will give an estimate of the effect of using different cross-section evaluations.

Example 6:

```
1   1   0.05  −1   2   −3   $ mat 1 at 0.05 x 10^24 atoms/cm^3
…
M1   1001  .1  8016  .2   92235  .7
M9   1001  .1  8016  .22  92235  .7
F14:n   1
FM14   (−1   1   −6   −7)   $ keff estimator for cell 1
PERT1:n    CELL=1   MAT=9   RHO=0.051   METHOD=1
PERT2:n    CELL=1   MAT=9   RHO=0.051   METHOD=−1
```

These perturbations involve a 10% increase in the oxygen atom fraction of material 1 (RHO=0.05 x [1.02/1.0] = 0.051). The effect of this perturbation on tally 14, which is a track length estimate of k_{eff}, will be provided as a differential change (PERT1), as well as with this change, added to the unperturbed estimate of k_{eff} (PERT2). Note: if the RHO keyword is omitted from the PERT cards, the ^{235}U composition will be perturbed, which can produce invalid results (see CAUTION 4 on page 3–158.)

Example 7:

```
1   1   −1.5   −1   2   −3   4   −5   6   $ mat 1 at 1.5 g/cm^3
…
M1   1001   −.4333   6000   −.2000   8016   −.3667   $ half water
                                                     $ half plastic
M2   1001   −.6666                    8016   −.3334   $ water
M3   1001   −.2000   6000   −.4000   8016   −.4000   $ plastic
PERT1:n   CELL=1   MAT=2   RHO=−1.0   METHOD=−1
PERT2:n   CELL=1   MAT=3   RHO=−2.0   METHOD=−1
```

This example demonstrates how to make significant composition changes (e.g., changing a region from water to plastic.) The unperturbed material is made from a combination of the two desired materials, typically half of each. PERT1 gives the predicted tally as if cell 1 were filled with water and PERT2 gives the predicted tally as if cell 1 were filled with plastic. The difference between these perturbation tallies is an estimate of the effect of changing cell 1 from water to plastic.

Example 8:

The MCNP perturbation capability assumes that changes in the relative concentrations or densities of the nuclides in a material are independent and neglects the cross-differential terms in the second-order perturbation term when changing two or more cross sections at once. In the case illustrated below there will be a large FALSE second-order perturbation term.

```
M1   6000.50c   .5   6012.50c   .5
M2   6000.50c   .9   6012.50c   .1
PERT1:n   CELL  1   MAT  2
```

The perturbation should be zero because 6000.50c is exactly the same as 6012.50c, making materials M1 and M2 identical. In fact, the first-order term will be zero (METHOD 2, correct) but the second-order term will be wrong because of the differential cross term. There is no problem if all the nuclides have the same density change (RHO option but no MAT option). There is also no cross term problem if only one nuclide has a density change, for example:

```
cell  1    material  1    density  rho=3.0
…
M1    1001   2   8016   1
M2    1001   2   8016   2
PERT1:n     CELL  1    MAT  2    RHO=4.0
```

The cell density times the normalized atom fraction of 1001 is unchanged (3 x 2/3 = 4 x 2/4) and only the density of 8016 is changed (from 3 x 1/3 to 4 x 2/4). But there will be a second-order cross-differential term that is neglected when the cell density times nuclide fraction changes for more than one nuclide in a perturbed material. Therefore, if the MAT keyword is used for a perturbation, the first- and second-order terms should be examined. If the second-order perturbation term is small relative to the first-order term (METHOD 3 and METHOD 2), then generally the differential cross term is small and the perturbed tally can be accepted with confidence.

V. SUMMARY OF MCNP INPUT FILE

A. Input Cards

Table 3.11 lists the various input cards and when they are required. Two kinds of defaults are involved in this table: (1) if a particular entry on a given card has a default value, that value is listed in the appropriate location on the card, and (2) the omission of a card from the input file sometimes has a default meaning, and if so, the default description is preceded by an asterisk

Table 3.11: Summary of MCNP Input Cards

Use	Card and Defaults	Page
	General Categories	
optional	Message block plus blank terminator	3–1
required	Problem title card	3–2
required	Cell cards plus blank terminator	3–9
required	Surface cards plus blank terminator	3–11
required	Data cards plus blank terminator	3–23
optional	C Comment card	3–4
	Problem type card	3–24
(a)	MODE N	

(a) Required for all but MODE N

	Geometry cards	3–24
optional	VOL 0	
optional	AREA 0	
optional	U 0	
optional	TRCL 0	
optional	LAT 0	
optional	FILL 0	
optional	TRn none	

Table 3.11: Summary of MCNP Input Cards

Use	Card and Defaults		Page
optional	URAN	none	
	Variance reduction cards		3–33
required	IMP	required unless weight windows used	
optional	ESPLT	*no energy splitting or roulette	
optional	TSPLT	*no time splitting or roulette (mirrors ESPLT)	
optional	PWT	−1 MODE N P or N P E only	
optional	EXT	0	
optional	VECT	none	
optional	FCL	0	
optional	WWE	none	
required	WWN	required unless importances used	
optional	WWP	5 3 5 0 0 0	
optional	WWG	none	
optional	WWGE	single energy or time interval	
optional	MESH	none	
optional	PDn	1	
optional	DXC	1	
optional	BBREM	none electron photon transport only	
	Source specification cards		3–53
optional	SDEF	ERG=14 TME=0 POS=0,0,0 WGT=1	
optional	SIn	H I_i ... I_k	
optional	SPn	D P_i ... P_k	
optional	SBn	D B_i ... B_k	
optional	DSn	H J_i ... J_k	
optional	SCn	none	
optional	SSW	SYM 0	
optional	SSR	OLD NEW COL m=0	
(b)	KCODE	1000 1 30 130 MAX(4500,2∗NSRCK) 0 6500 1 none	
(c)	KSRC	none	
(c)	HSRC	none	
	Tally specification cards		3–80
optional	Fn*a*	R_0 = 0 for n = 5	
optional	FCn	none	
optional	En	very large	
optional	Tn	very large	
optional	Cn	1	
optional	FQn	F D U S M C E T	
optional	FMn	1	
optional	DEn/DFn	none	

(b) neutron criticality problems only
(c) KCODE only

Table 3.11: Summary of MCNP Input Cards

Use	Card and Defaults		Page
optional	EMn	1	
optional	TMn	1	
optional	CMn	1	
optional	CFn	none	
optional	SFn	none	
optional	FSn	none	
optional	SDn	0	
optional	FUn	(Requires SUBROUTINE TALLYX)	
optional	TFn	1 1 last last 1 last last last	
optional	DDn	0.1 1000	
optional	DXT	– – – – – 0 0 0	
optional	FTn	none	
optional	FMESHn	none	
	Material specification cards		3–121
optional	Mn	no ZAID default; 0; set internally; first match in XSDIR; .01p; .01e	
optional	MPNn	none	
(d)	DRXS	*fully continuous	
(d)	TOTNU	*prompt $\bar{\nu}$ for non-KCODE; total $\bar{\nu}$ for KCODE	
(d)	NONU	*fission treated as real fission	
optional	AWTAB	*atomic weights from cross-section tables	
optional	XSn	none	
optional	VOID	none	
optional	PIKMT	*no photon-production biasing	
optional	MGOPT	*fully continuous	

(d) neutron problems only

	Energy and Thermal cards		3–131
optional	PHYS:N	*very large 0 0 –1 0	
optional	PHYS:P	*100 0 0 0 0	
optional	PHYS:E	*100 0 0 0 0 1 1 1 1	
(e)	TMP	2.53×10^{-8}	
(e)	THTME	0	
(e)	MTm	none	

(e) neutron problems only

	Problem cutoffs		3–139
optional	CUT:N	very large 0 –0.5 –0.25 *SWTM*	
optional	CUT:P	very large .001 –0.5 –0.25 *SWTM*	
optional	CUT:E	very large .001 0 0 *SWTM*	
optional	ELPT	cut card energy cutoff	
optional	NOTRN	direct-only neutral particle detector contributions	
optional	NPS	none	

Table 3.11: Summary of MCNP Input Cards

Use	Card and Defaults	Page
optional	CTME none	
	User arrays	3–142
optional	IDUM 0	
optional	RDUM 0	
	Peripheral cards	3–143
optional	PRDMP end –60 0 all 10 rendezvous points	
optional	LOST 10 10	
optional	DBCN $(15^{19})^{152917}$ 0 0 0 600 0 0 0 1.E–4 100 0 0 152917 1 0 1 0 0 0 0	
optional	FILES none none sequential formatted	
optional	PRINT *short output	
optional	TALNP no bin prints for tallies	
optional	MPLOT none	
optional	PTRAC none	
optional	PERT none	
optional	RAND 1 19073486328125 152917 1	

*This describes the effect of not using this particular card.

B. Storage Limitations

Table 3.12 summarizes some of the more important limitations that have to be considered when setting up a problem. It may be necessary to modify MCNP to change one or more of these restrictions for a particular problem.

Table 3.12: Storage Limitations

Item	Item Limit
Total number of tallies	NTALMX = 1000
Detectors	MXDT = 100
Neutron DXTRAN spheres	MXDX = 10
Photon DXTRAN spheres	MXDX = 10
IDUM card entries	*50
RDUM card entries	*50
ESPLT card entries	*40
TSPLT card entries	*40

*Set as a dimension in an array

VI. REFERENCES

1. Thomas E. Booth, "Monte Carlo Variance Reduction Approaches for Non-Boltzmann Tallies," Los Alamos National Laboratory report, LA-12433 (December 1992).
2. Thomas E. Booth, "Pulse Height Tally Variance Reduction in MCNP," Los Alamos National Laboratory report, LA-13955 (2002).
3. Thomas E. Booth, "A Supertrack Importance Generator for Pulse Height Tallies," *Transactions of the American Nuclear Society*, Vol. 71, 400 (1994).
4. Tim Goorley, "MCNP5 Tally Enhancements for Lattices (aka Lattice Speed Tally Patch)," Los Alamos National Laboratory report LA-UR-04-3400 (June 2004).
5. Alex F Bielajew, Rahde Mohan, and Chen-Shou Chui, "Improved Bremsstrahlung Photon Angular Sampling in the EGS4 Code System," National Research Council of Canada report, PIRS-0203 (November 1989). Available at the following URL: http://www.irs.inms.nrc.ca/inms/irs/papers/irs_www/irs_www.html.
6. F. B. Brown, W. R. Martin, W. Ji, J. L. Conlin, and J. C. Lee, "Stochastic Geometry and HTGR Modeling for MCNP5," ANS Monte Carlo 2005 Topical Meeting, Chattanooga TN, (April 2005), and Los Alamos National Laboratory report LA-UR-04-8668 (April 2005).
7. F. B. Brown and W. R. Martin, "Stochastic Geometry Capability in MCNP5 for the Analysis of Particle Fuel," *Annals of Nuclear Energy*, Vol. 31, Issue 17, pp. 2039-2047 (2004), and Los Alamos National Laboratory report LA-UR-04-5362 (November 2004).

CHAPTER 4 - EXAMPLES

In this chapter, cookbook examples of several topics provide instructive, real examples to follow. They should be studied in conjunction with the theory and instructions of Chapters 1, 2, and 3. The geometry discussions in Chapters 1 and 2 must be understood before studying the following examples. The concept of combining regions of space bounded by surfaces to make a cell must be fully appreciated; the following examples should help solidify this concept. The use of macrobodies will simplify many geometry definition situations.

Following the geometry specification examples are examples of coordinate transformation, repeated structure and lattice geometries, tally options, source specifications, a SOURCE subroutine, and SRCDX subroutines for point detectors and/or DXTRAN spheres. The tally examples include the FMn, FSn, and FTn cards and the TALLYX subroutine for user-defined tallies using the FUn card.

I. GEOMETRY SPECIFICATION

Several more examples of the union and complement operators are given to help you understand these features. In all examples, the cell numbers will be circled; the surface numbers will not be circled but will appear next to the surface they represent. All cells are voids.

The next several examples become progressively more difficult and usually take advantage of what you learned in the preceding ones. Remember that unless altered by parentheses, the hierarchy of operations is that intersections are performed first and then unions.

Example 1:

In Figure 4-1a, surfaces 2 and 4 are cylinders and the others are planes with their positive sides to the right. Cells 1 and 2 are easy to specify:

```
1     0    1  –2–3
2     0    3  –4–5
```

Cell 3 is harder to specify, and you need to have in mind Chapter 1, Figure 1-5 and its explanation. Remember that a union adds regions and an intersection gives you only the areas that overlap or are common to both regions. Regions can be added together more than once–or duplicated–with the union operator.

Let us start the definition of cell 3 at surface 2 (this is not a requirement). The expression 2 –3 defines the following region: everything in the *world* outside surface 2 intersected with everything to the left of surface 3. This region is hatched in Figure 4-1b. Let us examine in detail how Figure 4-1b was derived. First look at each region separately. The area with a positive sense with respect to surface 2 is shown in Figure 4-1c. It includes everything outside surface 2 extending to infinity

in all directions. The area with negative sense with respect to surface 2 is undefined so far. The area with negative sense with respect to surface 3 is shown in Figure 4-1d. It includes everything to the left of surface 3 extending to infinity, or half the universe. Recall that an intersection of two regions gives only the area common to both regions or the areas that overlap. Superimposing Figure 4-1c and Figure 4-1d results in Figure 4-1e. The cross-hatched regions show the space common to both regions. This is the same area hatched in Figure 4-1b.

Figure 4-1.

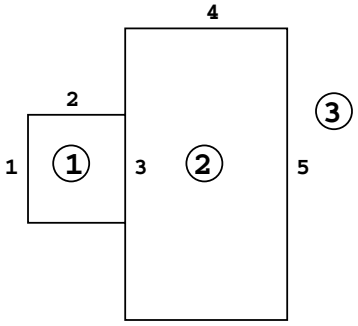


Figure 4-1a.

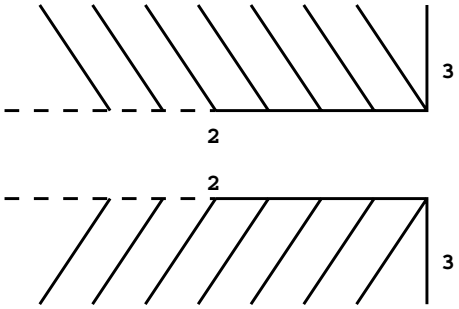


Figure 4-1b.

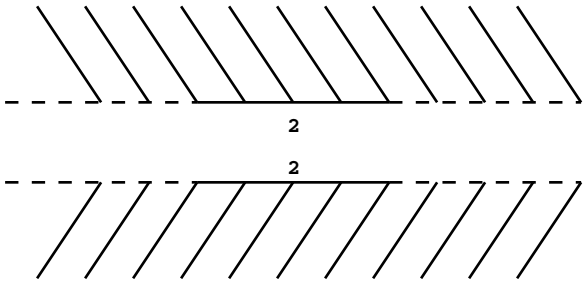


Figure 4-1c.

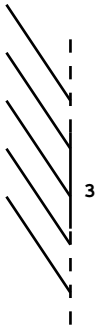


Figure 4-1d.

Let us now deal with surface 1. To the quantity 2 –3 we will add everything with a negative sense with respect to surface 1 as indicated by the expression 2 –3: –1, or (2 –3): –1 if you prefer. Recall (1) that in the hierarchy of operations, intersections are performed first and then unions (so the parentheses are unnecessary in the previous expression), and (2) that a union of two regions results in a space containing everything in the first region plus everything in the second region; this includes everything common to both regions. Superimposing the region shown in Figure 4-1b and the region to the left of surface 1 results in Figure 4-1f. Our geometry now includes everything hatched plus everything crosshatched and has added part of the tunnel which is interior to surface 2.

By the same method we will deal with surface 4. To the quantity 2 –3: –1 we will add everything with a positive sense with respect to surface 4, written as 2 –3: –1: 4. Figure 4-1g shows our new geometry. It includes everything in Figure 4-1f plus everything outside surface 4.

Our final step is to block off the large tunnel extending to infinity to the right by adding the region with a positive sense with respect to surface 5 to the region shown in Figure 4-1g. The final expression that defines cell 3 of Figure 4-1a is 2 –3: –1: 4: 5.

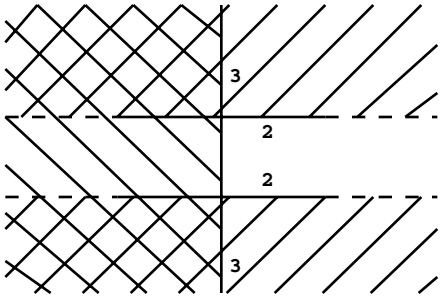


Figure 4-1e.

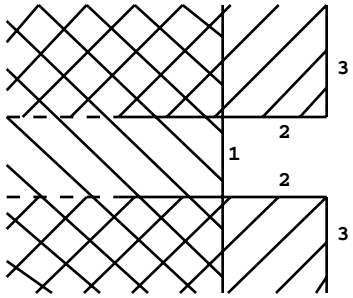


Figure 4-1f.

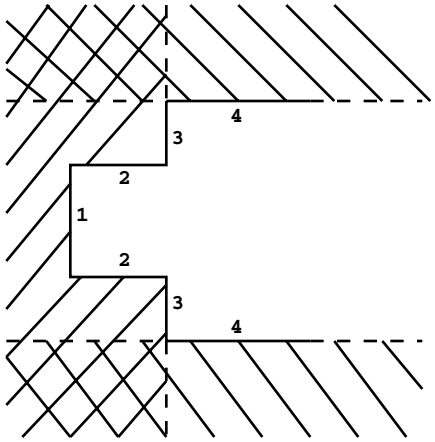


Figure 4-1g.

There is more than one way to define cell 3. Starting with surface 1, we can add the region to the left of 1 to the region outside surface 2 or –1: 2, which is illustrated in Figure 4-1h. We wish to intersect this space with the space having a negative sense with respect to surface 3. Superimposing Figure 4-1h and the region to the left of surface 3 results in Figure 4-1i. The cross-hatched area indicates the area common to both regions and is the result of the intersection. Note that the cross-hatched area of Figure 4-1i is identical to the entire hatched plus crosshatched area of Figure 4-1f. Therefore, we have defined the same geometry in both figures but have used two different approaches to the problem. To ensure that the intersection of –3 is with the quantity –1: 2 as we have illustrated, we must use parentheses giving the expression (–1: 2) –3. Remember the order in which the operations are performed. Intersections are done before unions unless parentheses alter the order. The final expression is (–1: 2) –3: 4: 5.

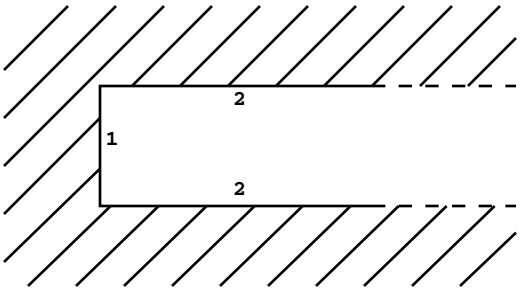


Figure 4-1h.

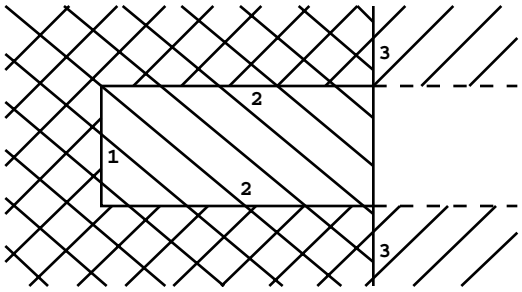


Figure 4-1i.

Another tactic uses a somewhat different approach. Rather than defining a small region of the geometry as a starting point and adding other regions until we get the final product, we shall start by defining a block of space and adding to or subtracting from that block as necessary. We arbitrarily choose our initial block to be represented by 4: −1: 5, illustrated in Figure 4-1j.

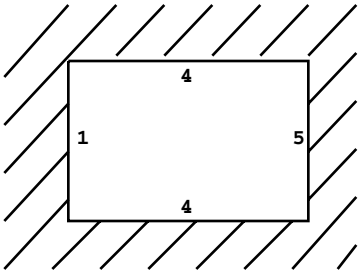


Figure 4-j.

To this block we need to add the space in the upper and lower left corners. The expression 2 −3 isolates the space we need to add. Adding 2 −3 to our original block, we have 4: −1: 5: (2 −3). The parentheses are not required for correctness in this case but help to illustrate the path our reasoning has followed. Figure 4-1k depicts the union of 2 −3 with the block of space we originally chose.

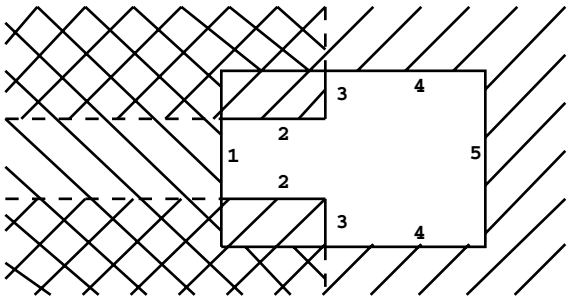


Figure 4-1k.

Let us arbitrarily choose a different initial block, 4: 5: −3, all the world except cell 2. From this region we need to subtract cell 1. If we intersect the region (2: −1) with (4: 5: −3), as shown in Figure 4-1l, we will have introduced an undefined tunnel to the right of surface 5. To correct this error, define an area (2: −1: 3) or (2: −1: 5) and intersect this region with the initial block.

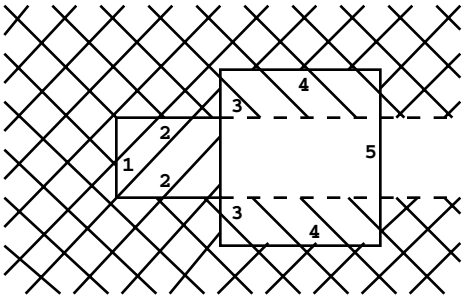


Figure 4-1l.

Another approach is to intersect the two regions −1: 2 and −3: 4, then add that to the region to the right of surface 5 by (−1: 2)(−3: 4): 5. In the above paragraph the expression (4 : 5 : −3)(2 : −1: 5) can have the common quantity: 5 factored out, also resulting in (−1: 2)(−3 : 4): 5.

Finally, another approach is to forget about the reality of the geometry and for cell 3 take the inverse (or complement) of all the cells bounding cell 3, which is cells 1 and 2. This says that cell 3 is all of the world excluding that which has already been defined to be in cells 1 and 2. The advantage of this is that cells 1 and 2 are easy to specify and you do not get bogged down in details for cell 3. Cell 3 thus becomes (−1 : 2 : 3)(−3 : 4 : 5). Note that the specifications for cells 1 and 2 are reversed. Intersections become unions. Positive senses become negative. Then each piece is intersected with the other. There is a complement operator in MCNP that is a shorthand notation for the above expression; it is the symbol #, which can be thought of as meaning not in. Therefore, cell 3 is specified by #1 #2, translated as everything in the world that is not in cell 1 and not in cell 2.

Example 2:

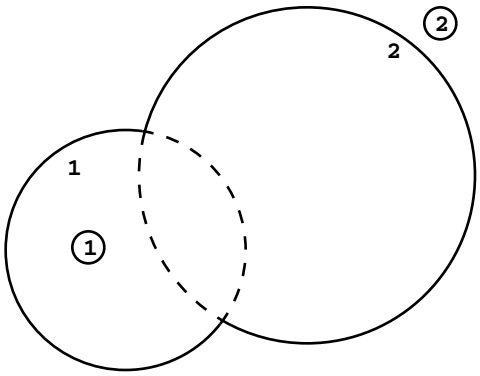


Figure 4-2.

In this example (Figure 4-2), cell 1 is everything interior to the surfaces 1 and 2:

```
1     0     −1     :     −2
2     0      1           2
```

Example 3:

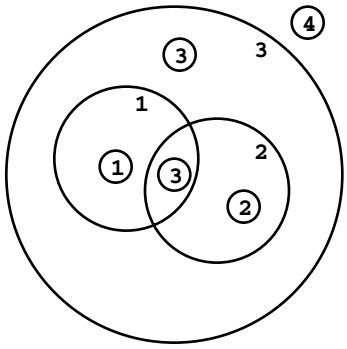


Figure 4-3.

In this geometry (Figure 4-3) of four cells defined by three spheres, cell 3 is disconnected. Cell 3 is the region inside surface 3 but outside surfaces 1 and 2 plus the region enclosed between surfaces 1 and 2:

```
1     0     −1     2
2     0     −2     1
3     0     −3     1     2 : −2 −1
4     0      3
```

Cell 3 could also be written as

```
3     0     (−3  1  2) : (−2  −1)     The parentheses are not required.
```

Example 4:

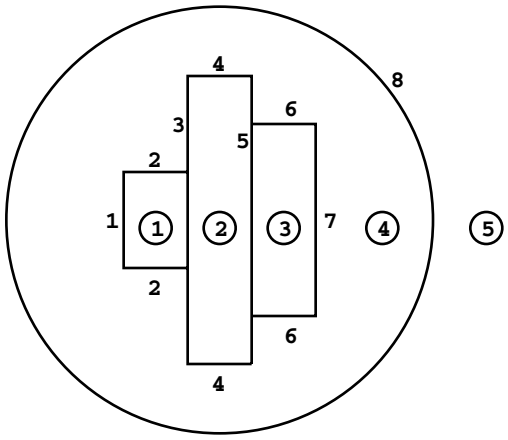


Figure 4-4.

In this example (Figure 4-4) all vertical lines are planes with their positive sides to the right and all horizontal lines are cylinders. Cells 1, 2, and 3 are simple; they are defined by 1 -2 -3, 3 −4 −5, and 5 −6 −7, respectively. Cell 4 is simple if the complement operator is used; it is #1 #2 #3 #5 or #1 #2 #3 −8. Cell 5 is also simple; it is no more than 8 (or verbally, everything in the world with a positive sense with respect to surface 8).

If cell 5 were defined as just #4, it would be incorrect. That says cell 5 is everything in the universe not in cell 4, which includes cells 1, 2, and 3. The specification #4 #1 #2 #3 is correct but should not be used because it tells MCNP that cell 5 is bounded by surfaces 1 through 7 in addition to surface 8. This will cause MCNP to run significantly more slowly than it should because any time a particle enters cell 5 or has a collision in it, the intersection of the particle's trajectory with each bounding surface has to be calculated.

Specifying cell 4 exclusively with the complement operator is very convenient and computationally efficient in this case. However, it will be instructive to set up cell 4 explicitly without complements. There are many different ways to specify cell 4; the following approach should not be considered to be *the* way.

First consider cell 4 to be everything outside the big cylinder of surface 4 that is bounded on each end by surfaces 1 and 7. This is specified by (−1:4:7). The parentheses are not necessary but may add clarity. Now all that remains is to add the corners outside cylinders 2 and 6. The corner outside cylinder 2 is (2 −3), whereas it is (5 6) outside cylinder 6. Again the parentheses are optional. These corners are then added to what we already have outside cylinder 4 to get

(−1:4:7):(2 −3):(5 6)

The region described so far does not include cells 1, 2, or 3 but extends to infinity in all directions. This region needs to be terminated at the spherical surface 8. In other words, cell 4 is everything we have defined so far that is also common with everything inside surface 8 (that is, everything so far intersected with −8). So as a final result,

((−1:4:7):(2 −3):(5 6)) −8

The inner parentheses can be removed, but the outer ones are necessary (remember the hierarchy of operations) to give us

(−1:4:7:2 −3:5 6) −8

If the outer parentheses are removed, the intersection of −8 will occur only with 5 and 6, an event that is clearly incorrect.

Example 5:

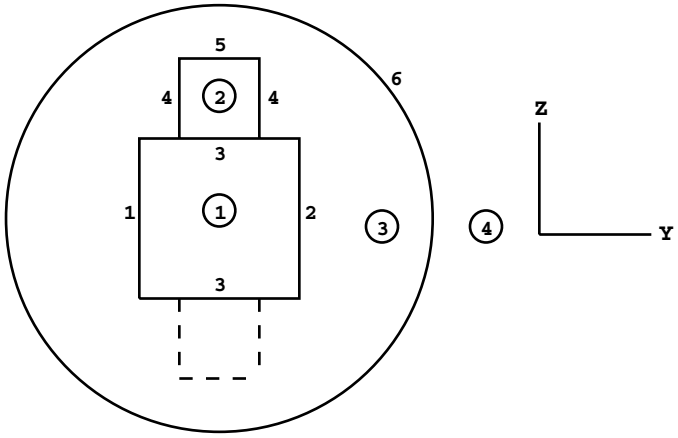


Figure 4-5.

This example (Figure 4-5) is similar to the previous one except that a vertical cylinder (surface 4) is added to one side of the horizontal cylinder (surface 3).

Cell 1 is (1 –3 –2), cell 3 is #1 #2 #4, and cell 4 is just 6.

Cell 2 is more than might initially meet the eye. It might appear to be simply (–5 –4 3), but this causes a mirror image of the cell 2 we want to show up on the bottom half of cell 1, as represented by the dashed lines in Figure 4-5. We need to add an ambiguity surface to keep cell 2 above the *y*-axis. Let surface 7 be an ambiguity surface that is a plane at $z = 0$. This surface appears in the MCNP input file as any other surface. Then cell 2 becomes (–5 –4 3 7) for the final result. You should convince yourself that the region above surface 7 intersected with the region defined by –5 –4 3 is cell 2 (do not even think of surface 7 as an ambiguity surface but just another surface defining some region in space). The mirror problem can also be avoided by defining cells 1 and 2 as right circular cylinder (rcc) macrobodies. The necessary cards for defining the macrobodies would be

```
1 rcc 0 -2 0   0 4 0 4

2 rcc 0 0 0   0 0 7   1
```

In this case cells 1, 2 and 3 would simply be (-1), (-2 1), and (1 2 -6) respectively. Notice that to get the interface between the cylinders correct, macrobody 2 extends into cell 1 and is then truncated by the definition of cell 1.

Example 6:

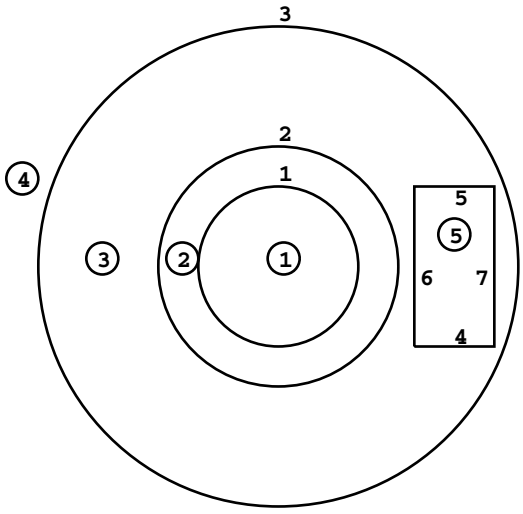


Figure 4-6.

Figure 4-6 contains three concentric spheres with a box cut out of cell 3. Surface 8 is the front of the box and 9 is the back of the box. The cell cards are

```
1     0   –1
2     0   –2   1
3     0   –3   2 (–4:5:–6:7:8:–9)      $ These parentheses are required.
4     0    3
5     0    4 –5 6 –7 –8 9
```

Cell 3 is everything inside surface 3 intersected with everything outside surface 2 but not in cell 5. Therefore, cell 3 could be written as

```
        3     0     –3  2  #(4 –5 6 –7 –8 9)
or      3     0     –3  2  #5
or      3     0     –3  2  (–4:5:–6:7:8:–9)
```

Cell 5 could also be specified using a RPP macrobody. The correct cell and surface cards for this would be

```
5     0    -4 $

4     rrp  2 4    7.5 8.5 -2 2
```

Example 7:

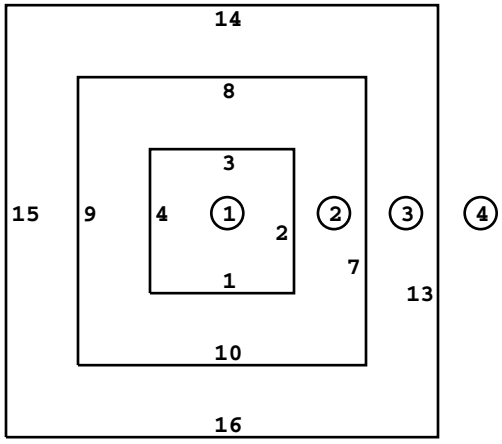


Figure 4-7.

Figure 4-7 contains three concentric boxes, a geometry very challenging to set up using only intersections, easier with unions, and almost trivial with the BOX macrobody. Surfaces 5, 11, and 17 are the back sides of the boxes (smaller to larger, respectively); 6, 12, and 18 are the fronts:

```
1    0   –2     –3      4     1       5      –6
2    0   –7     –8      9     10      11     –12
           (2  :  3  :  –4 :  –1   :  –5  :   6)
3    0   –13    –14     15    16      17     –18
           (7  :  8  :  –9 :  –10  :  –11 :   12)
4    0    13 :  14 :  –15:  –16  :  –17 :   18
```

Example 8:

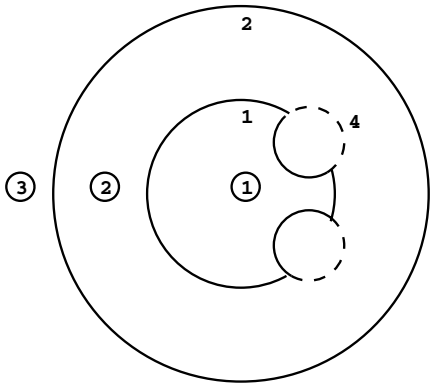


Figure 4-8.

Figure 4-8 contains two concentric spheres with a torus attached to cell 2 and cut out of cell 1:

```
1    0   –1     4
2    0   –2     (1 : –4)
3    0    2
```

If the torus were attached to cell 1 and cut out of cell 2, this bug-eyed geometry would be:

```
1    0   –1 : –4
2    0   –2    1   4
3    0    2
```

Example 9:

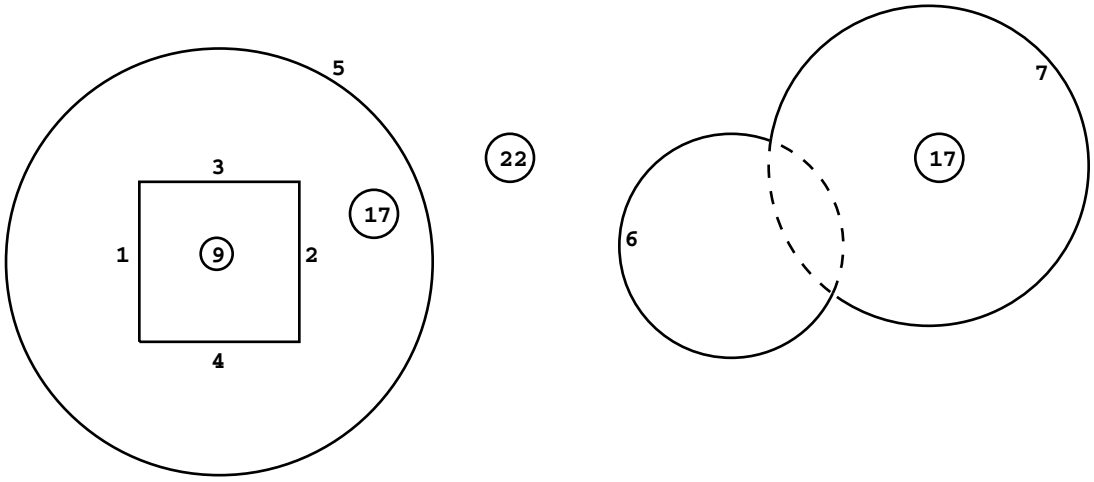


Figure 4-9.

Cell 9 in Figure 4-9 is a box cut out of the left part of spherical cell 17; surface 9 is the front of the box and 8 is the rear. Cell 17 is disconnected; the right part is the space interior to the spheres 6 and 7. An F4 tally in cell 17 would be the average flux in all parts of cell 17. An F2 surface tally on surface 7 would be the flux across only the solid portion of surface 7 in the figure. The cell specifications are:

```
 9   0   –3    –2   4   1   8   –9
17   0   –5    (3 : –4 : –1 : 2 : 9 : –8) : –6 : –7
22   0    5     6   7
```

A variation on this problem is for the right portion of cell 17 to be the intersection of the interiors of surfaces 6 and 7 (the region bounded by the dashed lines in Figure 4-9):

```
 9   0   –3   –2   4   1   8   –9
17   0   –5    (3 : –4 : –1 : 2 : 9 : –8) : –6   –7
22   0    5    (6 : 7)
```

Example 10:

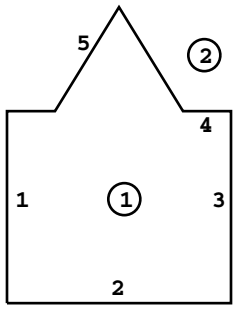


Figure 4-10.

Figure 4-10 contains a box with a cone sitting on top of it. Surface 6 is the front of the box and 7 is the rear. You should understand this example before going on to the next one.

```
1    0     1  2   –3  (-4  :  –5)   –6   7
2    0    –1 : –2 : 3 : 4  5 :  6 : –7
```

This problem could be simplified by replacing surfaces 1-6 with a BOX macrobody. The resulting cell and surface cards would be

```
c    cell cards
1    0     -8:(-5 8.5)
2    0     #1  $ or -8.4:-8.6:8.3:(8.5 5):8.1:-8.2

c    surface cards
5     kz  8 0.25 -1
8     box -2.5 -2.5 0   5 0 0   0 5 0  0 0 5
```

Example 11:

In this example (see Figure 4-11) surfaces 15 and 16 are cones, surface 17 is a sphere, and cell 2 is disconnected.

```
1    0   –1   2   3 (–4 : –16)   5   –6   (12 : 13 : –14)
             (10 : –9 : –11 : –7 : 8)   15
2    0   –10   9   11   7   –8   –1 : 2   –12   14   –6   –13   3
3    0   –17   (1 : –2 : –5 : 6 : –3 : –15 : 16   4)
4    0    17
```

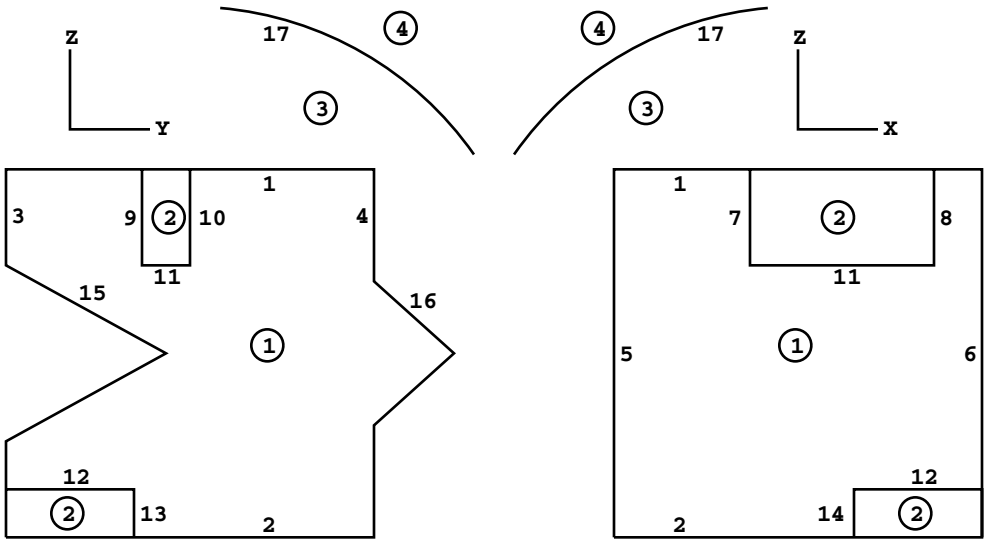


Figure 4-11.

Example 12:

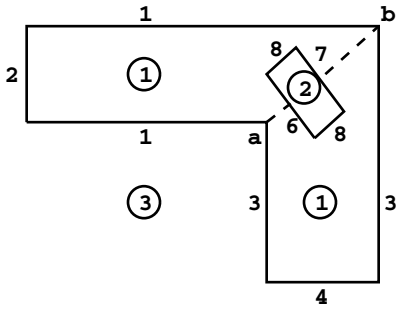


Figure 4-12.

In Figure 4-12, cell 1 consists of two cylinders joined at a 45° angle. Cell 2 is a disk consisting of a cylinder (surface 8) bounded by two planes. Surface 5 is a diagonal plane representing the intersection of the two cylinders. The problem is to specify the disk (cell 2) in one cell formed by the two cylinders (cell 1). A conflict arises in specifying cell 1 since, from the outside of cell 3, corner *a* between surfaces 1 and 3 is convex, but on the other side of the cell the same two surfaces form a concave corner at *b*. The dilemma is solved by composing cell 1 of two disconnected cells, each bounded by surface 5 between corners *a* and *b*. Surface 5 must be included in the list of surface cards in the MCNP input file. When the two parts are joined to make cell 1, surface 5 does not appear. Convince yourself by plotting it using an origin of 0 0 24 and basis vectors 0 1 1 0 –1 1. See Appendix B for an explanation of plotting commands.

```
1    0    (2 –1 –5 (7:8:–6)):(4 –3 5(–6:8:7))
2    0    –8  6 –7
3    0    (–2:1:5)(–4:3:–5)
```

A more efficient expression for cell 1 is

```
1     0    (2 –1 –5:4 –3 5)(–6:8:7)
```

Example 13:

This example (Figure 4-13) has the most complicated geometry so far, but it can be described very simply.

You can see that Example 13 is similar to Example 1. There is just a lot more of it.It is possible to set this geometry up by any of the ways mentioned in Example 1. However, going around the outer surfaces of the cells inside cell 10 is tedious. There is a problem of visualization and also the problem of coming up with undefined tunnels going off to infinity as in Example 1.

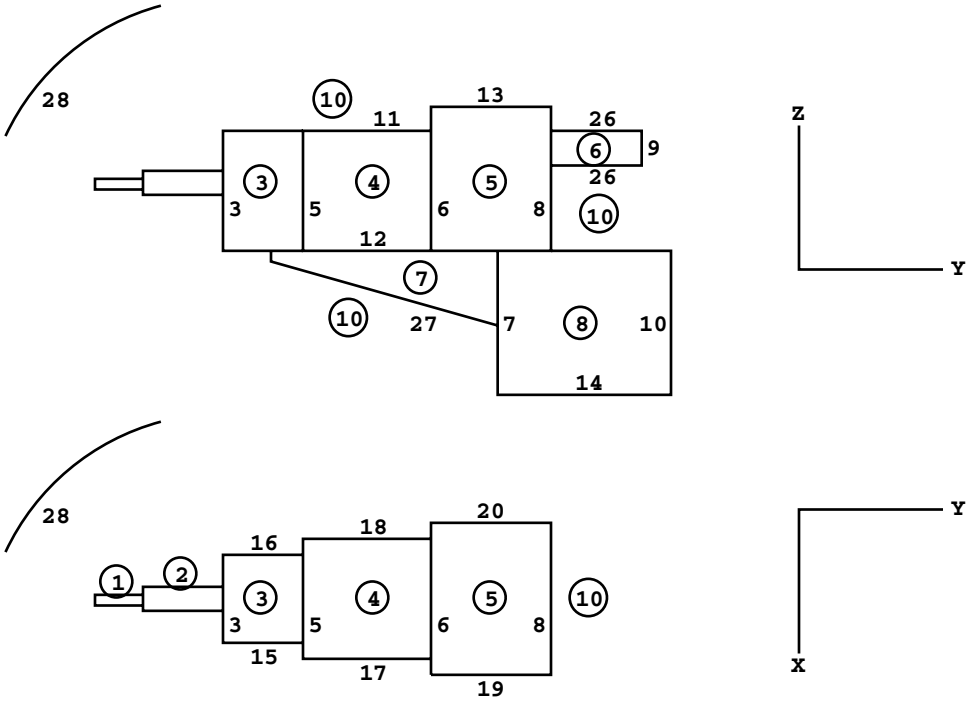


Figure 4-13.

The way to handle this geometry is by the last method in Example 1. Set up the cell/surface relations for each interior cell, then just take the complement for cell 10. For the interior cells,

```
1     0     1  –2  –23
2     0   –3  25   –24   2
3     0     3  –5   12  –15  16  –11
4     0     5  –6   12  –17  18  –11
5     0     6   –8  12  –13  –19  20
6     0     8   –9  –26
7     0   –12  4   –7  –27
```

```
8    0   –12  7  –10  14  –21   22
9    0    2  –3   –25
```

Cell 10 is surrounded by the spherical surface 28. Considering cell 10 to be everything outside cells 1 through 9 but inside surface 28, one can reverse the senses and replace all intersections with unions to produce

```
10   0   (–1:2:23)(3:–25:24:–2)
         (–3:5:–12:15:–16:11)
         (–5:6:–12:17:–18:11)
         (–6:8:–12:13:19:–20)
         (–8:9:26)(12:–4:7:27)
         (12:–7:10:–14:21:–22)
         (–2:3:25) –28
```

Note how easy cell 10 becomes when the complement operator is used:

```
10   0  #1 #2 #3 #4 #5 #6 #7 #8 #9 –28
```

Once again this example can be greatly simplified by replacing all but cell 7 with macrobodies. However the definition of cell 7 must then be changed to use the facets of the surrounding macrobodies instead of surfaces 12 and 7. The facets of macrobodies can be visualized using the MBODY OFF option of the geometry plotter.

Example 14:

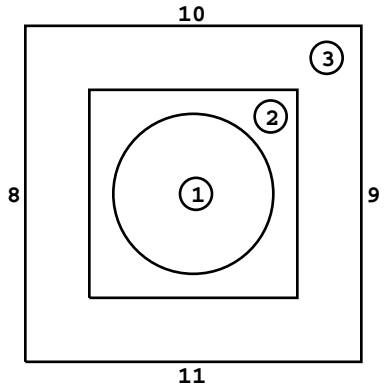


Figure 4-14.

Figure 4-14 illustrates some necessary conditions for volume and area calculations. The geometry has three cells, an outer cube, an inner cube, and a sphere at the center. If cell 3 is described as

```
3    0   8  –9  –10  11  –12  13  #2  #1
```

(and #1 must be included to be correct), the volume of cell 3 cannot be calculated. As described, it is not bounded by all planes so it is not a polyhedron, nor is it rotationally symmetric. If cell 3 is described by listing all 12 bounding surfaces explicitly, the volume can be calculated.

II. COORDINATE TRANSFORMATIONS

In most problems, the surface transformation feature of the TRn card will be used with the default value of 1 for M. When $M = 1$ applies, most of the geometry can be set up easily in an (x,y,z) coordinate system and only a small part of the total geometry will be difficult to specify. For example, a box with sides parallel to the (x,y,z) coordinate system is simple to describe, but inside might be a tilted object consisting of a cylinder bounded by two planes. Since the axis of the cylinder is neither parallel to nor on the x, y, or z axis, a general quadratic must be used to describe the surface of the cylinder. The GQ surface card has 10 entries that are usually difficult to determine. On the other hand, it is simple to specify the entries for the surface card for a cylinder centered on the y-axis. Therefore, we define an auxiliary coordinate system (x',y',z') so the axis of the cylinder is one of the primed axes, y' for example. Now we will use the TRn card to describe the relationship between one coordinate system and the other. $M = 1$ requires that the coordinates of a vector from the (x,y,z) origin to the (x',y',z') origin be given in terms of (x,y,z).

Only in rare instances will $M = -1$ be needed. Some unusual circumstances may require that a small item of the geometry must be described in a certain system which we will call (x,y,z), and the remainder of the surfaces would be easily described in an auxiliary system (x',y',z'). The O_i entries on the TRn card are then the coordinates of a vector from the (x',y',z') origin to the (x,y,z) origin given in terms of the primed system.

Example 1:

The following example consists of a can whose axis is in the yz plane and is tilted 30° from the y-axis and whose center is at (0,10,15) in the (x,y,z) coordinate system. The can is bounded by two planes and a cylinder, as shown in Figure 4-15.

The surface cards that describe the can in the simple (x',y',z') system are:

```
1    1    CY   4
2    1    PY  –7
3    1    PY   7
```

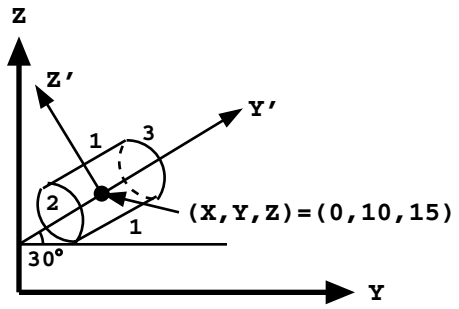


Figure 4-15.

The 1 before the surface mnemonics on the cards is the *n* that identifies which TRn card is to be associated with these surface cards. The TRn card indicates the relationship of the primed coordinate system to the basic coordinate system.

We will specify the origin vector as the location of the origin of the (x',y',z') coordinate system with respect to the (x,y,z) system; therefore, $M = 1$. Since we wanted the center of the cylinder at (0,10,15), the O_i entries are simply 0 10 15. If, however, we had wanted surface 2 to be located at (x,y,z) = (0,10,15), a different set of surface cards would accomplish it. If surface 2 were at $y' = 0$ and surface 3 at $y' = 14$ the O_i entries would remain the same. The significant fact to remember about the origin vector entries is that they describe one *origin* with respect to the other *origin*. The user must locate the surfaces about the auxiliary origin so that they will be properly located in the main coordinate system.

The B_i entries on the TRn card are the cosines of the angles between the axes as listed on page 3–30 in Chapter 3. In this example, the x-axis is parallel to the x'-axis. Therefore, the cosine of the angle between them is 1. The angle between y and x' is 90° with a cosine of 0. The angle between z and x', and also between x and y', is 90° with a cosine of 0. The angle between y and y' is 30° with a cosine of 0.866. The angle between z and y' is 60° with 0.5 the cosine. Similarly, 90° is between x and z'; 120° is between y and z'; and 30° is between z and z'. The complete TRn card is

```
TR1   0   10  15   1  0  0    0  .866  .5    0  −.5  .866
```

An asterisk preceding TRn indicates that the B_i entries are the angles in degrees between the appropriate axes. The entries using the ∗TRn mnemonic are

```
∗TR1  0  10  15    0  90  90    90  30  60    90  120  30
```

The default value of 1 for *M*, the thirteenth entry, has been used and is not explicitly specified.

The user need not enter values for all of the B_i. As shown on Chapter 3 page 3–30, B_i may be specified in any of five patterns. Pattern #1 was used above, but the simplest form for this example is pattern #4 since all the skew surfaces are surfaces of revolution about some axis. The complete input card then becomes

```
∗TR1   0  10  15    3J     90  30  60
```

Example 2:

The following example illustrates another use of the TRn card. The first part of the example uses the TR1 card and an $M = 1$ transformation; the second part with the TR2 card uses an $M = -1$ transformation. Both parts and transformations are used in the following input file.

```
EXAMPLE OF SURFACE TRANSFORMATIONS
    2     0         −4   3   −5
    6     0         −14   −13 : −15   41   −42

    3     1      PX     −14
    4     1      X      −14  10  0   12  14  10
    5     1      PX      14
```

```
13   2     SX   −15   70
14   2     CX    30
15   2     Y     75   0   30   16
41   2     PY    0
42   2     PY    75

TR1      20  31  37   .223954  .358401  .906308
TR2      −250  −100  −65   .675849  .669131  .309017
         J   J   .918650   J   J   −.246152   −1
```

A. TR1 and M = 1 Case

Cell 2 is bounded by the plane surfaces 3 and 5 and the spheroid surface 4, which is a surface of revolution about the skew axis x' in Figure 4-16.

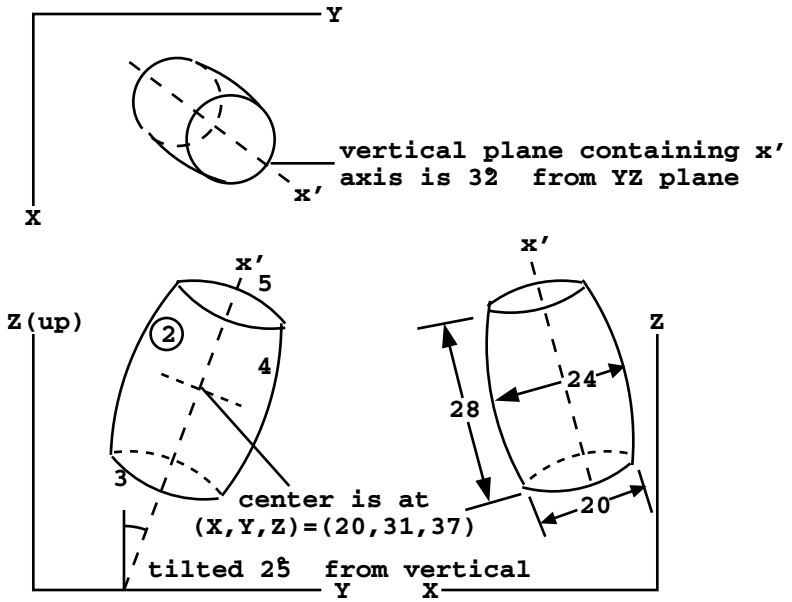


Figure 4-16.

To get the coefficients of surfaces 3, 4, and 5, define the x'-axis as shown in the drawings (since the surfaces are surfaces of revolution about the x'-axis, the orientation of the y'- and z'-axes does not matter), then set up cell 2 and its surfaces, with coefficients defined in the $x'y'z'$ coordinate system.

On the TR1 card, the origin vector is the location of the origin of the $x'y'z'$ coordinate system with respect to the main xyz system of the problem. The pattern #4 in Chapter 3 (page 3–31) is appropriate since the surfaces are all surfaces of revolution about the x'-axis. The components of one vector of the transformation matrix are the cosines of the angles between x' and the x, y, and z axes. They are obtained from spherical trigonometry as shown in Figure 4-17.

cos E = cos 58˚ x sin 25˚ = .223954
cos F = cos 32˚ x sin 25˚ = .358401
cos G = cos 25˚ = .906308

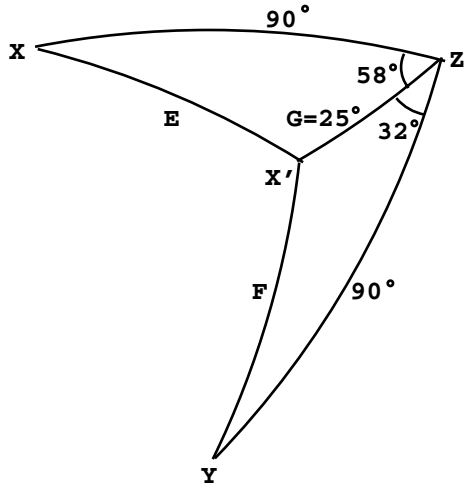


Figure 4-17.

B. TR2 and M = –1 Case

Cell 6 is the union of a can bounded by spherical surface 13 and cylindrical surface 14, and a conical piece bounded by conical surface 15 and ambiguity surfaces 41 and 42, which are planes. (Surface 42 is required because when surface 15 is defined in $x'y'z'$ it is as a type Y surface, which becomes a cone of one sheet; when it is transformed into the xyz system it becomes a type GQ surface, which in this case is a cone of two sheets. This may seem weird, but that's the way it has to be.) Surfaces 13 and 14 are surfaces of revolution about one axis, and surfaces 15, 41, and 42 are surfaces of revolution about an axis perpendicular to the first axis. Both axes are skewed with respect to the xyz coordinate system of the rest of the geometry.

Define the auxiliary $x'y'z'$ coordinate system as shown in Figure 4-18. Set up cell 6 with its surfaces specified in the $x'y'z'$ coordinate system as part of the input file and add a second transformation card, TR2.

Because the location of the origin of the xyz coordinate system is known relative to the $x'y'z'$ system (rather than the other way around, as in the first part of the example), it is necessary to use the reverse mapping. This is indicated by setting $M = -1$. In this reverse mapping the origin vector (–250,–100,–65) is the location of the origin of the xyz system with respect to the $x'y'z'$ system. For the components of the transformation matrix, pattern #3 out of the four possible choices from Chapter 3 is most convenient here. The xyz components of z' and the $x'y'z'$ components of z are easy to get, while the components of x and of y are not. The whole transformation matrix is shown here

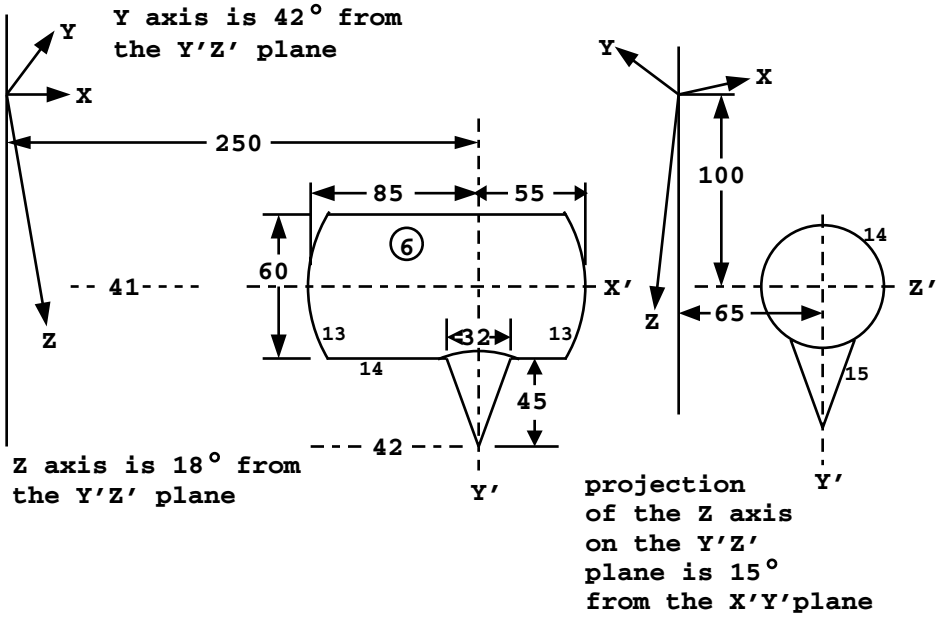


Figure 4-18.

with the components that are obtained from Figure 4-18 written in:

	x	y	z
x'	.675849	cos 48° = .669131	cos 72° = .309017
y'			cos 15° × cos 18° = .918650
z'			–.246152

The zz' component is –SQRT(1. – .309107**2 – .918650**2) = –.246152, and the xx' component is SQRT(1. – .669131**2 – .309017**2) = .675849, with the signs determined by inspection of the figure.

III. REPEATED STRUCTURE AND LATTICE EXAMPLES

Example 1:

This example illustrates the use of transformations with simple repeated structures. The geometry consists of a sphere enclosing two boxes that each contain a cylindrical can.

```
simple repeated structures
1   0   -27 #2 #5                imp:n=1
2   0   1 -2 -3 4 -5 6  fill=1 imp:n=1
3   0   -10 -11 12       u=1     imp:n=1
4   0   #3               u=1     imp:n=1
5   like 2 but trcl=3
```

```
7   0   27                          imp:n=0

1    px  -3
2    px   3
3    py   3
4    py   -3
5    pz   4.7
6    pz   -4.7
10   cz   1
11   pz   4.5
12   pz   -4.5
27   s     3.5 3.5 0 11

sdef pos 3.5 3.5 0
f2:n 1
tr3* 7 7 0  40 130 90  50 40 90  90 90 0
nps  10000
```

The geometric structure of this example can be displayed using the plot feature in MCNP. Specifically, Figure 4-19 can be obtained by typing:

b 1 0 0 0 1 0 ex 11 or 3.5 3.5 0

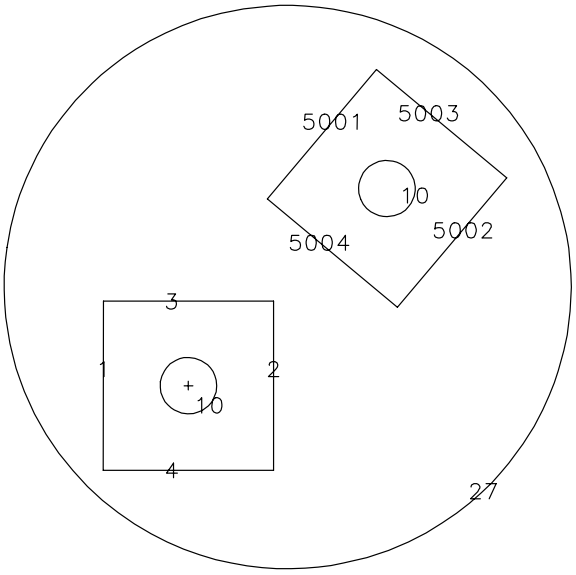


Figure 4-19.

Cell 2 is filled by universe 1. Two cells are in universe 1—the cylindrical can, cell 3, and the space outside the can, cell 4. Cell 2 is defined and the LIKE m BUT card duplicates the structure at another location. The TRCL entry identifies a TRn card that defines the displacement and rotational axis transformation for cell 5.

Example 2:

This example illustrates the LIKE m BUT construct, the FILL card, the U card, two forms of the TRCL card, and a multiple source cell definition.

```
 chapter 4 example 2
 1    1 -.5   -7 #2 #3 #4 #5 #6  imp:n=1
 2    0 1 -2 -3 4 5 -6 imp:n=2 trcl=2 fill=1
 3    like 2 but trcl=3
 4    like 2 but trcl=4
 5    like 2 but trcl=5  imp:n=1
 6    like 2 but trcl=6
 7    0 7 imp:n=0
 8    0 8 -9 -10 11 imp:n=1 trcl=(-.9 .9 0) fill=2 u=1
 9    like 8 but trcl=(.9 .9 0)
10    like 8 but trcl=(.1 -.9 0)
11    2 -18 #8 #9 #10 imp:n=1 u=1
12    2 -18 -12 imp:n=1 trcl=(-.3 .3 0) u=2
13    like 12 but trcl=(.3 .3 0)
14    like 12 but trcl=(.3 -.3 0)
15    like 12 but trcl=(-.3 -.3 0)
16    1 -.5 #12 #13 #14 #15 u=2 imp:n=1

 1    px -2
 2    py 2
 3    px 2
 4    py -2
 5    pz -2
 6    pz 2
 7    so 15
 8    px -.7
 9    py  .7
10    px  .7
11    py -.7
12    cz  .1

 sdef  erg=d1 cel=d2:d3:0 rad=d5 ext=d6 axs=0 0 1 pos=d7
#      si1  sp1  sb1
        1    0    0
        3   .22  .05
        4   .08  .05
        5   .25  .1
        6   .18  .1
        7   .07  .2
        8   .1   .2
        9   .05  .1
       11   .05  .2
si2    L 2 3 4 5 6
sp2      1 1 1 1 1
```

```
 si3   L 8 9 10
 sp3     1 1 1
 si5   0 .1
 sp5   -21 1
 si6   -2 2
 sp6   0 1
 si7   L .3 .3 0 .3 -.3 0 -.3 .3 0 -.3 -.3 0
 sp7        1          1          1        1
  m1   6000 1
  m2   92235 1
drxs
 tr2   -6 7 1.2
 tr3    7 6 1.1
 tr4    8 -5 1.4
tr5*   -1 -4 1 40 130 90 50 40 90 90 90 0
 tr6   -9 -2 1.3
f4:n   2 3 4 5 6 12 13 14 15
  e4   1 3 5 7 9 11 13
 sd4   5j 1.8849555921 3r
  fq   f e
cut:n  1e20 .1
 nps   100000
print
```

Cell 2 could be replaced with an RPP macrobody that can then be replicated and translated identically to cell 2 above.

Figure 4-20 can be displayed by typing:

```
1  0  0    0  1  0    ex  21    la  0
```

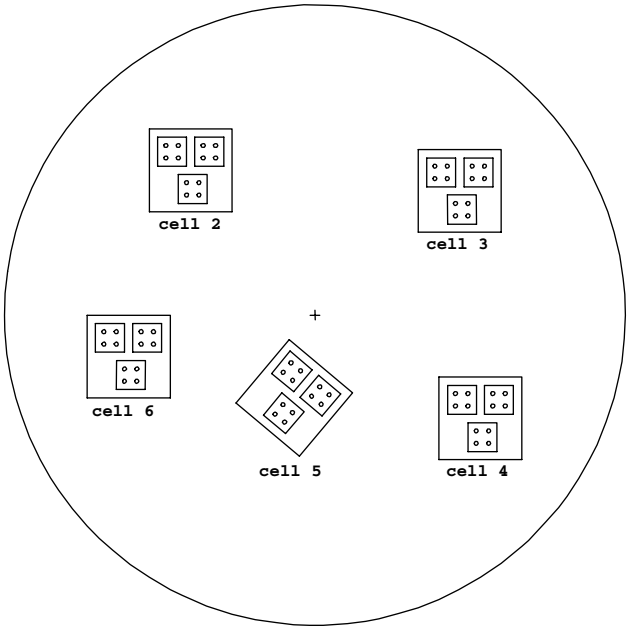


Figure 4-20.

Figure 4-20 shows five cells, numbers 2 through 6, identical except for their locations. Cell 2 is described fully and the other four are declared to be like cell 2 but in different locations. Cell 2 is defined in an auxiliary coordinate system that is centered in the cell for convenience. That coordinate system is related to the main coordinate system of the problem by transformation number 2, as declared by the TRCL = 2 entry and the TR2 card. Cells 2 through 6 are all filled with universe number 1. Because no transformation is indicated for that filling, universe 1 inherits the transformation of each cell that it fills, thereby establishing its origin in the center of each of those five cells.

As shown in Figure 4-21, universe 1 contains three infinitely long square tubes embedded in cell 11, which is unbounded. All four of these infinitely large cells are truncated by the bounding surfaces of each cell that is filled by universe 1, thus making them effectively finite. The transformations that define the locations of cells 8, 9 and 10 are entered directly on the cell cards after the TRCL symbol rather than indirectly through TR cards as was done for cells 2 through 6 to illustrate the two possible ways of performing transformations. Cells 8, 9 and 10 are each filled with universe 2, which consists of five infinite cells that are truncated by the boundaries of higher level cells. The simplicity and lack of repetition in this example were achieved by careful choice

of the auxiliary coordinate systems at all levels. All of the location information is contained in just a few TRCL entries, some direct and some pointing to a few TR cards.

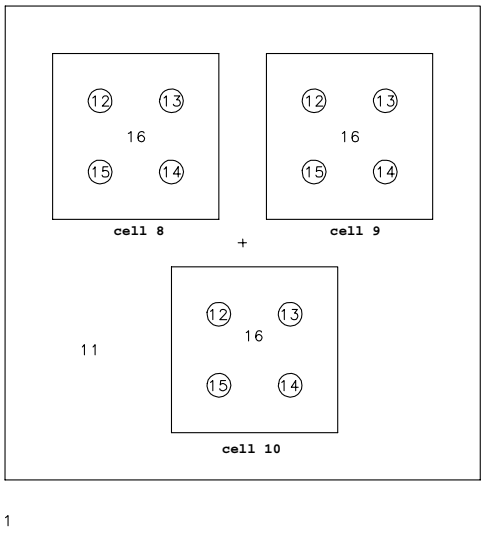


Figure 4-21.

The source definition is given on the SDEF, SIn, and SPn cards. The source desired is a cylindrical volume distribution, equally probable in all the cylindrical rods. The energies are given by distribution 1. The entry for CEL shows that level 0 cells are given by distribution 2 and level 1 cells by distribution 3. The zero means that cells are searched for at level 2 and also that the sampled position and direction will apply to the universe indicated by the entry just preceding the first entry that is ≤ 0. In this case the position and direction will be defined in the coordinate system of the cell sampled by distribution 3 at level 1. The SI2 card lists all the cells at level 0 that will contain the source. SP2 indicates equally probable source distributions. SI3 lists the cells in level 1, and the positions on the SI7 card are given in the coordinates of this level. A cylindrical volume distribution is specified by RAD, EXT, AXS, and POS. The cylinder is centered about the origin, with a radius of 0.1 (SI5) and a length of 4 (SI6, from -2 to 2). The four sets of entries on the SI7 card are the origins of the four cylinders of cells 12–15. These parameters describe exactly the four cells 12–15.

Example 3:

This is a simple example illustrating the use of the FILL, U, and LAT cards to create an object within several cells of a lattice. A cylinder contains a square lattice, and the cells in the inner 3x3 array of that lattice each contain a small cylinder.

```
simple lattice
 1    0 -1 fill=1 imp:n=1
 2    0 -301 302 -303 304 lat=1 u=1 imp:n=1 fill=-2:2 -2:2 0:0
      1 1 1 1 1 1 2 2 2 1 1 2 2 2 1 1 2 2 2 1 1 1 1 1 1
 3    0 -10 u=2 imp:n=1
 4    0 #3 imp:n=1 u=2
```

```
     5    0 1 imp:n=0

     1    cz 45
    10    cz 8
   301    px 10
   302    px -10
   303    py 10
   304    py -10
```

The resulting geometry is shown in Figure 4-22. Cell 1 is the interior of the cylinder, and cell 5 is everything outside (all surfaces are infinite in the *z*-direction). Cell 1 is filled by universe 1. Cell 2 is defined to be in universe 1. Surfaces 301-304 define the dimensions of the square lattice:

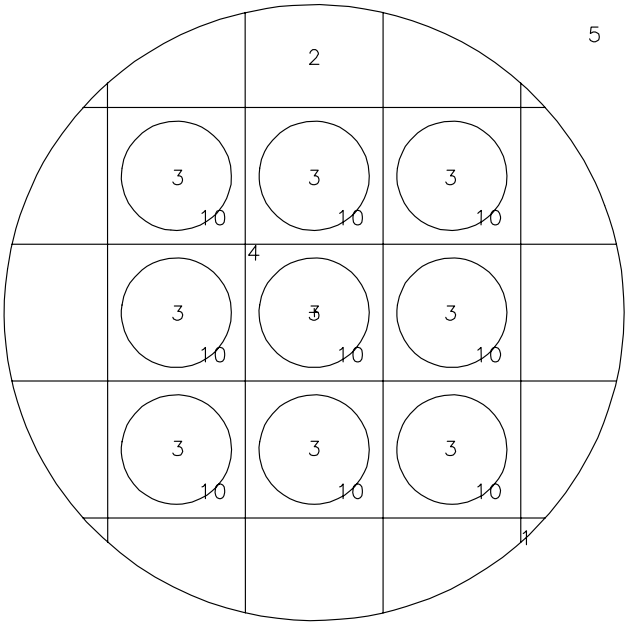


Figure 4-22.

When filling the cells of a lattice, all visible cells, even those only partially visible, must be specified by the FILL card. In this case, the "window" created by the cylinder reveals portions of 25 cells (5x5 array). A FILL card with indices of –2 to 2 in the *x*- and *y*-directions will place the [0,0,0] element at the center of the array. Universe 2, described by cells 3 and 4, is the interior and exterior, respectively, of an infinite cylinder of radius 8 cm. The cells in universe 1 not filled by universe 2 are filled by universe 1, so in effect they are filled by themselves.

Example 4:

This example illustrates a lattice geometry and uses the FILL entries followed by transformations, universes, and lattices.

```
example 4
   1   1 -.6 -1  imp:n=1
   2   0 1 -2 -4 fill=1 (-6 -6.5 0)  imp:n=1
   3   0 2 -3 -4 *fill=2 (-7 5 0 30 60 90 120 30 90)  imp:n=1
   4   0 2 3 -4 *fill=2 (4 8 0 15 105 90 75 15 90)  imp:n=1
   5   0 4  imp:n=1
   6   0 -5 6 -7 8 -9 10 fill=3 u=1 lat=1  imp:n=1
   7   3 -2.7 -11 12 -13 14 -15 16 u=2 lat=1  imp:n=1
   8   2 -.8 -17  u=3
   9   0 17  u=3

   1   sy -5 3
   2   py 0
   3   px 0
   4   so 15
   5   px 1.5
   6   px -1.5
   7   py 1
   8   py -1
   9   pz 3
  10   pz -3
  11   p 1 -.5 0 1.3
  12   p 1 -.5 0 -1.3
  13   py .5
  14   py -.5
  15   pz 3
  16   pz -3
  17   sq 1 2 0 0 0 0 -1 .2 0 0

sdef   pos 0 -5 0 erg d1 rad d2
 si1   0 10
 sp1   0 1
 si2   3
 sp2   -21
  e0   1 2 3 4 5 6 7 8 9 10 11 12
f2:n   3
 sd2   1
f4:n   8 9
 sd4   1 1
  m1   4009 1
  m2   6000 1
  m3   13027 1
```

```
  nps 100000
print
dbcn  0 0 1 4
```

The geometry for this example is shown in Figure 4-23.

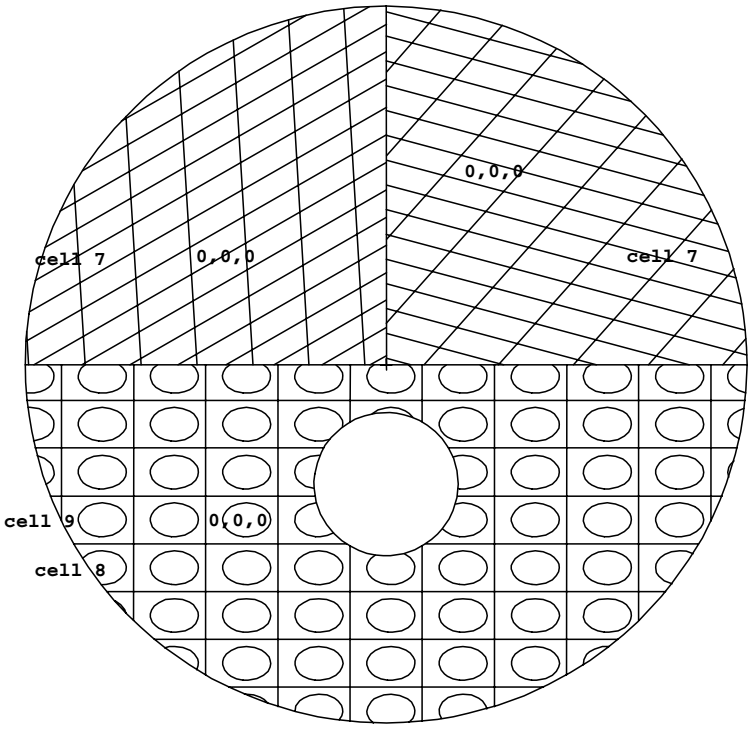


Figure 4-23.

Cell 2 is the bottom half of the large sphere outside the small sphere (cell 1) and is filled by universe 1. The transformation between the filled cell and the filling universe immediately follows in parentheses.

Cell 6 describes a hexahedral lattice cell (LAT=1) and, by the order of specification of its surfaces, also describes the order of the lattice elements. The (0,0,0) element has its center at (-6,-6.5,0), according to the transformation information on the card for cell 2. Element (1,0,0) is beyond surface 5, element (–1,0,0) is beyond surface 6, element (0,1,0) is beyond surface 7, etc. Cell 6 is filled by universe 3, which consists of two cells: cell 8 inside the ellipsoid and cell 9 outside it.

Alternatively, cell 6 could have been defined using a macrobody, either RPP or BOX. When a lattice cell is defined with a macrobody, some of the lattice-element indexing is predetermined. For example, the first, third and fifth facets are used to define the direction of increasing indices. For the RPP, the second index increases in the positive *y* direction and the third index increases in the positive *z*-direction. For the BOX, the order of defining the three vectors will determine the axis each index will increase in a positive direction.

Cell 3 is the top left-hand quarter of the sphere; cell 4 is the top right-hand quarter. Both are filled by universe 2. Both FILL entries are followed by a transformation. The inter-origin vector portion of the transformation is between the origin of the filled cell and the origin of the filling universe, with the universe considered to be in the auxiliary coordinate system. The (0,0,0) lattice element is located around the auxiliary origin and the lattice elements are identified by the ordering of the surfaces describing cell 7. The skewed appearance is caused by the rotation part of the transformation.

The source is centered at (0,–5,0) (i.e., at the center of cell 1). It is a volumetric source filling cell 1, and the probability of a particle being emitted at a given radius is given by the power law function. For RAD the exponent defaults to 2, so the probability increases as the square of the radius, resulting in a uniform volumetric distribution.

Example 5:

This example illustrates a more complicated lattice geometry and uses the FILL card followed by the array specification. It builds on the expertise from example 4.

```
example 5
   1     1 -.6 -5 imp:n=1
   2     0 -1 2 -3 4 5 -22 23 imp:n=1  fill=1
   3     0 1:-2:3:-4:22:-23 imp:n=0
   4     2 -.8 -6 7 -8 9 imp:n=1  lat=1  u=1
         fill=-2:2  -4:4  0:0   1 1 1 1 1   1 1 1 2(3) 1   1 3 1 1 1
         1 2 3 2 1    1 1 1 1 1    1 4(2) 2 1 1    1 1 3 4(1) 1
         1 2 3 1 1    1 1 1 1 1
   5     3 -.5 -11 10 12 imp:n=1  u=2
   6     4 -.4 11:-10:-12 imp:n=1  u=2
   7     0 -13 imp:n=1  u=3  fill=5
   8     3 -.5 13 imp:n=1  u=3
   9     4 -.4 -14 15 -16 17  imp:n=1  lat=1  u=5
  10     3 -.5 -18 19 -20 21  imp:n=1  u=4
  11     4 -.4 18:-19:20:-21  imp:n=1  u=4

   1     px  15
   2     px -15
   3     py  15
   4     py -15
   5     s   7 2.1 0 3.5
   6     px  4
   7     px -5
   8     py  2
   9      py -2
  10     p  .7 -.7 0 -2.5
  11     p  .6 .8 0 .5
  12     py -1
  13     x -4.5 0 -.5 1.7 3.5 0
  14     px  1.6
```

```
     15     px -1.4
     16     py  1
     17     py -1.2
     18     px  3
     19     px -3
     20     py  .5
     21     py -.6
     22     pz  6
     23     pz -7

   sdef     erg d1  pos 7 2 0  cel=1  rad d2
    si2     3.6
    si1     0 10
    sp1     0 1
   f4:n     10
     e4     1 3 5 7 9 11
     m1     4009 1
     m2     6000 1
     m3     13027 1
     m4     1001 2 8016 1
    nps     100000
   dbcn     0 0 1 4
   *tr      0 0 0 10 80 90 100 10 90
   *tr2     1 0 0 2 88 90 92 2 90
   tr3      3 0 0
   vol      1 10r
   print
```

This example has three “main” cells: cell 1 is inside surface 5, cell 3 is the outside world, and cell 2 is the large square (excluding cell 1) that is filled with a lattice, some of whose elements are filled with three different universes. A schematic of the geometry is given in Figure 4-24.

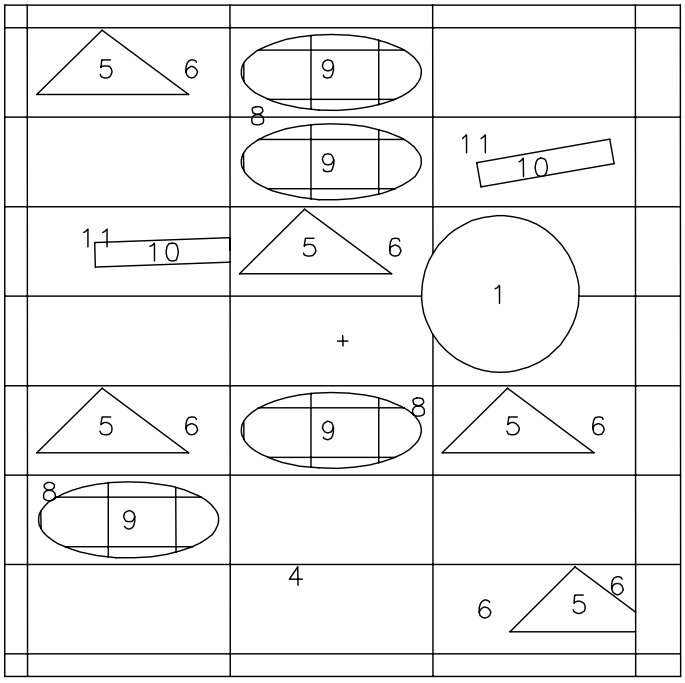


Figure 4-24.

Universe 1 is a hexahedral lattice cell infinite in the *z* direction. Based on the FILL parameters, it can be seen that the lattice has five elements in the first direction numbered from -2 to 2, nine elements in the second direction numbered from -4 to 4, and one element in the third direction. The remaining entries on the card are the array that identifies which universe is in each element, starting in the lower left-hand corner with (-2,-4,0), (-1,-4,0), (0,-4,0), etc. An array entry (in this case 1) that is the same as the number of the universe of the lattice itself means that element is filled by the material specified for the lattice cell. Element (1,-3,0) is filled by universe 2, which is located within the element in accordance with the transformation defined on the TR3 card. Element (-1,-2,0) is filled by universe 3. Cell 7, part of universe 3, is filled by universe 5, which is also a lattice. Note the use of the X parameter to describe surface 13. The quadratic surface, which is symmetric about the *x*-axis, is defined by specifying three coordinate pairs on the surface.

The source is a volumetric source of radius 3.6 which is centered in and completely surrounds cell 1. CEL rejection is used to sample uniformly throughout the cell. That is, the source is sampled uniformly in volume and any points outside cell 1 are rejected. The same effect could have been achieved using cookie-cutter rejection. The PRINT card results in a full output print, and the VOL card sets the volumes of all the cells to unity.

Example 6:

This example primarily illustrates a fairly complex source description in a lattice geometry. The geometry consists of two "main" cells, each filled with a different lattice.

```
 example 6
1    0  1:-3:-4:5:6:-7  imp:n=0
2    0 -2 3 4 -5 -6 7  imp:n=1  fill=1 (-25 0 0)
3    0 -1 2 4 -5 -6 7  imp:n=1  fill=2 (0 -20 0)
4    0 -11 12 -14 13 imp:n=1 lat=1 u=1 fill=-1:1 -1:1 0:0 3 8r
5    0 -15 2  -18 17 imp:n=1 lat=1 u=2
     fill=0:1 0:3 0:0 4 4 4(5 0 0) 4 4 5 4 4
6    1 -.9  21:-22:-23:24  imp:n=1  u=3
7    1 -.9  19  imp:n=1  u=4
8    2 -18 -21 22 23 -24  imp:n=1  u=3
9    1 -.9  20(31:-32:-33:34)  imp:n=1  u=5
11   2 -18 -19  imp:n=1  u=4
13   2 -18 -20  imp:n=1  u=5
15   2 -18 -31 32 33 -34  imp:n=1  u=5

1    px 50
2    px 0
3    px -50
4    py -20
5    py 20
6    pz 60
7    pz -60
11   px 8.334
12   px -8.334
13   py -6.67
14   py 6.67
15   px 25
17   py 0
18   py 10
19   c/z 10 5 3
20   c/z 10 5 3
21   px 4
22   px -4
23   py -3
24   py 3
31   px 20
32   px 16
33   py 3
34   py 6

m1   6000 .4  8016 .2  11023 .2  29000 .2
m2   92238 .98  92235 .02
sdef erg fcel d1  cel d6  x fcel d11  y fcel d13  z fcel d15
     rad fcel d17  ext fcel d19  pos fcel d21  axs fcel d23
```

```
ds1   s d2 d3 d4 d5
sp2   -2 1.2
sp3   -2 1.3
sp4   -2 1.4
sp5   -2 1.42
si6   s d7 d8 d9 d10
sp6   .65 .2 .1 .05
si7   l 2:4:8
sp7   1
si8   l 3:5(0 0 0):11 3:5(1 0 0):11 3:5(0 1 0):11 3:5(1 1 0):11
      3:5(0 2 0):11 3:5(0 3 0):11 3:5(1 3 0):11
sp8   1 1 1 1 1 1 1
si9   l 3:5(1 2 0):13
sp9   1
si10  l 3:5(1 2 0):15
sp10  1
ds11  s d12 0 0 d25
si12  -4 4
sp12  0 1
ds13  s d14 0 0 d26
si14  -3 3
sp14  0 1
ds15  s d16 0 0 d16
si16  -60 60
sp16  0 1
ds17  s 0 d18 d18 0
si18  0 3
sp18  -21 1
ds19  s 0 d20 d20 0
si20  -60 60
sp20  0 1
ds21  s 0 d22 d22 0
si22  l 10 5 0
sp22  1
ds23  s 0 d24 d24 0
si24  l 0 0 1
sp24  1
si25  16 20
sp25  0 1
si26  3 6
sp26  0 1
f2:n  1
e2    .1 1 20
f6:n  2 4 6 8   3 5 7 9 11 13 15
sd6   1 1 1 1   1 1 1 1  1  1  1
print
nps   5000
```

The geometry for this example is shown in Figure 4-25.

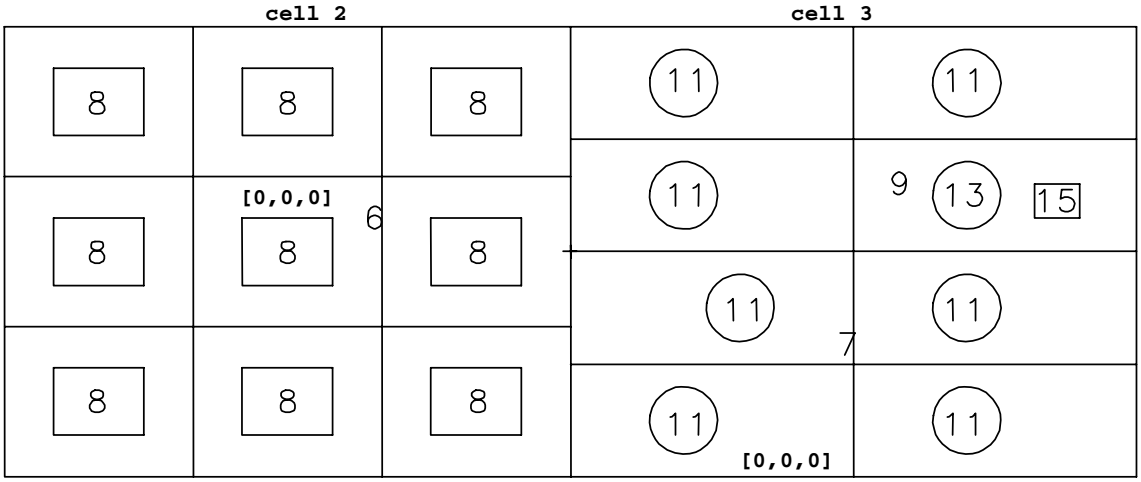


Figure 4-25.

Cell 2, the left half of Figure 4-25, is filled with a hexahedral lattice, which is in turn filled with a universe consisting of a rectangular cell and a surrounding cell. The relation of the origin of the filling universe, universe 1, to the filled cell, cell 2, is given by the transformation in parentheses following FILL=1. Cell 3, the right half, is filled with a different hexahedral lattice, in turn filled by universes 4 and 5. Lattice cells must be completely specified by an expanded FILL card if the lattice contains a source (cell 5) or by selecting a coordinate system of a higher level universe (SI7 1 –2:4:8). Print table 110 lists the lattice elements that are being sampled.

The reader is cautioned to become familiar with the geometry before continuing with the source description that follows. In this example, a distributed volumetric source located in each of the ten boxes and eight circles (in two dimensions) is desired. The cells involved are given by distribution 6. The S on the SI6 card indicates distribution numbers will follow. The four distributions will describe the cells further. The probabilities for choosing each distribution of cells are given by the SP6 card.

The SI7 card shows the entire path from level 0 to level *n* for the nine boxes on the left. The expanded FILL notation is used on the cell 4 card to describe which elements of the lattice exist and which universe fills each one. All nine are filled by universe 3. SI12 indicates that *x* is sampled from -4 to 4, and SI14 indicates that *y* is sampled from –3 to 3. Used together with the expanded FILL notation, source points will be sampled from all nine lattice elements. Without the expanded FILL notation, only the [0,0,0] element would have source points.

Another method would be to use the following input cards:

```
4      0 -11 12 -14 13  imp:n=1  lat=1  u=1 fill=3
si7    1 -2:4:8
si12   -46 -4
si14   -17 17
```

The minus sign in front of the second entry on the SI7 card means that the sampled position and direction will be in the coordinate system of the level preceding that entry. In this case, however, there is no preceding entry, so the position and direction will be in the coordinate system of cell 2. If a point is chosen that is not is cell 8, it is rejected and the variable is resampled.

SI8 describes a path from cell 3 through element (0,0,0) of cell 5 to cell 11, from cell 3 through element (1,0,0) of cell 5 to cell 11, etc. Element (1,2,0) is skipped over and will be treated differently. SI9 is the path to cell 13, the circle in element (1,2,0), and SI10 is the path to cell 15, the box in element (1,2,0). All the other source variables are given as a function of the cell and follow explanations given in Chapter 3 (see page 3–53).

Example 7:

This example illustrates a hexagonal prism lattice and shows how the order of specification of the surfaces on a cell card identifies the lattice elements beyond each surface.

```
 hexagonal prism lattice
  1      0 -1 -19 29 fill=1 imp:n=1
  2      0 -301 302 -303 305 -304 306 lat=2 u=1 imp:n=1
  3      0 1:19:-29 imp:n=0

  1      cz 20
 19      pz 31.75
 29      pz -31.75
301      px 1
302      px -1
303      p  1 1.7320508076 0 2
304      p  -1 1.7320508076 0 2
305      p  1 1.7320508076 0 -2
306      p  -1 1.7320508076 0 -2

sdef
f1:n     1
nps      2000
```

The geometry for this example is shown in Figure 4-26.

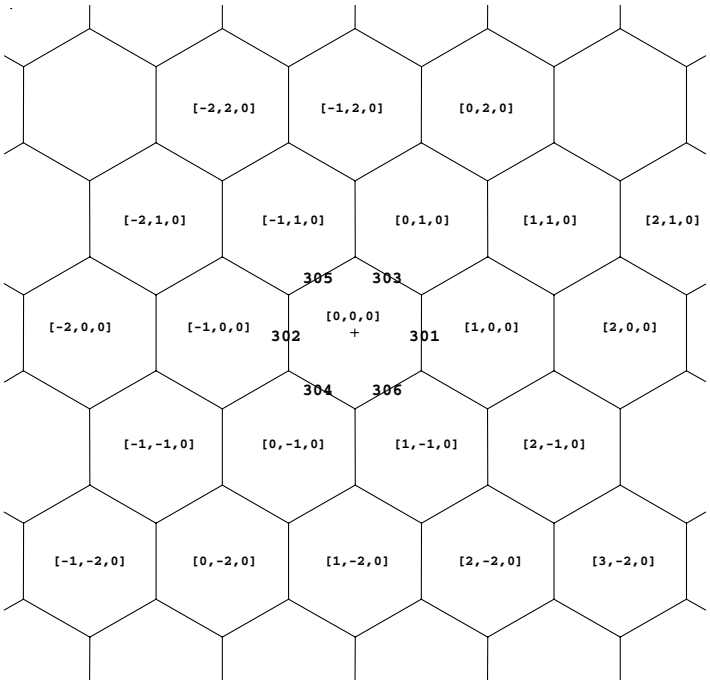


Figure 4-26.

The (0,0,0) element is the space described by the surfaces on the cell card, perhaps influenced by a TRCL entry. The user chooses where the (0,0,0) element will be. The user chooses the location of the (1,0,0) element—it is beyond the first surface entered on the cell card. The (–1,0,0) element MUST be in the opposite direction from (1,0,0) and MUST be beyond the second surface listed. The user then chooses where the (0,1,0) element will be—it must be adjacent to the (1,0,0) element—and that surface is listed next. The (0,–1,0) element MUST be diagonally opposite from (0,1,0) and is listed fourth. The fifth and sixth elements are defined based on the other four and must be listed in the correct order: (–1,1,0) and (1,–1,0). Pairs can be picked in any order, but once set the pattern must be followed. The example illustrates one pattern that could be selected and shows how the numbering of elements progresses outward from the center.

One of the most powerful uses of macrobodies is for the specification of hexagonal prisms. The example above can be simplified by using the RHP (also called HEX) macrobody as follows:

```
hexagonal prism lattice
C Cell Cards
1 0 -2           fill=1                  imp:n=1
2 0 -1                          lat=2 u=1 imp:n=1
3 0 2                                     imp:n=0

C Surface Cards
1 rhp 0 0 -31.75  0 0 63.5  2 0 0
2 rcc 0 0 -31.75  0 0 63  20
```

Example 8:

This example demonstrates how the LIKE m BUT and TRCL cards can be used to create an array of nonidentical objects within each cell of a lattice.

```
example of pwrlat
    1   0 -1 -19 29 fill=1 imp:n=1
    2   2 -1 -301 302 -303 304 lat=1 u=1 imp:n=1 fill=-3:3 -3:3 0:0
        1 1 1 1 1 1 1  1 1 2 2 2 1 1  1 2 2 2 2 2 1  1 2 2 2 2 2 1
        1 2 2 2 2 2 1  1 1 2 2 2 1 1  1 1 1 1 1 1 1
    3   1 -18 -10 u=2 imp:n=1
    4   2 -1 #3 #5 #6 #7 #8 #9 #10 #11 #12 #13 #14 #15 #16 #17 #18
        #19 #20 #21 #22 #23 #24 #25 #26 #27 #28 imp:n=1 u=2
    5   like 3 but trcl=(-6 6 0)
    6   like 3 but trcl=(-3 6 0)
    7   like 3 but trcl=(0 6 0)
    8   like 3 but trcl=(3 6 0)
    9   like 3 but trcl=(6 6 0)
   10   like 3 but trcl=(-6 3 0)
   11   like 3 but trcl=(0 3 0)
   12   like 3 but trcl=(6 3 0)
   13   like 3 but trcl=(-6 0 0)
   14   like 3 but trcl=(-3 0 0)
   15   like 3 but trcl=(3 0 0)
   16   like 3 but trcl=(6 0 0)
   17   like 3 but trcl=(-6 -3 0)
   18   like 3 but trcl=(0 -3 0)
   19   like 3 but trcl=(6 -3 0)
   20   like 3 but trcl=(-6 -6 0)
   21   like 3 but trcl=(-3 -6 0)
   22   like 3 but trcl=(0 -6 0)
   23   like 3 but trcl=(3 -6 0)
   24   like 3 but trcl=(6 -6 0)
   25   like 3 mat=3 rho=-9 trcl=(-3 3 0)
   26   like 25 but trcl=(3 3 0)
   27   like 25 but trcl=(-3 -3 0)
   28   like 25 but trcl=(3 -3 0)
   50   0 1:19:-29 imp:n=0

    1   cz 60
   10   cz 1.4
   19   pz 60
   29   pz -60
  301   px 10
  302   px -10
  303   py 10
  304   py -10
```

```
kcode   1000 1 5 10
 ksrc   0 0 0
   m1   92235 .02 92238 .98
   m2   1001 2 8016 1
   m3   48000 1
```

A horizontal slice through this configuration is shown in Figure 4-27.

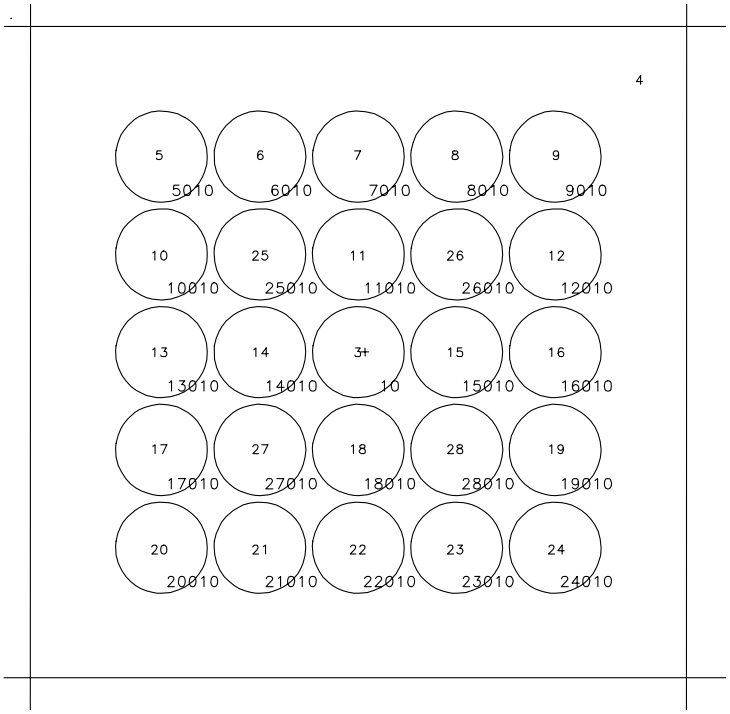


Figure 4-27.

Only one lattice element is shown in Figure 4-27. A lattice of hexahedral subassemblies, each holding an array of 25 cylindrical rods, is contained within a cylindrical cell. Cell 1 is the space inside the large cylinder and is filled with universe 1. Cell 2 is the only cell in universe 1 and is the hexahedral lattice that fills cell 1. The lattice is a 7x7x1 array, indicated by the array indices on the FILL card, and it is filled either by universe 2 or by itself, universe 1. Cell 3, a fuel rod, is in universe 2 and is the space inside the cylindrical rod. The other fuel cells, 5–24, are like cell 3 but at different *x,y* locations. The material in these 21 fuel cells is slightly enriched uranium. Cells 25–28 are control rods. Cell 25 is like 3 but the material is changed to cadmium, and the density and the *x,y* location are different. Cells 26–28 are like cell 25 but at different *x,y* locations. Cell 4 is also in universe 2 and is the space outside all 25 rods. To describe cell 4, each cell number is complemented. All the surfaces in Figure 4-27 except for the center one have a new predictable surface number—1000 * cell number + surface number. These numbers could be used in the description of cell 4 if desired.

The KCODE and KSRC cards appear because this example is a criticality calculation. The KCODE card specifies that there are 1000 particles per cycle, the initial guess for k_{eff} is 1, 5 cycles are skipped before the tally accumulation begins, and a total of 10 cycles will be run. The KSRC indicates that the neutron source for the first cycle will be a point source at the origin.

IV. TALLY EXAMPLES

This section contains examples of the FMn, FSn, and FTn tally cards, a complicated repeated structures/lattice example, and the TALLYX subroutine. Refer also to page 3–99 for the FMn card, page 3–106 for the FSn card, page 3–116 for the FTn card, page 3–92 for the basic repeated structure/lattice tally, and page 3–109 for TALLYX before trying to understand these examples.

A. FMn Examples (Simple Form)

Example 1:

Consider the following input cards.

```
F4:N      10
FM4       0.04786     999   102
M999      92238.13    1
```

The F4 neutron tally is the track length estimate of the average fluence in cell 10. Material 999 is ^{238}U with an atomic fraction of 100%.

$C = 0.04786$	normalization factor (such as atom/barn·cm)
$M = 999$	material number for ^{238}U as defined on the material card (with an atom density of 0.04786 atom/barn·cm)
$R_1 = 102$	ENDF reaction number for radiative capture cross-section (microscopic)

The average fluence is multiplied by the microscopic (n,γ) cross section of ^{238}U (with an atomic fraction of 1.0) and then by the constant 0.04786 (atom/barn·cm). Thus the tally 4 printout will indicate the number of ^{239}U atoms/cm^3 produced as a result of (n,γ) capture with ^{238}U.

Standard F6 and F7 tallies can be duplicated by F4 tallies with appropriate FM4 cards. The FM4 card to duplicate F6 is

```
FM4       C  M  1  –4.
```

For F7 it is

```
FM4       C  M  –6 –8.
```

C	=	10^{-24}	x number of atoms per gram
R_1	=	1	ENDF reaction number for total cross section (barns)
R_2	=	–4	reaction number for average heating number (MeV/collision)
R_1	=	–6	reaction number for total fission cross section (barns)
R_2	=	–8	reaction number for fission Q (MeV/fission)

This technique applied to F2 tallies can be used to estimate the average heating over a surface rather than over a volume. It provides the surface equivalents of F6 and F7 tallies, which are not available as standard tallies in MCNP.

Example 2:

Consider a point detector.

```
F25:N     0          0       0          0
FM25      0.00253    1001    –6         –8
M1001     92238.60   .9      92235.60   .1
```

This F25 neutron tally is the fission heating per unit volume of material 1001 at the origin. Material 1001 does not actually have to be in a cell at the origin. The FM25 card constants are:

C	= 0.00253	atoms per barn·cm (atomic density) of material 1001
M	= 1001	material number for material being heated
R_1	= –6	reaction number for total fission cross section (barn)
R_2	= –8	reaction number for fission Q (MeV/fission)

Example 3:

Lifetime calculation

```
F4:N      1
SD4       1
FM4       (-1 1 16:17)     $ bin 1 = (n,xn) reaction rate
          (-1 1 -2)        $ bin 2 = capture (n,0n) reaction rate
          (-1 1 -6)        $ bin 3 = fission reaction rate
          (1 -2)           $ bin 4 = prompt removal lifetime=flux/velocity
M1        92235   –94.73   92238   –5.27
```

This F4 neutron flux tally from a Godiva criticality problem is multiplied by four FM bins and will generate four separate tally quantities. The user can divide bin 4 by bins 1, 2, and 3 to obtain the (n,xn) lifetime, the (n,0n) lifetime, and the (n,f) lifetime, respectively. The FM4 card entries are:

C	= –1	multiply by atomic density of material 1
M	= 1	material number on material card
R_1	= 16:17	reaction number for (n,2n) cross section *plus* reaction number for (n,3n) cross section
R_2	= –2	reaction number for capture cross section
R_3	= –6	reaction number for total fission cross section
R_4	= 1 –2	prompt removal lifetime = flux/velocity = time integral of population

More examples:

(Remember $C = -1 = \rho$ for type 4 tally)

```
F5:N      0    0    0    0     Neutron heating per cm^3 with an atom density of
FM5       ρ    M    1    –4    ρ of material M at a point detector

F5Y:P     10   5    0          Photon heating per cm^3 of material M
FM5       ρ    M    –5   –6    with an atom density ρ at a ring detector
```

```
F1:N     1    2    3          Number of neutron tracks crossing surfaces 1, 2, and 3
FM1      1    0               per neutron started

F35:P    0    0    0    0     Number of photon collisions per source particle
FM35     1    0               that contribute to point detector

M99      3007 1               7Li tritium production per cm3 in cell 10
F4:N     10
FM4      –1   99   91

F104:N   8                    Number of reactions per cm3 of type R in cell 8
FM104    –1   M    R          of material M of atom density ρ
```

B. FMn Examples (General Form)

Remember that the hierarchy of operation is multiply first and then add, and that this hierarchy can not be superseded by the use of parentheses.

Example 1:

```
F4:N     1
FM4      (ρ 1 (1 –4)(–2)) (ρ 1 1)    where C = ρ = atomic density (atom/barn·cm)
M1       6012.10 1
```

In this example there are three different tallies, namely

```
(a)  ρ    1    1   –4
(b)  ρ    1   –2
(c)  ρ    1    1
```

Thus tally (a) will yield the neutron heating in MeV/cm^3 from ^{12}C in cell 1. The advantage in performing the multiplication 1 –4 in tally (a) is that the correct statistics are determined for the desired product. This would not be true if tally (a) were to be done as two separate tallies and the product formed by hand after the calculation.

Example 2:

```
F4:N     1
FM4      (0.04635 1 (105:91))
M1       3006.50 0.0742 3007.50 0.9258
```

In this example we obtain the total tritium production per cm^3 from natural lithium (ENDF/B-V evaluation) in cell 1. The constant C on the FM4 card is the atomic density of natural lithium. A subtle point is that the R = 105 reaction number contains the reaction data for just the ^{6}Li reaction and R = 91 contains the reaction data for the ^{7}Li reaction (see Appendix G page G–1). However, this example uses both sets of reaction data in the FM4 card to calculate the tritium production in a media composed of both ^{6}Li and ^{7}Li. Thus, four calculations are carried out (two for ^{6}Li using

R = 91,105, and two for ^{7}Li using R = 91,105). Note that two of these calculations (^{6}Li with R = 91, and ^{7}Li with R = 105) will contribute nothing to the total tritium production.

Example 3:

Suppose we have three reactions—R_1, R_2, and R_3—and wish to add R_2 and R_3 and multiply the result by R_1. The following would *NOT* be valid: FMn (C m R_1 (R_2:R_3)).
The correct card is: FMn (C m (R_1 R_2: R_1 R_3)).

C. FSn Examples

The FSn card allows you to subdivide your tally into geometry segments, avoiding overspecifying the problem geometry with unnecessary cells.

The entries on the FS card are the names and senses of surfaces that define how to segment any surface or cell tally.

Example 1:

Consider a 1-MeV point isotropic source at the center of a 2-cm cube of carbon. We wish to calculate the flux through a 1-cm^2 window in the center of one face on the cube. The input file calculating the flux across one entire face is shown in Figure 4-28.

```
EXAMPLE 1,   SIMPLE CUBE
1       1 –2.22     1 2 –3 –4 –5 6   IMP:N=1
2       0           #1               IMP:N=0

1       PY  0
2       PZ –1
3       PY  2
4       PZ  1
5       PX  1
6       PX –1

SDEF    POS = 0  1  0    ERG = 1
M1      6012.60   –1
F2:N    3
```

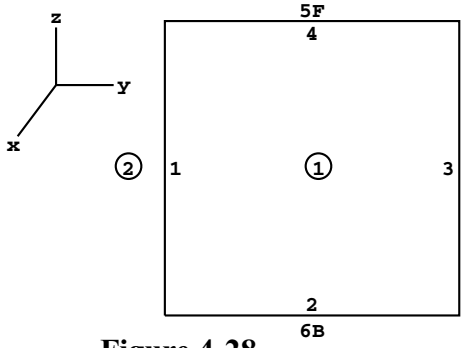


Figure 4-28.

The FS card retains the simple cube geometry and four more surface cards are required,

```
7          PX    .5
8          PX   –.5
9          PZ    .5
10         PZ   –.5

FS2    7   –10   –8   9
```

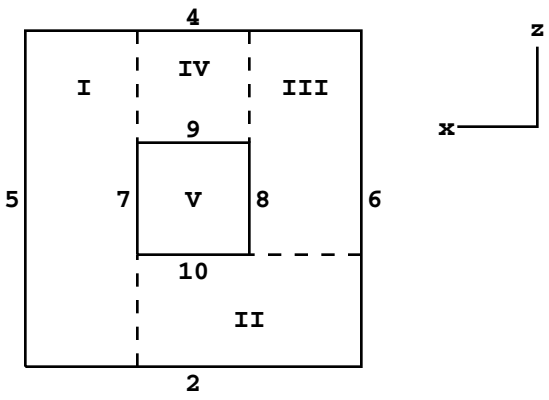


Figure 4-29.

The four segmenting surface cards are listed with the other surface cards, but they are not part of the actual geometry and hence do not complicate the cell-surface relationships.

The F2 tally is subdivided into five separate tallies as shown in Figure 4-29: (1) the first is the flux of particles crossing surface 3 but with a positive sense to surface 7; (2) the second is the remaining flux with negative sense to surface 7 crossing surface 3 but with a negative sense to surface 10; (3) the third is the remaining flux (negative sense to 7 and positive sense to 10) crossing 3 but with a negative sense to 8; (4) the remaining flux with positive sense to 9; and (5) everything else. In this example, the desired flux in the window is in the fifth subtally—the "everything else" portion.

The FS segmenting card could have been set up other ways. For example:

```
FS2    –10    7   9    –8     and
FS2    –8     9   –10   7
```

Each works, but the order of the subtallies is changed. A way to avoid the five subtallies and to get only the window of interest is to use the TALLYX subroutine described later.

Example 2:

Consider a source at the center of a 10-cm radius sphere called cell 1. We want to determine the fission heating in a segment of the sphere defined by the intersection of the 10-cm sphere, an 8-cm inner sphere, and a 20° cone whose vertex is at the source and is about the *Y*-axis. This is accomplished by using

```
F7:N        1
FS7        –2   –3
```

where surface 2 is the 8-cm surface and surface 3 is the cone. This breaks the F7 tally up into three portions: (1) the heating inside the 8-cm sphere; (2) the heating outside the 8-cm sphere but within the cone—this is the desired portion; and (3) everything else, which is a 2-cm shell just inside the 10-cm sphere but outside the cone.

D. FTn Examples

Example 1:

Consider the following input cards.

```
F1:N      2
FT1       FRV    V1   V2   V3
```

The FTn card is the special treatment for tallies card. Various tally treatments are available for certain specific tally requirements. The FTn tally with the FRV card used in conjunction with tally type 1 will redefine the vector normal to the tally surface. In this case, the current over surface 2 (tally type 1) uses the vector V as its reference vector for getting the cosine for binning.

Example 2:

```
F5:P        4
FT5         ICD
FU5         1   3
```

In this example the photon flux at detector 5 is being tallied. However, only the contributions to the detector tally from cells 1 and 3 are of interest. The ICD keyword allows the user to create a separate bin for each cell, and only contributions from one of the specified cells are scored. The FUn card specifies the cells from which tallies are to be made, but TALLYX is not called.

Example 3:

When keeping track of charged particle current across a surface, it is sometimes desirable to track both positive and negative score contributions, applicable in cases that include electrons and positrons. Consider a photon source that is enclosed in a spherical shell of lead. If a surface current tally is taken over the sphere and it is desirable to tally both the positron and electron current separately, then the special treatment card option is invoked.

```
1       1 –.001124  –11        imp:e=1   imp:p=1
2       2 –11.0       11 –21     imp:e=1   imp:p=1
3       0               21          imp:e=0   imp:p=0

11      so  30
21      so  32

m1      6012  .000125    7014  .6869    8016  .301248    18040  .011717
m2      82000  1.
mode    p e
sdef     pos = 0. 0. 0.  erg = 2.5
f1:e    21
ft1     elc 2
f2:p     21
e2      1e-3 1e-2 0.1 0.5 1.0 1.5 2.0 2.5 C
nps     10000
```

The input deck shown above models a sphere filled with dry air surrounded by a spherical shell of lead. The centrally located source emits 2.5 MeV photons that travel through the air into the lead shell. The F1 surface current tally has been modified with the ELC special tally option. The parameter value of 2 that follows the ELC keyword specifies that positrons and electrons be placed into separate tally user bins. Once this option has been invoked, the user can inspect the output tally bins for the respective scoring of either particle.

The F2 tally scores photon flux crossing surface 21, scored into energy bins defined on the E2 card. The C at the end of the energy bin card indicates that the bins are cumulative. Therefore, the bin with an upper limit of 1 MeV would contain scores from particles that cross surface 21 with energy less than or equal to 1 MeV.

Example 4:

Consider the following two point sources, each with a different energy distribution:

```
sdef        pos=d1   erg=fpos d2
si1         L  5 3 6    75 3 6
sp1         .3 .7
ds2         S  3   4
si3         H 2 10 14
sp3         D 0  1   2
si4         H .5 2 8
sp4         D 0  3 1
f2:n        2
ft2         scd
fu2         3  4
```

The SCD option causes tallies to be binned according to which source distribution was sampled. The FUn card is used to list the distribution numbers of interest. Thus, the tallies in this example are placed in one of two bins, depending on which of the two sources emitted the particle. The two sources may represent two nuclides with different energy distributions, for instance, with the use of the SCD option allowing the user to determine each nuclide's contribution to the final tally.

E. Repeated Structure/Lattice Tally Example

An explanation of the basic repeated structure/lattice tally format can be found in Chapter 3 beginning on page 3–92. The example shown here illustrates more complex uses. Figure 4-30 (a–f) indicates the tally regions for each tally line. The number of bins generated by MCNP is shown at the end of each tally line following the $.

```
example 1 - repeated structure lattice tally example
 1 0     -1 -2 3 13 fill=4
 2 0     -1 -2 3 -13 fill=1
 3 0     -4 5 -6 7 u=1 lat=1
      fill=-2:2 -2:0 0:0   1 1 3 1 1   1 3 2 3 1   3 2 3 2 3
 4 0     -8 9 -10 11 u=2 fill=3 lat=1
 5 1 -0.1 -12 u=3
```

```
 6 0     12 u=3
 7 0     -14 -2 3 u=4 fill=3 trcl=(-60 40 0)
 8 like 7 but trcl=(-30 40 0)
 9 like 7 but trcl=(0 40 0)
10 like 7 but trcl=(30 40 0)
11 like 7 but trcl=(60 40 0)
12 0     #7 #8 #9 #10 #11 u=4
13 0     1:2:-3

 1 cz 100
 2 pz 100
 3 pz -100
 4 px 20
 5 px -20
 6 py 20
 7 py -20
 8 px 10
 9 px -10
10 py 10
11 py -10
12 cz 5
13 py 19.9
14 cz 10

f4:n  5 6 (5 6 3)                          $ 3 bins
     (5<3) (5<(3[-2:2 -2:0 0:0]))          $ 2 bins
     (5<(7 8 9 10 11)) (5<7 8 9 10 11<1) (5<1) $ 7 bins
     ((5 6)<3[0 -1 0]) ((5 6)<3[0:0 -1:-1 0:0]) ((5 6)<3[8]) $
     3 bins
     (5<(4[0 0 0]3[8]))(5<4[0 0 0]<3[8])
        (3<(3[1]3[2]3[4]3[5]3[6]3[10]))    $ 3 bins
     (5<u=3)                               $ 12 bins
```

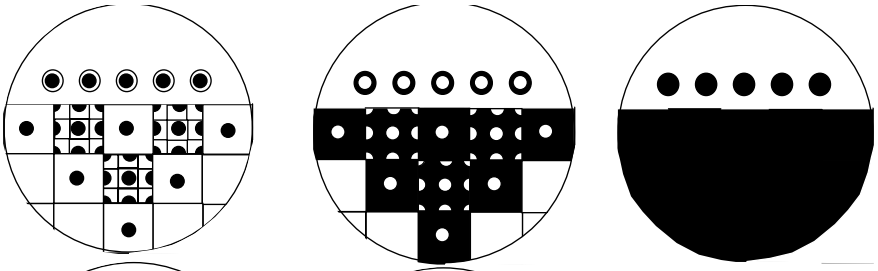


Figure 4-30a.

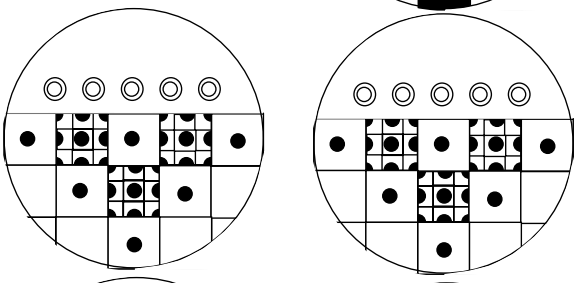


Figure 4-30b.

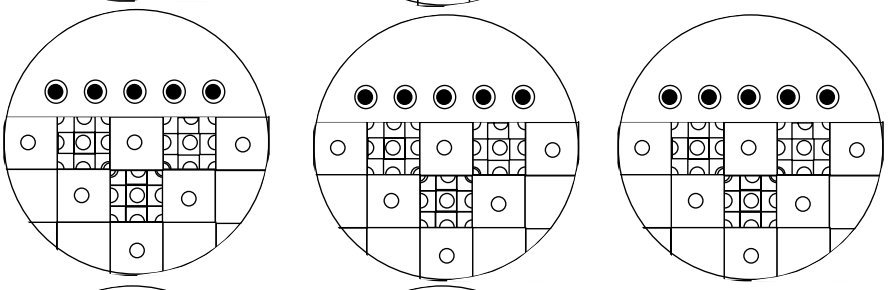


Figure 4-30c.

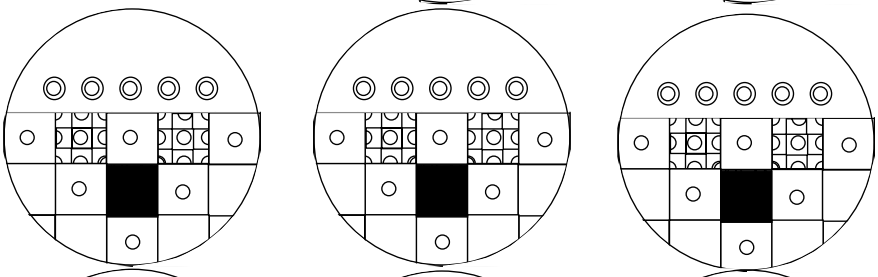


Figure 4-30d.

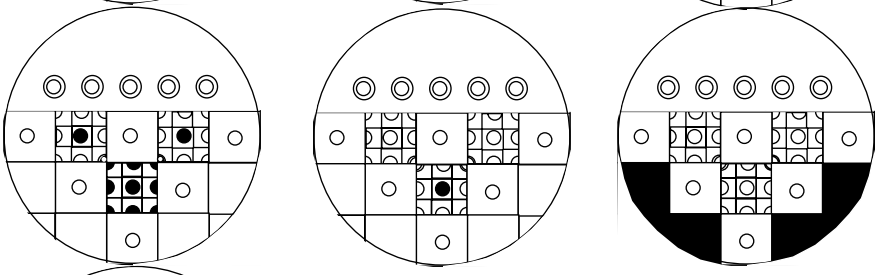


Figure 4-30e.

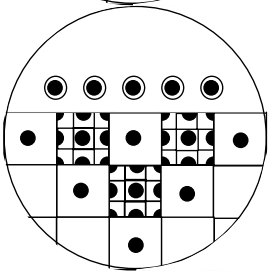


Figure 4-30f.

Figure 4-30.

Tally line 1: This first line creates three tally output bins: cell 5, cell 6, and the union of cells 5, 6, and 3, as indicated in Figure 4-30a. Because cell 3 is filled entirely by cells 5 and 6, a tally over cell 5 plus cell 6 is the same as a tally over cell 3. If a particle is tallied in cell 5 and tallied in cell 3, it will be tallied twice in the bin (5 6 3).

CAUTION: A true union IS performed when first level cells overlap (or fill) another cell. This is NOT a tally that is normally desired. If an average of cell 3 and region (5 6) outside cell 3 is desired, separate bins must be defined and properly combined using correct volume weighting.

Tally line 2: These two input tally bins result in identical output tallies, as shown in Figure 4-30b. The use of lattice index brackets that include all existing lattice elements makes the two tallies equivalent. The simpler format will execute faster.

Tally line 3: This line illustrates omission of geometry levels and a single output bin versus multiple bins. All three input bins tally cell 5 within cells 7 through 11. The second bin specifies the entire path explicitly. Because the only place cell 5 exists within cell 1 is in cells 7–11, the 7–11 specification can be omitted, as in the third input bin. In the second input bin, the parentheses around cells 7–11 are omitted, creating multiple output bins. Five tally bins are produced: (5<7<1), (5<8<1), (5<9<1), (5<10<1), and (5<11<1). The sum of these five bins should equal the tally in the first and last output bins on this line. The tally regions are shown in Figure 4-30c.

Tally line 4: This line illustrates the union of multiple tally cells, (5 6), and various ways of specifying lattice index data. The three input tally bins create three output tally bins with identical values because the three different lattice descriptions refer to the same lattice element, the eighth entry on the FILL array. If the parentheses around (5 6) were removed, two output bins would be created for each input bin, namely (5<3[0 –1 0]) and (6<3[0 –1 0]), etc. The tally regions are shown in Figure 4-30d.

Tally line 5: This line illustrates tallies in overlapping regions in repeated structures in a lattice and a tally in lattice elements filled with themselves. Three tally output bins are produced. In the first input bin, a particle is tallied only once when it is in cell 5 and in 4[0 0 0] or when it is in cell 5 and in 3[0 –1 0]. Figure 4-30e shows all the cell 5's included in this tally bin. This tally is probably more useful than the overlapping regions in tally line 1. Input bin 2 demonstrates a tally for a nested lattice. A tally is made when a particle is in cell 5 and in cell 4, element [0 0 0] and in cell 3, element [0 –1 0]. Note that 3[0 –1 0] is indeed filled with cell 4 (u=2). If that were not true, a zero tally would result in this bin. The final input tally bin demonstrated a tally in lattice elements that are filled with their own universe number. This method is the only way to tally in these elements separate from the rest of cell 3.

Tally line 6: This line illustrates the universe format. The single input bin includes all possible chains involving cell 5. Because u=3 is not within parentheses, the input is expanded into twelve output bins: (5<3[3], etc.). The format 3[3] indicates the third lattice element of cell 3 as entered on the cell 3 FILL array. Note that the third element is filled by universe 3, consisting of cells 5 and 6. The tally regions are shown in Figure 4-30f.

F. TALLYX Subroutine Examples

An explanation of the TALLYX subroutine arguments can be found on page 3–109 in Chapter 3. Only examples illustrating some uses of TALLYX will be found here.

Example 1:

In the example of using the FSn card (see page 4–42) to get the flux through a window on the face of a cube, instead of using the FS2 card, which established five subtallies, TALLYX could have been used to get only the desired window tally. Two input cards are used:

```
FU2      1
RDUM     –.5  .5  –.5  .5
```

The following subroutine (which is implemented just like a user-provided SOURCE subroutine by replacing the file tallyx.F90) does the job. Note that IB=0 and IBU=1 upon entry into TALLYX.

```
subroutine tallyx(t,ib)
  use mcnp_global
  use mcnp_debug

  implicit none
  integer :: ib
  real(dknd) :: t

  if( (xxx < rdum(1)) .or. (xxx > rdum(2)) ) ib=-1
  if( (zzz < rdum(3)) .or. (zzz > rdum(4)) ) ib=-1

  return
end subroutine tallyx
```

The subroutine was generalized a bit by using the RDUM input card, although the card could have been avoided by hard wiring the dimensions of the window into TALLYX.

Example 2:

Dump 18 words of the GPBLCM array to a BCD file called UOUT each time a neutron crosses surface 15. The input cards are

```
F2:N      15
FU2        1
FILES      7   UOUT
```

The user-provided subroutine is

```
subroutine tallyx(t,ib)
  use mcnp_global
  use mcnp_debug
```

```
      implicit none
      integer :: ib
      real(dknd) :: t
      integer :: i

      write(7,20)(gpblcm(i),i=1,10),npa,icl,jsu,ipt,iex,node,
                 idx,ncp
      20 format (5e14.6/5e14.6/7i10/2i10)

      return
      end subroutine tallyx
```

Every time surface 15 is crossed and the F2 tally is scored, TALLYX is called and part of the GPBLCM array is written to the file UOUT. If more discrimination is desired, such as dumping the GPBLCM array only for neutrons with energy between 2.5 and 4.5 MeV and crossing surface 15 at less than 30° with respect to the normal (assume surface 15 has been defined by a PY card), add the following two lines before the WRITE statement:

```
    if(vvv < 0.866) return
    if( (erg < 2.5) .or. (erg > 4.5) ) return
```

To write a binary file, the FILES card entries are 7 UOUT S U and the WRITE statement in TALLYX is unformatted:

```
  subroutine tallyx(t,ib)
    use mcnp_global
    use mcnp_debug

    implicit none
    integer :: ib
    real(dknd) :: t
    integer :: i

    write(7)(gpblcm(i),i=1,10),npa,icl,jsu,ipt,iex,node,idx,ncp

    return
  end subroutine tallyx
```

The advantage of a BCD file is that it is easy to look at and manipulate, but it requires more I/O time and a larger file. A binary file is more compact than a BCD file and requires less I/O time to write; however, it may be more difficult to use.

Example 3:

Calculate the number of neutron tracks exiting cell 20 per source neutron. This is also done in Chapter 5 with the TEST1 example using the FMn card (see page 5–8). The input cards are

```
F4:N      20
FU4        1
SD4        1
```

and TALLYX becomes

```
subroutine tallyx(t,ib)
  use mcnp_global
  use mcnp_debug

  implicit none
  integer :: ib
  real(dknd) :: t

  t=1.0_dknd
  if (pmf < dls) ib = -1

  return
end subroutine tallyx
```

The quantity T=1.0 is scored every time a track exits cell 20. The variables used in this subroutine, PMF (the distance to collision) and DLS (distance to the boundary), are available to TALLYX from the modules TSKCOM and PBLCOM.

Example 4:

Divide the point detector scores into separate tallies (that is, user bins) depending upon which of the 20 cells in a problem geometry caused the contributions. The input cards are

```
F5:N      0    0   0    0
FU5       1    18I  20
```

and TALLYX is

```
subroutine tallyx(t,ib)
   use mcnp_global
   use mcnp_debug

   implicit none
   integer :: ib
   real(dknd) :: t

   ibu=icl9(npb)

   return
end subroutine tallyx
```

The FU5 card establishes 20 separate user bins, one for each cell in the problem. Note the use of the “nI” input format, described in Chapter 3 on page 3–4, which creates 18 linear interpolates between 1 and 20. The variable ICL9 contains, for the current history, the number of the cell that produced the original particle.

Example 5:

Determine the quantity $\int \varphi(E)\, f(E)\, dE$ in cell 14 where $f(E) = e^{\alpha t}$. The input cards are

```
F4:N      14
FU4       α
```

where α is a numerical value and TALLYX is

```
subroutine tallyx(t,ib)
   use mcnp_global
   use mcnp_debug

   implicit none
   integer :: ib
   real(dknd) :: t

   t=t*exp(tds(iptal(3,1,ital)+1)*tme)

   return
end subroutine tallyx
```

The FU4 card establishes a single user bin, and the value of α is stored in `TDS(IPTAL(3,1,ITAL)+1)` and used for the tally label.

Example 6:

Tally the number of neutrons passing through cell 16 that have had 0, 1, 2, 3, or 4 collisions. The input cards are

```
F4:N      16
FU4       0  1  2  3  4
SD4       1
```

and TALLYX is

```
subroutine tallyx(t,ib)
   use mcnp_global
   use mcnp_debug

   implicit none
   integer :: ib
   real(dknd) :: t

   ibu = int(spare(1))+1
   if(ibu > 5 ) ib=-1
   t=wgt

   return
end subroutine tallyx
```

The subroutine can be generalized by replacing the 5 in the IF statement with `IPTAL(3,3,ITAL)`, which is the number of entries on the FU4 card.

If no tracks were put into the bank (from fission, geometry splitting, etc.,), `INT(SPARE(1))` could be replaced by `NCH(1)`, the number of neutron collisions per history. However, to be general, use the quantity `SPARE(1)`, which goes into the bank with the rest of the banked track parameters. `SPARE(1)` must be set to 0 when a source particle is started and then incremented at collisions. This is done with the following patch in the STARTP and HSTORY subroutines:

```
# To install this patch:
#   1) cd to MCNP5/Source/src directory
#   2) patch with "patch -p1 < thispatchfile"
#
--- old/startp.F90
+++ src/startp.F90
@@  -45,2 +45,3 @@
     mbb = 0
+    spare(1) = 0.
     lev = 0
--- old/hstory.F90
+++ src/hstory.F90
@@  -427,2 +427,3 @@
     nch(ipt) = nch(ipt)+1
+    spare(1) = spare(1)+1.
     ncp = ncp+1
```

If the IF statement in this TALLYX is omitted, a count will be made of the cases of five or more collisions, and in these cases no score will be tallied but a count will be printed of the times that the tally was unable to be made because IBU was a value where no bin existed.

In the five user bins, T is the number of neutrons per source neutron passing through cell 16 that has undergone 0, 1, 2, 3, or 4 collisions, respectively. Note that the FU4 card has five entries to establish the five user bins and provide labels. Note also that in this example, the neutrons are calculated so that T=T∗ renormalization factor (which preserves the weight associated with the tracks), where in Example 3 the neutron tracks are calculated so that T=1. Again the value of `SPARE(1)` is available from the module PBLCOM. Finally, note that if `SPARE(1)` > 5 (six or more collisions) no tally is made because IB is set to be less than zero. If an E4 card was added, the neutrons would be tallied as a function of energy for each user bin.

V. SOURCE EXAMPLES

Some examples of the general source are given here to illustrate the power and complexity of this feature. Refer to Chapter 3 page 3–53 for a more complete explanation and other examples.

Example 1:

```
SDEF ERG = D1 DIR FERG D2 SUR = D6 CEL FSUR D7
     POS FSUR D8 RAD FSUR D9 AXS FSUR D10 VEC FSUR D11
c Source Definition Card.
```

```
c In this example, AXS is needed to define a vector which
c defines the source plane of a disk source.
c In this example, POS defines the location of the center
c of the disk.
c VEC is the direction that source particles will be
c travelling once created.
c AXS and VEC can be different.
c For this duct streaming problem, they should be the same.
c
SI1 H 1E-7 1E-5 ... 13.5 14 ... 20
c Source Information 1 (SI1) corresponds to D1.
c H indicates histogram values follow.
c
SP1 D 0 10E-4 ... 10E-2 10E-1 ... 3
c Source Probability 1 (SP1) augments SI1.
c D indicates discrete values.
c Probability of each bin on SI1.
c The probability a source particle will be between 10E-7
c and 10E-5 MeV is 10E-4.
c
DS2 S 3 ... 3 4 ... 4
c Dependent Source 2 (Depends as a function of ERG).
c S indicates numbers following are themselves other
c distributions.
c In this example, if a particle has an energy in bin 10E-7 to
c 10E-5, then it will have a direction associated with source
c distribution 3.
c
SI3 0 .2 ... 1
c Source Information 3 (Second Level)
c Default is histogram values.
c
SP3 D 0 1E-4 ... .1
c Source Probability 3 (Second Level).
c Probability of each bin on SI3.
c
SI4 0 .1 ... 1
c Source Information 4 (Second Level).
c Default is histogram values.
c
SP4 D 0 1E-2 ... .1
c Source Probability 4 (Second Level).
c Probability of each bin on SI3.
c
SI5 37
c Source Information 5.
c Default is histogram values.
```

```
c There is one bin from 0 to 37.
c When used with the RAD keyword on the SDEF card, it indicates
c a circular distribution from 0 to 37 cm.
c
SP5 -21 1
c Source Probability 5
c The -21 indicates a sampling scheme based on the square of the
c variable.
c In this case, the sampling is a function of radius^1,
c which results in a uniform spatial distribution over the disk.
c Since a uniform spatial distribution is the default for disk
c sources, this card is optional.
c
```

This example of the general source illustrates two levels of dependency. Let us assume a duct streaming problem where the source at the duct opening has been obtained from a reactor calculation. Energies above 13.5 MeV have one angular distribution and energies below 13.5 MeV have a different angular distribution. The source has a uniform spatial distribution on a circular disk of radius 37 cm centered at *x,y,z* on planar surface 1 going into cell 2.

This example can be expanded by having the source in two ducts instead of one (with the same energy and angular distribution as before). The SI1, SP1, DS2, SI3, SP3, SI4, and SP4 cards remain unchanged. The SDEF card is changed as shown below and the other cards are added.

```
SDEF      ERG = D1   DIR FERG D2   SUR = D6   CEL FSUR D7
          POS FSUR D8   RAD FSUR D9   VEC FSUR D10
          SI6      L      1       7
          SP6      D     .6      .4
          DS7      L      2       8
          DS8      L   x1 y1 z1    x2 y2 z2
          DS9      S     11      12
          DS10     L   u1 v1 w1    u2 v2 w2
          SI11           0      37
          SP11         -21       1
          SI12           0      25
          SP12         -21       1
```

Example 2:

This example is a two-source-cell problem where the material in one cell is uranium and in the other is thorium. The uranium cell has two isotopes, ^{235}U and ^{238}U, and the thorium has one, ^{232}Th. Each isotope has many photon lines from radioactive decay. The following input cards describe this source.

```
SDEF ERG = D1 DIR FERG D2 SUR = D6 CEL FSUR D7
     POS FSUR D8 RAD FSUR D9 AXS FSUR D10 VEC FSUR D10
c Source Definition Card.
```

```
c In this example, AXS is needed to define a vector which
c defines the source plane of a disk source.
c In this example, POS defines the location of the center
c of the disk.
c VEC is the direction that source particles will be
c travelling once created. AXS and VEC can be different.
c
SI1 H 1E-7 1E-5 ... 13.5 14 ... 20
c Source Information 1 (SI1) corresponds to D1.
c H indicates histogram values follow.
c
SP1 D 0 10E-4 ... 10E-2 10E-1 ... 3
c Source Probability 1 (SP1) augments SI1.
c D indicates discrete values.
c Probability of each bin on SI1.
c The probability a source particle will be between
c 10E-7 and 10E-5 MeV is 10E-4.
c
DS2 S 3 ...0 3 4 ... 4
c Dependent Source 2 (Depends as a function of ERG).
c S indicates numbers following are themselves other
c distributions.
c In this example, if a particle has an energy in bin
c 10E-7 to 10E-5, then it will have a direction associated
c with source distribution 3.
c
SI3 0 .2 ... 1
c Source Information 3 (Second Level).
c Default is histogram values.
c
SP3 D 0 1E-4 ... 0.1
c Source Probability 3 (Second Level).
c Probability of each bin on SI3
c
SI4 0 0.1 ... 1
c Source Information 4 (Second Level).
c Default is histogram values.
c
SP4 D 0 1E-2 ... 0.1
c Source Probability 4 (Second Level).
c Probability of each bin on SI3.
c
SI5 37
c Source Information 5.
c Default is histogram values.
c One bin from 0 to 37.
c When used with the RAD keyword on the SDEF card,
```

```
c it indicates a circular distribution from 0 to 37 cm.
c
SP5 -21 1
c Source Probability 5.
c The -21 indicates a sampling scheme based on the square of
c the c variable.
c In this case, the sampling is a function of radius^1,
c which results in a uniform spatial distribution over
c the disk.
c Since a uniform spatial distribution is the default for
c disk sources, this card is optional.
c
SI6 L 1 7
c Source Information 6.
c L indicates discrete values, in this case surface 1 or 7.
c
SP6 D 0.6 0.4
c Source Probability 6.
c Probability of each value on SI6.
c
DS7 L 2 8
c Dependent Source 7 (Depends as a function of SUR).
c L indicates discrete values, in this case cell 2 or 8,
c depending on whether surface 1 or 7, respectively, was
c chosen.
c
DS8 L x1 y1 z1 x2 y2 z2
c Dependent Source 8 (Depends as a function of SUR).
c L indicates discrete values, in this case the respective
c centers, of two disks, depending on whether surface 1 or 7
c was chosen.
c
DS9 S 11 12
c Dependent Source 9 (Depends as a function of SUR).
c S indicates other distributions, in this case the
c respective radii, of two disks, depending on whether
c surface 1 or 7 was chosen.
c
DS10 L u1 v1 w1 u2 v2 w2
c Dependent Source 10 (Depends as a function of SUR).
c L indicates discrete values, in this case the vectors
c that define a plane that the disk is on and the vector
c which DIR is measured from.
c In this streaming problem, AXS = VEC, and both depend on
c whether surface 1 or 7 was chosen.
c
SI11 0 37
```

```
SP11 -21 1
SI12 0 25
SP12 -21 1
c In this problem, the radius of the duct depends on the
c which duct was chosen.
```

Example 3:

```
SDEF CEL D1 ERG FCEL D2 POS FCEL D3
c
SC1 Source Cells
c Source Comment 1
c
SI1 L 1 2
c Source Information 1
c L indicates discrete values, in this case cell 1 or 2.
c The cell also determines the element in this problem.
c
SP1 D 2 1
c Source Probability 1
c Probability of each value on SI1. Here the cell with
c uranium is twice as likely as the thorium cell.
c Other distributions based on volume or decay rate,
c for example, are also possible.
c
SC2 source "spectra"
DS2 S 4 5
c Dependent Source 2 (Depends as a function of CEL).
c S indicates numbers following are themselves other
c distributions.
c In this example, if a particle starts in cell 1, then the
c ERG is defined by source distribution 4.
c
DS3 L 0 0 0 10.5 0 0
c
SC4 uranium nuclides
SI4 S 6 7
SP4 D 1 3
c Source Distribution and Probability 4.
c Here the specific uranium isotope is chosen, 238U is
c three times more likely than 235U.
c
SC5 thorium nuclide
SI5 S 8
SP5 D 1
c Source Distribution and Probability 5.
c Only one isotope of thorium is possible.
```

```
c
SC6 235U photon lines
SI6 L 1.0 2.0 $ E1 ... EI
SP6 D 1 2 $ I1 ... II
SC7 238U photon lines
SI7 L 0.1 0.2 $ E1 ... EI
SP7 D 2 1 $ I1 ... II
SC8 232Th photon lines
SI8 L .01 .02 $ E1 ... EI
SP8 D 1 1 $ I1 ... II
```

Of the particles from this source, 80% start on surface 10, and the rest start in cell 88. When a particle starts in cell 88, its position is sampled, with rejection, in the rectangular polyhedron bounded by $x = 20$ to 30, $y = -17$ to 36, and $z = -10$ to 10. When a particle starts on surface 10, its cell is found from its position and direction. The energy spectrum of the particles from surface 10 is different from the energy spectrum of the particles from cell 88. A zero after the S option invokes the default variable value.

Example 4:

```
SDEF SUR=D1 CEL FSUR D2 ERG FSUR D6
    X FSUR D3 Y FSUR D4 Z FSUR D5
c
SI1 L 11 0
c Source Information 1
c L indicates discrete values, in this case surface 11 or 0
c (meaning the source point is not on a surface).
c
SP1 0.8 0.2
DS2 L 0 88
c Dependent Source 2 (Depends as a function of FSUR).
c L indicates discrete values, in this case cell 0,
c (meaning the point may not be within a cell), or cell 88.
c Note that with Distribution 1, the source point may either be
c on surface 11 (80% probability) or within cell 88
c (20% probability).
c
DS6 S 61 62
SP61 -3 0.98 2.2
SP62 -3 1.05 2.7
c Source Probabilities 61 and 62.
c The -3 indicates the energy is sampled from the Watt Fission
c Spectrum.
c
DS3 S 0 31
SI31 20 30
SP31 0 1
```

```
c Source Information and Probabilities for Distribution 3.
c In this case, the 0 on the DS3 card indicates that no
c distribution is given; the default variable will be selected.
c For this case, if surface 11 was selected, the variable
c POS will default to the coordinates 0 0 0.
c If surface 11 was not selected, the source point must be
c within cell 88,and the x coordinate is sampled from a single
c bin histogram with values between 20 and 30.
c Since this value corresponds to a position, the units are cm.
c
DS4 S 0 41
SI41 -17 36
SP41 0 1
DS5 S 0 51
SI51 -10 10
SP51 0 1
```

This is an example of using the Q option. The low-energy particles from surface *m* come out with a cosine distribution of direction, but the higher-energy particles have a more nearly radial distribution. The energy values on the DS2 card need not be the same as any of the E_i on the SI1 card.

VI. SOURCE SUBROUTINE

When possible, you should take advantage of the standard sources provided by the code rather than write a source subroutine. When you write your own source subroutine, you lose features such as sampling from multiple distributions, using dependent distributions, and having frequency prints for each tabular distribution. Also, subroutine SRCDX is needed.

The standard sources, however, cannot handle all problems. If the general source (SDEF card), surface source (SSR), or criticality source (KCODE card) is unsuitable for a particular application, MCNP provides a mechanism to furnish your own source-modeling capability. The absence of SDEF, SSR, or KCODE cards causes MCNP to call subroutine SOURCE, which you must supply. Subroutine SOURCE specifies the coordinates, direction, weight, energy, and time of source particles as listed and defined on page 3–54. If the value of IPT (particle type) set by STARTP, which calls SOURCE, is not satisfactory, SOURCE must also specify IPT. STARTP sets IPT=1 (neutron) for MODE N, N P, and N P E; sets IPT=2 (photon) for MODE P and P E; and sets IPT=3 (electron) for MODE E. MCNP checks the user's source for consistency of cell, surface, direction, and position. If the source direction is anisotropic and there are point detectors or DXTRAN spheres, an SRCDX subroutine is also required (see page 4–62).

The following example of a subroutine SOURCE uses SIn, SPn, and SBn cards and demonstrates the use of MCNP subroutines SMPSRC, ROTAS, CHKCEL, and the function NAMCHG. The geometry is a 5-cm-long cylinder centered about the *y*-axis, divided into 5 cells by PY planes at 1-cm intervals. The 1-MeV monoenergetic source is a biased isotropic distribution that is also biased along the *y*-axis. The input distribution cards are

```
SI1     –1  0   1                       $ These 3 cards
SP1     0   1   1                       $ represent a biased
SB1     0   1   2                       $ isotropic distribution.
SI2     0   1   2   3   4   5           $ These 3 cards
SP2     0   4   2   2   1   1           $ represent a biased
SB2     0   1   1   2   2   4           $ distribution in y.
RDUM    1                               $ cylindrical radius
IDUM    2   4   6   8   10              $ source cells
```

This problem can be run with the general source by removing the RDUM and IDUM cards and adding:

```
SDEF   ERG=1   VEC=0 1 0   AXS=0 1 0   DIR=D1   EXT=D2   RAD=D3
SI3      0  1   $ represents a covering surface of radius 1
SP3   –21  1   $ samples from the power law with k=1
```

Below is an example source subroutine, which would replace the empty subroutine source provided with the source code.

```
subroutine source
 ! dummy subroutine. aborts job if source subroutine is missing.
 ! if nsr=0, subroutine source must be furnished by the user.
 ! at entrance, a random set of uuu,vvv,www has been defined. the
 ! following variables must be defined within the subroutine:
 ! xxx,yyy,zzz,icl,jsu,erg,wgt,tme and possibly ipt,uuu,vvv,www.
 ! subroutine srcdx may also be needed.
 use mcnp_global
 use mcnp_debug
 use mcnp_random

 implicit real(dknd) (a-h,o-z)

 real(dknd), dimension(1:3):: A

 wgt=1.0
 ! rdum(1)--Radius of Source Cylinder
 ! sample radius uniform in area.
 r=rdum(1)*sqrt(rang())
 ! Y coordinate position, probability and bias are
 ! defined in distribution 2 by the SI2, SP2, SB2 cards.
 ! sample for y.
 ! IB returns the index sampled and FI the interpolated fraction.
 ! neither are used in this example.
 call smpsrc(yyy,2,IB,FI)
 ! Sample for X and Z.
 TH=2.*pie*rang()
 xxx=-r*sin(TH)
```

```
 zzz=r*cos(TH)
 ! Direction is isotropic but biased in cone along Y axis
 ! Defined as distribution 1 by the SI1, SP1, SB1 cards.
 ! Sample for cone opening C=cos(NU)
 ! Rotas samples a direction U,V,W at an angle ARCCOS(C)
 ! From the reference vector UOLD(3)
 ! and at an azimuthal angle sampled uniformly.
 call smpsrc(C,1,IB, FI)
 UOLD(1)=0.
 UOLD(2)=1.
 UOLD(3)=0.
 call ROTAS(C,UOLD,A,LEV,IRT)
 UUU=A(1)
 VVV=A(2)
 WWW=A(3)
 ! Cell source - find starting cell.
 ! IDUM(1) - IDUM(5) -- list of source cells on IDUM card.
 JSU=0
 J=1
 I=1
 Imax=5
 do while ((J.NE.0) .and. (I.LE.Imax))
   icl=namchg(1,IDUM(I))
   call chkcel(ICL,2,J)
   i=i+1
 enddo
 if (J.ne.0) call expire(1,'Source', &
   & 'Source is not in any cells on the idum card.')
 ERG=1.
 TME=0.
 return
end subroutine source
```

VII. SRCDX SUBROUTINE

If a user has supplied a subroutine SOURCE that does not emit particles isotropically (uniform emission in all directions) and is using either a detector tally or DXTRAN in the calculations, then subroutine SRCDX must also be supplied to MCNP. The structure of this subroutine is the same as for subroutine SOURCE, except that usually only a single parameter, *PSC*, needs to be specified for each detector or set of DXTRAN spheres. *PSC* as defined in SRCDX is used to calculate the direct contribution from the source to a point detector, to the point selected for the ring detector or DXTRAN sphere. Other parameters may also be specified in SRCDX. For example, if a quantity such as particle energy and/or weight is directionally dependent, its value must be specified in both subroutine SOURCE and SRCDX. When using detectors and a subroutine SOURCE with an anisotropic distribution, check the direct source contribution to the detectors carefully to see if it is close to the expected result.

In general, it is best to have as few directionally-dependent parameters as possible in subroutine SOURCE. Directionally dependent parameters must also be dealt with in subroutine SRCDX.

The most general function for emitting a particle from the source in the laboratory system can be expressed as $p(\mu,\varphi)$, where μ is the cosine of the polar angle and φ is the azimuthal angle in the coordinate system of the problem. Most anisotropic sources are azimuthally symmetric and $p(\mu,\varphi) = p(\mu)/2\pi$. The quantity $p(\mu)$ is the probability density function for the μ variable only (that is, $\int p(\mu)\, d\mu = 1$, $p(\mu) \geq 0$). *PSC* is $p(\mu_0)$, where μ_0 is the cosine of the angle between the direction defining the polar angle for the source and the direction to a detector or DXTRAN sphere point in the laboratory system. (MCNP includes the 2π in the calculation automatically.) Note that $p(\mu_0)$ and hence *PSC* may have a value greater than unity and must be nonnegative. It is valuable to point out that every source must have a cumulative distribution function based on $p(\mu,\varphi)$ from which to sample angular dependence. The probability density function $p(\mu,\varphi)$ needs only to be considered explicitly for those problems with detectors or DXTRAN.

Table 4.1 gives the equations for *PSC* for six continuous source probability density functions. More discussion of probability density functions is given in the detector theory section of Chapter 2 (see page 2-104). The isotropic case is assumed in MCNP; therefore SRCDX is required only for the anisotropic case.

TABLE 4.1:
Continuous Source Distributions and their Associated PSCs

	Source Description	Source Distribution	*PSC*	Range of μ_0
1.	Isotropic	Uniform	0.5	$-1 \leq \mu_0 \leq 1$
2.	Surface Cosine	μ	$2\lvert\mu_0\rvert$	$0 \leq \mu_0 \leq 1$ (or $-1 \leq \mu_0 \leq 0$)
			0	$-1 \leq \mu_0 < 0$ (or $0 < \mu \leq 1$)
3.	Point Cosine	$\lvert\mu\rvert$	$\lvert\mu_0\rvert$	$-1 \leq \mu_0 \leq 1$
4.	Point Cosine*	$a + b\mu$	$\frac{2(a + b\mu_0)}{2a + b}$	$0 \leq \mu_0 \leq 1$
			$\left(\frac{2(a + b\mu_0)}{2a - b}\right)$	$(-1 \leq \mu_0 \leq 0)$
			0	$-1 \leq \mu_0 < 0$ (or $0 < \mu_0 \leq 1$)
5.	Point Cosine*	$a + b\mu$, $a \neq 0$	$\frac{a + b\mu_0}{2a}$	$-1 \leq \mu_0 \leq 1$

TABLE 4.1:
Continuous Source Distributions and their Associated PSCs

6.	Point Cosine*	$a + b\|\mu\|$	$\frac{a + b\|\mu_0\|}{2a + b}$	$-1 \le \mu_0 \le 1$

*The quantities a and b must have values such that *PSC* is always nonnegative and finite over the range of μ_0.

As an example of calculating μ_0, consider a spherical surface cosine source (type 2 in Table 4.1) with several point detectors in the problem. Assume that a point on the spherical surface has been selected at which to start a particle. The value of μ_0 for a detector is given by the scalar (or dot) product of the two directions; that is,

$$\mu_0 = uu' + vv' + ww' \quad , \tag{4.1}$$

where u, v, and w are the direction cosines of the line from the source point to the point detector location and u', v', and w' are the direction cosines for either the outward normal if the surface source is outward or the inward normal if the source is inward.

If $u = u'$, $v = v'$, and $w = w'$, then $\mu_0 = 1$, indicating that the point detector lies on the normal line. The value of *PSC* for the detector point is

$$\begin{aligned} PSC &= 2|\mu_0|, \quad \mu_0 > 0 \quad (\mu_0 < 0) \\ &= 0, \qquad \mu_0 \le 0 \quad (\mu_0 \ge 0) \quad , \end{aligned}$$

where the parenthetical values of μ_0 are for the inward-directed cosine distribution.

For $|\mu_0|$ less than 0.25 in case 2 of Table 4.1, *PSC* is less than 0.5, which is the value for an isotropic source. This means that source emissions for these values of $|\mu_0|$ are less probable than the isotropic case for this source distribution. The converse is also true. Note that if $|\mu_0|$ is greater than 0.5, *PSC* is greater than one, which is perfectly valid.

An example of a subroutine SRCDX for a surface outward cosine distribution is shown below. This is basically the technique that is used in MCNP to calculate *PSC* for a spherical surface source in a cosine distribution; the only difference is that MCNP uses the cosines of the direction from the center of the sphere that selected the source point because this is normal to the spherical surface. The primed direction cosines were calculated in the example below to aid in illustrating this example. The direction cosines u, v, and w as defined in Equation (4.1) have already been calculated in subroutine DDDET when SRCDX is called and are available through COMMON.

```
subroutine srcdx
 ! dummy subroutine for use with user-defined sources
 use mcnp_global
 use mcnp_params
 use mcnp_debug

 implicit real(dknd) (a-h,o-z)
```

```
! Calculate PSC for a surface (Sphere) outward cosine distribution.
! Find the direction cosines for this example based on the source
! point on the sphere (X,Y,Z).
  up=(XXX-RDUM(1))/RDUM(4)
  vp=(YYY-RDUM(2))/RDUM(4)
  wp=(ZZZ-RDUM(3))/RDUM(4)
! (RDUM(1),RDUM(2),RDUM(3)) are the coordinates of the center
! of the sphere from the RDUM card. RDUM(4) is the radius.
! U,V, and W have been calculated for the current point detector
! in subroutine DDDET.
  PSC=2.*MAX(ZERO,UUU*UP+VVV*VP+WWW*WP)

  return
end subroutine srcdx
```

For many sources, a discrete probability density function will be used. In this situation, a cumulative distribution function $P(\mu)$ is available and is defined as

$$P(\mu) = \int_{-1}^{\mu} p(\mu')d\mu' \text{ and } P_{i+1} = \sum_{j=1,i} p_j \Delta\mu_j \quad ,$$

where p_j is an average value of the probability density function in the interval $\Delta\mu_j$. Thus, the probability density function is a constant p_j in the interval $\Delta\mu_j$. For this case, there are N values of P_i with $P_1 = 0$, $P_{N+1} = 1.0$ and $P_{i-1} < P_i$. Each value of P_i has an associated value of μ_i. Because PSC is the derivative of $P(\mu_0)$, then

$$PSC = \frac{P_i - P_{i-1}}{\mu_i - \mu_{i-1}}, \ \mu_{i-1} \le \mu_0 < \mu_i \quad . \tag{4.2}$$

This is an average PSC between μ_{i-1} and μ_i and is also an average value of $p(\mu)$ in the specified range of μ.

Frequently, the cumulative distribution function is divided into N equally probable intervals. For this case,

$$PSC = \frac{1}{N} \frac{1}{\mu_i - \mu_{i-1}} \quad .$$

This is precisely the form used in MCNP for calculating contributions to the point detector for elastic scattering with $N = 32$.

An example of a subroutine SRCDX for a discrete probability density function is shown in the example on page 4–66. This subroutine would work with the subroutine SOURCE example on page 4–60, and would calculate $PSC = 1/2$ for the isotropic distribution.

A biased anisotropic distribution can also be represented by

SIn	μ_o	$\mu_1 \ldots \mu_n$
SPn	0	$p_1 \ldots p_n$
SBn	0	$q_1 \ldots q_n$

A reference vector u',v',w' for this distribution is also needed.

The subroutine SOURCE input cards can be modified for this case by changing the SI1, SP1, SB1, and RDUM cards as follows:

```
  SI1     -1   0   1       $ These 3 cards
  SP1      0   2   1       $ represent a biased
  SB1      0   1   2       $ anisotropic distribution.
RDUM       1   0   1   0   $ cylindrical radius and reference vector
```

SOURCE would sample this anisotropic distribution and SRCDX would calculate the appropriate *PSC* as shown in the following example.

```
I,SX.5
C THE VARIABLY DIMENSIONED BLOCK SPF HOLDS THE SI, SP,
C SB ARRAYS.
C THE KSD ARRAY IS A POINTER BLOCK TO THE SPF ARRAY.
C THE FOLLOWING STATEMENT FUNCTION IS DEFINED.

subroutine srcdx
! dummy subroutine for use with user-defined sources
use mcnp_global
use mcnp_params
use mcnp_debug

implicit real(dknd) (a-h,o-z)

! Calculate PSC for a surface (Sphere) outward cosine
! distribution.
! Find the direction cosines for this example based on the
! source.
! point on the sphere (X,Y,Z).
  up=(XXX-RDUM(1))/RDUM(4)
  vp=(YYY-RDUM(2))/RDUM(4)
  wp=(ZZZ-RDUM(3))/RDUM(4)
! (RDUM(1),RDUM(2),RDUM(3)) are the coordinates of the center
! of the sphere from the RDUM card. RDUM(4) is the radius.
! U,V, and W have been calculated for the current point detector
! in subroutine DDDET.
  PSC=2.*MAX(ZERO,UUU*UP+VVV*VP+WWW*WP)
```

```
! The variably dimensioned block SPF holds the SI, SP, SB
! Arrays.
! RDUM(2), RDUM(3),RDUM(4) -- Directional cosines
! for the source reference direction.
  AM=UUU*RDUM(2)+VVV*RDUM(3)+WWW*RDUM(4)
! KSD(4,1) is the length of the distribution.
! KSD(12,1) is the offset into the SPF block.
  DO 10 I=1,KSD(4,1)-1
10 IF(SPF(KSD(13,1)+1,I).LE.AM.AND.SPF(KSD(13,1)+1,I+1)&
  &.GE.AM GO TO 20
  GO TO 30
20 PSC=(SPF(KSD(13,1)+2,I+1)-SPF(KSD(13,1)+2,I))/ &
  & (SPF(KSD(13,1)+1,I+1)-SPF(KSD(13,1)+1,I))
  PSC=PSC*SPF(KSD(13,1)+3,I+1)
  return
30 PSC=0.
return
end subroutine srcdx
```

It is extremely important to note that the above case applies only when the source is anisotropic with azimuthal symmetry. For the general case,

$$PSC = 2\pi\ p(\mu_0, \varphi_0) \quad .$$

The 2π factor must be applied by the user because MCNP assumes azimuthal symmetry and, in effect, divides the user-defined *PSC* by 2π.

For a continuous $p(\mu, \varphi)$ function, *PSC* is calculated as above. In the case of a discrete probability density function,

$$PSC = 2\pi \cdot \overline{p(\mu_0, \varphi_0)} = \frac{2\pi(P_i - P_{i-1})}{(\mu_i - \mu_{i-1})(\varphi_i - \varphi_{i-1})}$$

$$= \frac{2\pi(P_i - P_{i-1})}{\Delta\mu_i \Delta\varphi_i}$$

where $\mu_{i-1} \le \mu_0 < \mu_i$, $\varphi_{i-1} \le \varphi_0 < \varphi_i$ and $\overline{p(\mu_0, \varphi_0)}$ is an average probability density function in the specified values of μ_0 and φ_0 and $P_i - P_{i-1}$ is the probability of selecting μ_0 and φ_0 in these intervals. For N equally probable bins and n equally spaced $\Delta\varphi$'s, each $2\pi/n$ wide,

$$PSC = \frac{n}{N}\ \frac{1}{\Delta\mu_i} \quad .$$

Another way to view this general case is by considering solid angles on the unit sphere. For an isotropic source, the probability $(P_i - P_{i-1})$ of being emitted into a specified solid angle is the ratio

of the total solid angle (4π) to the specified solid angle ($\Delta\varphi\Delta\mu$). Then, $PSC \equiv 0.5$. Thus, for the general case (normed to $PSC \equiv 0.5$ for an isotropic source)

$$PSC = \frac{(0.5)(P_i - P_{i-1})4\pi}{\Delta\mu\Delta\varphi_i} = \frac{2\pi(P_i - P_{i-1})}{\Delta\mu_i\Delta\varphi_i} \quad .$$

Note that *PSC* is greater than 0.5 if the specified solid angle $\Delta\mu\Delta\varphi_i$ is less than $(P_i - P_{i\text{-}1})4\pi$. This is the same as the previous general expression.

CAUTIONS:

Be extremely careful when using your own subroutine SOURCE with either detectors or DXTRAN. This caution applies to the calculation of the direct contribution from the source to a point detector, point on a ring, or point on a DXTRAN sphere. Not only is there the calculation of the correct value of PSC for an anisotropic source, but there may also be problems with a biased source.

For example, if an isotropic source is biased to start only in a cone of a specified angle (for example, ψ), the starting weight of each particle should be $WGT*(1 - cos\ \psi)/2$, where *WGT* is the weight of the unbiased source (that is, *WGT* is the expected weight from a total source). The weight in SRCDX must be changed to the expected weight *WGT* to calculate the direct contribution to a point detector correctly if *PSC* is defined to be 0.5.

This example can be viewed in a different way. The probability density function for the above biased source is

$$p(\mu) = \frac{1}{1 - cos\Psi} \ , \ \text{for} \ \ cos\Psi \le \mu \le 1$$
$$= 0 \qquad \text{for} \ -1 \le \mu < cos\Psi \quad .$$

Thus, *PSC* is this constant everywhere in the cone and zero elsewhere. Multiplying this PSC and biased starting weight gives

$$WGT * (1 - cos\ \psi) * 0.5/(1 - cos\ \psi)$$

or $WGT * 0.5$, which is the expected result for an isotropic source.

Another source type that requires caution is for a user-supplied source that is energy-angle correlated. For example, assume a source has a Gaussian distribution in energy where the mean of the Gaussian is correlated in some manner with μ. In subroutine SRCDX, the μ_0 to a point detector must be calculated and the energy of the starting particle must be sampled from the Gaussian based on this μ_0. This must be done for each point detector in the problem, thus guaranteeing that the direct source contribution to each detector will be from the proper energy spectrum. The original energy of the starting particle as well as all the other starting parameters selected in subroutine SOURCE are automatically restored after the direct source contribution to detectors is made. Thus, the subroutine SOURCE is still sampled correctly.

CHAPTER 5 - OUTPUT

WHAT IS COVERED IN CHAPTER 5

This chapter shows annotated output from four test problems and an event log print:

DEMO	illustrates tally flexibility
TEST1	annotated tables produced by PRINT card
CONC	output associated with detectors and detector diagnostics
KCODE	output from a criticality calculation (GODIVA)
Event log	event log and debug prints

Portions of the complete output have been excluded. The line “SKIP nnn LINES OF OUTPUT” indicates these omissions.

The event log and debug prints help find errors if you set up a geometry improperly or modify the code. The DBCN input card also is useful when finding errors but is not discussed here.

MCNP prints out warning messages if needed. Do not ignore these warning messages. Look up the pertinent section in the manual if you need explanation to help you understand what you are being warned about.

I. DEMO PROBLEM AND OUTPUT

DEMO has a point isotropic neutron source (SDEF) in the center of a tungsten cube (material M2), with energy uniformly distributed from 0.1 to 10 MeV (SI1,SP1). The neutron surface flux is calculated across each facet of the cube (F2), across the sum of all facets (F22), and across the sum of some of the facets (F12). A pulse height tally (F8) is made in the tungsten cell. Selected tally results from the output file follow.

The FQ cards in the DEMO input file changes the tally printing order in the OUTP file. Depending upon what you are interested, the tally output can be made more readable. FQ2 causes energy to be printed as a function of surface. FQ22 causes surface to be printed as a function of energy. FQ62 prints multiplier bins as a function of energy for the two surfaces desired. The NT (no total) and T (total) features also are illustrated in Tallies 62 and 22, respectively. The generalized FM62 card used with the F62:N tally is a useful feature for normalization, unit conversion, reaction rate, etc., and has three multiplier bins instead of one. Finally, the TF62 card causes the tally fluctuation chart for the second surface, the first multiplier bin (default), and the second energy bin to be printed. By default the fluctuation chart for Tally 62 would contain information for the first surface, the first multiplier bin, and the last energy bin.

The F8:E card provides a pulse height tally in cell 1. The F8 tally capability is currently limited to an analog problem when neutrons are present. The default implicit neutron capture is turned off by the CUT:N card. The pulse height tally records the energy deposited in a cell by both photons and electrons, even if only E or P is on the F8 card. The F8 tally is not available for

neutrons and will return an error if attempted. The output contains a warning that “f8 tally unreliable since neutron transport nonanalog.” This message means some nonanalog neutron events such as (n,2n) may occur where the history neutron energy is not conserved. (Neutron energies are conserved in the average of many histories.) Thus, photon production will not be exactly correct for such a neutron history.

A tally fluctuation chart bin analysis follows each tally. Only an analysis for Tally 8 is shown in this example. This analysis checks the variance of the variance (VOV) as well as the general behavior of the history score probability density function of each tally and provides an additional set of checks to assess the reliability of a tally. Ten different statistical checks are analyzed for the tally and presented in tabular form. The results of the ten checks are presented in “pass? yes/no” table format. These checks do not guarantee the absolute reliability of the tally, but they assist in identifying tallies that have not been sampled well. A more complete description of the significance of each entry in the tally fluctuation section is presented in TEST1 beginning on page 5-8.

There are three possible physics treatments for photons. The first is the explicit p,e treatment (MODE P E) where photons generate electrons, which are tracked and generate photons (ad infinitum). This is the most accurate model but is costly in terms of run time. The second physics treatment is MODE P only that uses the default thick target bremsstrahlung (TTB) model where electrons are generated in the direction of the incident photon and are immediately annihilated after generating bremsstrahlung photons. The third photon physics treatment is a MODE P only with the TTB turned off (IDES=1 on the PHYS card). Bremsstrahlung photons from electrons are completely ignored, which is a poor approximation for a high Z material.

The choice of which photon physics treatment to use depends on the objective of the problem being solved. Using a test problem similar to that of the cube, it was found that F4 photon tallies for the three treatments agreed reasonably well above 2 MeV. Below 1 MeV, the results from the simplest model (photon mode, no bremstrahlung) began to diverge from the full physics model results. Below the annihilation photon peak, the TTB treatment also begins to diverge from the MODE P E results. The choice of physics treatment had a drastic impact on the runtime of the problem. To run 104,000 particles on a SGI 2000 MODE P with and without TTB took 0.14 and 0.10 minutes respectively, while the full physics MODE P E problem took 27.28 minutes. If it is necessary to model photon generation and transport below 0.5 MeV, then the full MODE P E physics model should be used. However, if these low energy photons are not important, then the MODE P without the TTB model should be sufficient.

The small table preceding the summary of statistical checks indicates that some of the tally scores were not made for some reason. In the case of Tally 2, 93,547 particles did not score in any of the bins because their energy was greater than that of the upper limit of the highest energy bin. Tallies 12, 22, and 62 also had significant numbers of particles that had energies above the highest energy bin. Nonscoring particles are a concern because for Tally 2: the number of particles not scoring is nearly 90% of the initial source particles. This can be fixed by simply increasing the upper limit of the last energy bin or by adding more bins to cover the energy range up to the maximum energy of the source (10 MeV). Note that only Tally 8 passed all ten statistical checks, which implies that valid statistical confidence intervals can be created for the tally fluctuation chart bin.

```
                                _
          .-_ _    _  .-   .-   |_
          | | |  (_  | |  |_)   _)
                         |
 +--------------------------------------------------------------------+
 |   This program was prepared by the Regents of the University of    |
 |California at Los Alamos National Laboratory (the University) under |
 |  contract number W-7405-ENG-36 with the U.S. Department of Energy  |
 |(DoE).  The University has certain rights in the program pursuant to|
 |  the contract and the program should not be copied or distributed  |
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 | University makes any warranty, express or implied, or assumes any  |
 |     liability or responsibility for the use of this software.      |
 +--------------------------------------------------------------------+

1mcnp     version 5     ld=12212002                    01/08/03 17:38:35
 ***********************************************************************
 i=demo n=demo.

    1-       demo: a box with flux across surfaces in various combinations
    2-       1     2 -1.6 -1
    3-       2     0  1
    4-
    5-       1 rpp  -1 1 -1 1 -1 1
    6-
    7-       cut:n 10000 0.0 0.0 0.0
    8-       mode  n p e
 comment. photonuclear physics may be needed (phys:p).
    9-       sdef  pos=0 0 0 cel=1 wgt=1 erg=d1
   10-       si1   0.1 10
   11-       sp1   0 1
   12-       imp:n,p,e  1 0
   13-       e0    0.2 0.4 0.6 0.8 1
   14-       f2:n  1.1 1.2 1.3 1.4 1.5 1.6
   15-       fq2   e f
   16-       f12:n (1.3 1.5) (1.4 1.6) (1.2 1.1)
   17-       f22:n 1.1 1.2 1.3 1.4 1.5 1.6 t
   18-       fq22  f e
   19-       m1    6000 1
 warning. material    1 is used only for a perturbation or tally.
   20-       m2    74000 1
   21-       f62:n 1.3 1.4
   22-       fm62  (1 2 (1 -4) (-2)) (1 1 1)
   23-       e62   0.2 0.4 0.6 0.8 1 nt
   24-       fq62  m e
```

probid = 01/08/03 17:38:35

```
   25-       tf62  2 5j 2
   26-       f8:e  1

 warning. f8 tally unreliable since neutron transport nonanalog.
SKIP 416 LINES OF OUTPUT
1tally  22        nps =   104000
          tally type 2    particle flux averaged over a surface.       units   1/cm**2
          tally for  neutrons

          areas
               surface:      1.1          1.2          1.3          1.4          1.5          1.6          total
                        4.00000E+00  4.00000E+00  4.00000E+00  4.00000E+00  4.00000E+00  4.00000E+00  2.40000E+01

       energy:       2.0000E-01           4.0000E-01           6.0000E-01           8.0000E-01           1.0000E+00
     surface
       1.1       7.30357E-04 0.0942   1.29205E-03 0.0513   1.18025E-03 0.0653   1.17268E-03 0.0651   1.16323E-03 0.0534
       1.2       6.57953E-04 0.0686   1.15327E-03 0.0508   1.05268E-03 0.0545   1.13600E-03 0.0519   1.18122E-03 0.0643
       1.3       6.33307E-04 0.0756   1.27882E-03 0.0717   1.13639E-03 0.0528   1.17168E-03 0.0521   1.13825E-03 0.0524
       1.4       6.52386E-04 0.0705   1.07859E-03 0.0576   1.21496E-03 0.0528   1.25657E-03 0.0495   1.05426E-03 0.0537
       1.5       6.11844E-04 0.0711   1.21984E-03 0.0522   1.25661E-03 0.0487   1.26987E-03 0.0496   1.15210E-03 0.0516
       1.6       6.60230E-04 0.0686   1.15995E-03 0.0522   1.19812E-03 0.0515   1.10335E-03 0.0526   1.07351E-03 0.0543
      total      6.57680E-04 0.0312   1.19709E-03 0.0231   1.17317E-03 0.0221   1.18503E-03 0.0217   1.12710E-03 0.0224

       energy:          total
     surface
       1.1       5.53857E-03 0.0284
       1.2       5.18112E-03 0.0258
       1.3       5.35846E-03 0.0273
       1.4       5.25677E-03 0.0248
       1.5       5.51027E-03 0.0237
       1.6       5.19516E-03 0.0244
      total      5.34006E-03 0.0102
SKIP 157 LINES OF OUTPUT
1tally   8        nps =   104000
          tally type 8    pulse height distribution.                   units   number
          tally for  photons   electrons

 cell  1
      energy
    1.0000E-03   1.88365E-02 0.0224
    1.8191E+00   1.50962E-02 0.0250
    3.6372E+00   2.59615E-04 0.1924
    5.4553E+00   7.69231E-05 0.3535
    7.2734E+00   4.80769E-05 0.4472
    9.0915E+00   1.92308E-05 0.7071
    1.0910E+01   0.00000E+00 0.0000
    1.2728E+01   0.00000E+00 0.0000
    1.4546E+01   0.00000E+00 0.0000
    1.6364E+01   0.00000E+00 0.0000
```

```
   1.8182E+01   0.00000E+00 0.0000
   2.0000E+01   0.00000E+00 0.0000
     total      3.43365E-02 0.0164
```

==========

```
          results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally   8

tfc bin     --mean--      ---------relative error---------      ----variance of the variance----      --figure of merit--      -pdf-
behavior    behavior      value    decrease    decrease rate      value    decrease    decrease rate       value     behavior     slope

desired      random       <0.10      yes       1/sqrt(nps)       <0.10      yes         1/nps           constant    random      >3.00
observed     random        0.02      yes           yes            0.00      yes          yes            constant    random      10.00
passed?        yes          yes      yes           yes             yes      yes          yes               yes        yes         yes
```

==========

```
this tally meets the statistical criteria used to form confidence intervals: check the tally fluctuation chart to verify.
the results in other bins associated with this tally may not meet these statistical criteria.

----- estimated confidence intervals:  -----

estimated asymmetric confidence interval(1,2,3 sigma): 3.3776E-02 to 3.4906E-02; 3.3212E-02 to 3.5470E-02; 3.2647E-02 to 3.6035E-02
estimated  symmetric confidence interval(1,2,3 sigma): 3.3772E-02 to 3.4901E-02; 3.3207E-02 to 3.5466E-02; 3.2643E-02 to 3.6030E-02

1analysis of the results in the tally fluctuation chart bin (tfc) for tally   8 with nps =    104000    print table 160


normed average tally per history  = 3.43365E-02          unnormed average tally per history  = 3.43365E-02
estimated tally relative error    = 0.0164               estimated variance of the variance  = 0.0003
relative error from zero tallies  = 0.0164               relative error from nonzero scores  = 0.0000

number of nonzero history tallies =        3571          efficiency for the nonzero tallies  = 0.0343
history number of largest  tally  =          13          largest  unnormalized history tally = 1.00000E+00
(largest  tally)/(average tally)  = 2.91235E+01          (largest  tally)/(avg nonzero tally)= 1.00000E+00

(confidence interval shift)/mean  = 0.0001               shifted confidence interval center  = 3.43410E-02


if the largest  history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:

     estimated quantities          value at nps          value at nps+1          value(nps+1)/value(nps)-1.

     mean                          3.43365E-02           3.43458E-02                  0.000270
     relative error                1.64444E-02           1.64420E-02                 -0.000145
     variance of the variance      2.51529E-04           2.51451E-04                 -0.000310
     shifted center                3.43410E-02           3.43410E-02                  0.000000
```

```
      figure of merit                 4.91883E+03             4.92026E+03                     0.000290

 the 100 largest  history tallies appear to have a  maximum value of about 1.00000E+00
 the large score tail of the empirical history score probability density function appears to have no unsampled regions.

 fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (1.383E+05)*( 1.886E-01)**2 = (1.383E+05)*(3.556E-02) = 4.919E+03

1    some tally scores were not made for various reasons:

                                  beyond last bin     not in
                  tally      angle   energy   time     user
                    2          0    93547       0        0
                   12          0    93547       0        0
                   22          0    93547       0        0
                   62          0    31134       0        0

1status of the statistical checks used to form confidence intervals for the mean for each tally bin


 tally   result of statistical checks for the tfc bin (the first check not passed is listed) and error magnitude check for all bins

     2   missed  2 of 10 tfc bin checks: the figure of merit has a trend during the last half of the problem
         passed all bin error check:    36 tally bins all have relative errors less than 0.10 with no zero bins

    12   missed  3 of 10 tfc bin checks: the variance of the variance does not monotonically decrease over the last half of problem
         passed all bin error check:    18 tally bins all have relative errors less than 0.10 with no zero bins

    22   missed  2 of 10 tfc bin checks: the figure of merit has a trend during the last half of the problem
         passed all bin error check:    42 tally bins all have relative errors less than 0.10 with no zero bins

    62   missed  1 of 10 tfc bin checks: there is insufficient tfc bin tally information to estimate the large tally slope reliably
         passed all bin error check:    30 tally bins all have relative errors less than 0.10 with no zero bins

     8   passed the 10 statistical checks for the tally fluctuation chart bin result
         missed all bin error check:    13 tally bins had     6 bins with zeros and     4 bins with relative errors exceeding 0.10


 the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

 the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

 warning.     4 of the   5 tally fluctuation chart bins did not pass all 10 statistical checks.
 warning.     1 of the   5 tallies had bins with relative errors greater than recommended.
1tally fluctuation charts

                     tally    2                                  tally   12                                  tally   22
      nps       mean      error   vov  slope    fom       mean      error   vov  slope    fom       mean      error   vov  slope    fom
     8000   4.6911E-03 0.0945 0.0153  0.0    2453   5.6745E-03 0.0580 0.0033  0.0    6503   4.6911E-03 0.0945 0.0153  0.0    2453
    16000   4.8398E-03 0.0645 0.0059  0.0    2305   5.6055E-03 0.0416 0.0020  3.2    5549   4.8398E-03 0.0645 0.0059  0.0    2305
```

```
    24000   5.2302E-03 0.0505 0.0035  0.0    2303   5.5189E-03 0.0342 0.0013  3.5    5044   5.2302E-03 0.0505 0.0035  0.0    2303
    32000   5.2548E-03 0.0433 0.0025  2.0    2278   5.5052E-03 0.0299 0.0013  2.2    4789   5.2548E-03 0.0433 0.0025  2.0    2278
    40000   5.3488E-03 0.0401 0.0074  1.7    2154   5.3085E-03 0.0272 0.0011  2.4    4662   5.3488E-03 0.0401 0.0074  1.7    2154
    48000   5.3088E-03 0.0364 0.0056  1.7    2143   5.3638E-03 0.0248 0.0009  2.3    4639   5.3088E-03 0.0364 0.0056  1.7    2143
    56000   5.5486E-03 0.0425 0.0630  1.5    1333   5.3419E-03 0.0231 0.0009  2.1    4510   5.5486E-03 0.0425 0.0630  1.5    1333
    64000   5.6121E-03 0.0383 0.0534  1.6    1451   5.3601E-03 0.0216 0.0008  2.0    4577   5.6121E-03 0.0383 0.0534  1.6    1451
    72000   5.5574E-03 0.0355 0.0468  1.6    1497   5.3959E-03 0.0203 0.0007  2.0    4591   5.5574E-03 0.0355 0.0468  1.6    1497
    80000   5.5380E-03 0.0332 0.0408  1.6    1575   5.3570E-03 0.0193 0.0006  2.1    4683   5.5380E-03 0.0332 0.0408  1.6    1575
    88000   5.5665E-03 0.0316 0.0340  1.6    1591   5.3594E-03 0.0192 0.0064  1.9    4315   5.5665E-03 0.0316 0.0340  1.6    1591
    96000   5.5762E-03 0.0298 0.0302  1.6    1617   5.3934E-03 0.0188 0.0091  1.9    4043   5.5762E-03 0.0298 0.0302  1.6    1617
   104000   5.5386E-03 0.0284 0.0274  1.7    1654   5.4344E-03 0.0179 0.0078  1.9    4143   5.5386E-03 0.0284 0.0274  1.7    1654


                    tally   62                                  tally    8
      nps      mean      error   vov  slope    fom      mean      error   vov  slope    fom
     8000   2.2306E-05 0.2087 0.0992  0.0     502   3.3500E-02 0.0601 0.0034  0.0    6068
    16000   2.0345E-05 0.1462 0.0436  0.0     449   3.2250E-02 0.0433 0.0018 10.0    5117
    24000   1.9682E-05 0.1195 0.0259  0.0     412   3.2708E-02 0.0351 0.0012 10.0    4775
    32000   2.0456E-05 0.1000 0.0167  0.0     427   3.2594E-02 0.0305 0.0009 10.0    4611
    40000   2.1405E-05 0.0960 0.0550  0.0     375   3.2850E-02 0.0271 0.0007 10.0    4700
    48000   2.1120E-05 0.0866 0.0429  0.0     379   3.3104E-02 0.0247 0.0006 10.0    4671
    56000   2.1137E-05 0.0793 0.0335  0.0     382   3.3304E-02 0.0228 0.0005 10.0    4638
    64000   2.1388E-05 0.0732 0.0264  0.0     397   3.3734E-02 0.0212 0.0004 10.0    4751
    72000   2.2092E-05 0.0691 0.0232  0.0     396   3.4250E-02 0.0198 0.0004 10.0    4823
    80000   2.1131E-05 0.0666 0.0212  0.0     392   3.4000E-02 0.0188 0.0003 10.0    4892
    88000   2.0994E-05 0.0634 0.0184  0.0     395   3.4284E-02 0.0179 0.0003 10.0    4950
    96000   2.1022E-05 0.0602 0.0160  0.0     395   3.4656E-02 0.0170 0.0003 10.0    4933
   104000   2.1130E-05 0.0574 0.0140  0.0     404   3.4337E-02 0.0164 0.0003 10.0    4919

************************************************************************************************************************
dump no.    2 on file demo.r       nps =    104000     coll =        9352864     ctm =    0.75     nrn =       46800292


       15 warning messages so far.


run terminated when    104000 particle histories were done.

computer time =    0.83 minutes

mcnp     version 5     12212002                    01/08/03 17:39:29                    probid =  01/08/03 17:38:35
```

II. TEST1 PROBLEM AND OUTPUT

TEST1 defines a disk of concrete 100-cm thick, with a 75-cm radius. A 14.19 MeV neutron source is incident at a point in the center of a face of the disk (surface 2) and perpendicular to it. Several neutron and photon tallies are made on surface 18 and in cell 17. There is no energy cutoff and the simple physics treatment that includes implicit capture is used for photons with energy greater than 0.001 MeV.

The disk is divided into 16 cells, each 6.25-cm thick, as seen in Figure 5-1. The cell numbers are circled; surface numbers are not circled. The neutron importance of each cell varies from 0 in cell 1 to 32 in cell 17. Photon importances are set equal to neutron importances (see IMP cards in Chapter 3 on page 3-34). The problem ran 10,000 particles and the tally means, errors, and Figures of Merit (FOMs) shown in the tally fluctuation charts seem to be stable.

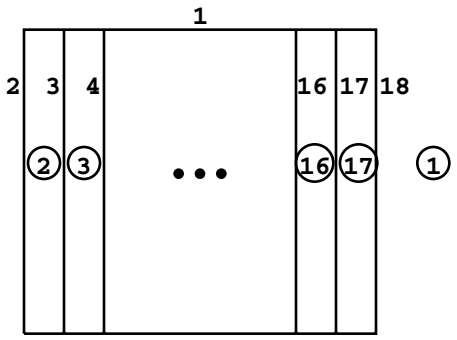


Figure 5-1

The weight window generator was used to generate a better importance function for subsequent runs. The resulting cards are printed at the end of the TEST1 output file and can be copied into an input file to be run a second time. Generation of weight windows did not affect the results of TEST1 but did slow down the calculation by 14%. When the importances in TEST1 were replaced by the generated weight windows (WWP and WWN cards), the problem took 14.27 minutes to run 10000 particles vs. 10.01 minutes for TEST1. However, the photon FOMs increased by a factor of 2 to 3 and the errors decreased by one-half, while the means appeared to remain stable. The neutron means, errors, and FOMs stayed approximately the same, indicating that they were already well chosen to optimize Tally 12. The use of the mesh-based weight window generator instead of the cell-based weight window generator for this problem did not significantly improve the FOM because the cell-based weight windows were quite good.

Following is a partial output from TEST1. The symbol X appearing left of a table title indicates that table does not appear in the OUTP file unless the PRINT option or card is used. If N*n*, where *n* is an integer, appears before an item on a page or below a column, that item is explained or discussed in Note N*n* in the text following the output.

```
                                _
          .  _ _     _   .  _    .  _    |_
          | | | |   (_   | |   |_)     _)
                              |
 +--------------------------------------------------------------------+
 |   This program was prepared by the Regents of the University of    |
 |California at Los Alamos National Laboratory (the University) under |
 |  contract number W-7405-ENG-36 with the U.S. Department of Energy  |
 |(DoE).  The University has certain rights in the program pursuant to|
 |  the contract and the program should not be copied or distributed  |
 | outside your organization.  All rights in the program are reserved |
 |by the DoE and the University.  Neither the U.S. Government nor the |
 | University makes any warranty, express or implied, or assumes any  |
 |     liability or responsibility for the use of this software.      |
 +--------------------------------------------------------------------+

N1 1mcnp     version 5     ld=12212002                    01/08/03 17:40:43
 ***********************************************************************                probid =  01/08/03 17:40:43

N2 i=test1 n=test1.

N3 1-       test1: 100 cm thick concrete disk with 15 splitting surfaces
    2-       c
    3-        1     0           1 : -2 : 18
    4-        2     1 -2.2505  -1  -3   2
    5-        3     1 -2.2505  -1  -4   3
    6-        4     1 -2.2505  -1  -5   4
    7-        5     1 -2.2505  -1  -6   5
    8-        6     1 -2.2505  -1  -7   6
    9-        7     1 -2.2505  -1  -8   7
   10-        8     1 -2.2505  -1  -9   8
   11-        9     1 -2.2505  -1  -10  9
   12-       10     1 -2.2505  -1  -11  10
   13-       11     1 -2.2505  -1  -12  11
   14-       12     1 -2.2505  -1  -13  12
   15-       13     1 -2.2505  -1  -14  13
   16-       14     1 -2.2505  -1  -15  14
   17-       15     1 -2.2505  -1  -16  15
   18-       16     1 -2.2505  -1  -17  16
   19-       17     1 -2.2505  -1  -18  17
   20-
   21-        1     cy  75
   22-        2     py  0
   23-        3     py  6.25
   24-        4     py  12.50
   25-        5     py  18.75
```

```
   26-         6     py  25.00
   27-         7     py  31.25
   28-         8     py  37.50
   29-         9     py  43.75
   30-        10     py  50.00
   31-        11     py  56.25
   32-        12     py  62.50
   33-        13     py  68.75
   34-        14     py  75.00
   35-        15     py  81.25
   36-        16     py  87.50
   37-        17     py  93.75
   38-        18     py  100.00
   39-
   40-        mode   n p
 comment. photonuclear physics may be needed (phys:p).
   41-        c        the following is los alamos concrete
   42-        m1      1001 8.47636e-2
   43-               8016 6.04086e-1
   44-              11023 9.47250e-3
   45-              12000 2.99826e-3
   46-              13027 2.48344e-2
   47-              14000 2.41860e-1
   48-              19000 6.85513e-3
   49-              20000 2.04808e-2
   50-              26054 2.74322e-4
   51-              26056 4.26455e-3
   52-              26057 9.76401e-5
   53-              26058 1.30187e-5
N4 54-        sdef   pos=0 0 0 cel=2 wgt=1 vec=0 1 0 sur=2 dir=1 erg=14.19
   55-        imp:n  0 1 5r 2 2 2 4 4 4 8 8 16 32
   56-        imp:p  0 1 5r 2 2 2 4 4 4 8 8 16 32
N5 57-        pwt    0 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1.7 -1.4 -1.0 -0.7 -0.4 -0.3 -0.2
   58-        f1:p   18
   59-        f11:n  18
   60-        fc12   optimize weight window generator on tally 12
   61-        f12:p  18
   62-        e12    20
   63-        wwg    12 2
   64-        f6:n,p 17
   65-        e6     .00001 .0001 .001 .01 .05 .1 .5 1 13i 15 20
   66-        f16:n  17
   67-        f26:p  17
   68-        f34:n  17
   69-        fm34   -1 1 1 -4
N6 70-        e0     .0001 .001 .01 .05 .1 .5 1 13i 15 20
   71-        phys:n  15  0
   72-        phys:p  .001
```

```
   73-       nps     10000
   74-       print
   75-
```

x 1source print table 10

N7 values of defaulted or explicitly defined source variables

cel	2.0000E+00		
sur	2.0000E+00		
erg	1.4190E+01		
tme	0.0000E+00		
dir	1.0000E+00		
pos	0.0000E+00	0.0000E+00	0.0000E+00
x	0.0000E+00		
y	0.0000E+00		
z	0.0000E+00		
rad	0.0000E+00		
ext	0.0000E+00		
axs	0.0000E+00	0.0000E+00	0.0000E+00
vec	0.0000E+00	1.0000E+00	0.0000E+00
ccc	0.0000E+00		
nrm	1.0000E+00		
ara	0.0000E+00		
wgt	1.0000E+00		
eff	1.0000E-02		
par	0.0000E+00		
tr	0.0000E+00		

```
 order of sampling source variables.
 cel sur pos vec dir erg tme
```

x 1tally 11 print table 30

N8 tally type 1 number of particles crossing a surface.
tally for neutrons

N9 warning. energy bin limits adjusted for tally 11
surfaces 18

N10 energy bins

```
      0.00000E+00  to  1.00000E-04 mev
      1.00000E-04  to  1.00000E-03 mev
      1.00000E-03  to  1.00000E-02 mev
      1.00000E-02  to  5.00000E-02 mev
      5.00000E-02  to  1.00000E-01 mev
      1.00000E-01  to  5.00000E-01 mev
      5.00000E-01  to  1.00000E+00 mev
```

```
      1.00000E+00  to  2.00000E+00 mev
      2.00000E+00  to  3.00000E+00 mev
      3.00000E+00  to  4.00000E+00 mev
      4.00000E+00  to  5.00000E+00 mev
      5.00000E+00  to  6.00000E+00 mev
      6.00000E+00  to  7.00000E+00 mev
      7.00000E+00  to  8.00000E+00 mev
      8.00000E+00  to  9.00000E+00 mev
      9.00000E+00  to  1.00000E+01 mev
      1.00000E+01  to  1.10000E+01 mev
      1.10000E+01  to  1.20000E+01 mev
      1.20000E+01  to  1.30000E+01 mev
      1.30000E+01  to  1.40000E+01 mev
      1.40000E+01  to  1.50000E+01 mev
      total bin
SKIP 164 LINES OF OUTPUT
```

X 1material composition print table 40

```
 material
  number     component nuclide, atom fraction

     1            1001, 8.47636E-02       8016, 6.04086E-01      11023, 9.47250E-03      12000, 2.99826E-03
                 13027, 2.48344E-02      14000, 2.41860E-01      19000, 6.85513E-03      20000, 2.04808E-02
                 26054, 2.74322E-04      26056, 4.26455E-03      26057, 9.76401E-05      26058, 1.30187E-05
```

```
 material
  number     component nuclide, mass fraction

     1            1001, 4.53200E-03       8016, 5.12597E-01      11023, 1.15530E-02      12000, 3.86599E-03
                 13027, 3.55480E-02      14000, 3.60364E-01      19000, 1.42190E-02      20000, 4.35460E-02
                 26054, 7.84990E-04      26056, 1.26547E-02      26057, 2.94921E-04      26058, 4.00121E-05
```

X 1cell volumes and masses print table 50

N11

cell		atom density	gram density	input volume	calculated volume	mass	pieces	reason volume not calculated
1	1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0	infinite
2	2	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	
3	3	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	
4	4	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	
5	5	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	
6	6	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	
7	7	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	
8	8	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1	

9	9	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
10	10	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
11	11	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
12	12	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
13	13	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
14	14	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
15	15	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
16	16	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1
17	17	7.18983E-02	2.25050E+00	0.00000E+00	1.10447E+05	2.48560E+05	1

x 1surface areas print table 50

surface		input area	calculated area	reason area not calculated
1	1	0.00000E+00	4.71239E+04	
2	2	0.00000E+00	1.76715E+04	
3	3	0.00000E+00	1.76715E+04	
4	4	0.00000E+00	1.76715E+04	
5	5	0.00000E+00	1.76715E+04	
6	6	0.00000E+00	1.76715E+04	
7	7	0.00000E+00	1.76715E+04	
8	8	0.00000E+00	1.76715E+04	
9	9	0.00000E+00	1.76715E+04	
10	10	0.00000E+00	1.76715E+04	
11	11	0.00000E+00	1.76715E+04	
12	12	0.00000E+00	1.76715E+04	
13	13	0.00000E+00	1.76715E+04	
14	14	0.00000E+00	1.76715E+04	
15	15	0.00000E+00	1.76715E+04	
16	16	0.00000E+00	1.76715E+04	
17	17	0.00000E+00	1.76715E+04	
18	18	0.00000E+00	1.76715E+04	

x 1cells print table 60

cell	mat	atom density	gram density	volume	mass	pieces	neutron importance	photon importance	photon wt generation
1	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0	0.0000E+00	0.0000E+00	0.000E+00
2	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	1.0000E+00	1.0000E+00	-1.000E+01
3	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	1.0000E+00	1.0000E+00	-9.000E+00
4	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	1.0000E+00	1.0000E+00	-8.000E+00
5	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	1.0000E+00	1.0000E+00	-7.000E+00
6	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	1.0000E+00	1.0000E+00	-6.000E+00
7	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	1.0000E+00	1.0000E+00	-5.000E+00
8	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	2.0000E+00	2.0000E+00	-4.000E+00
9	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	2.0000E+00	2.0000E+00	-3.000E+00
10	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	2.0000E+00	2.0000E+00	-2.000E+00
11	1	7.18983E-02	2.25050E+00	1.10447E+05	2.48560E+05	1	4.0000E+00	4.0000E+00	-1.700E+00

```
    12    12    1  7.18983E-02 2.25050E+00 1.10447E+05 2.48560E+05     1  4.0000E+00 4.0000E+00 -1.400E+00
    13    13    1  7.18983E-02 2.25050E+00 1.10447E+05 2.48560E+05     1  4.0000E+00 4.0000E+00 -1.000E+00
    14    14    1  7.18983E-02 2.25050E+00 1.10447E+05 2.48560E+05     1  8.0000E+00 8.0000E+00 -7.000E-01
    15    15    1  7.18983E-02 2.25050E+00 1.10447E+05 2.48560E+05     1  8.0000E+00 8.0000E+00 -4.000E-01
    16    16    1  7.18983E-02 2.25050E+00 1.10447E+05 2.48560E+05     1  1.6000E+01 1.6000E+01 -3.000E-01
    17    17    1  7.18983E-02 2.25050E+00 1.10447E+05 2.48560E+05     1  3.2000E+01 3.2000E+01 -2.000E-01

N12total                                  1.76715E+06 3.97696E+06
x 1surfaces                                                                                print table 70

N13      surface     trans  type   surface coefficients

     1       1                cy    7.5000000E+01
     2       2                py    0.0000000E+00
     3       3                py    6.2500000E+00
     4       4                py    1.2500000E+01
     5       5                py    1.8750000E+01
     6       6                py    2.5000000E+01
     7       7                py    3.1250000E+01
     8       8                py    3.7500000E+01
     9       9                py    4.3750000E+01
    10      10                py    5.0000000E+01
    11      11                py    5.6250000E+01
    12      12                py    6.2500000E+01
    13      13                py    6.8750000E+01
    14      14                py    7.5000000E+01
    15      15                py    8.1250000E+01
    16      16                py    8.7500000E+01
    17      17                py    9.3750000E+01
    18      18                py    1.0000000E+02
1  cell temperatures in mev for the free-gas thermal neutron treatment.                   print table 72

N14all non-zero importance cells with materials have a temperature for thermal neutrons of 2.5300E-08 mev.

    minimum source weight = 1.0000E+00    maximum source weight = 1.0000E+00

 ************************************************
 * Random Number Generator  =                  1 *
 * Random Number Seed       =       19073486328125 *
 * Random Number Multiplier =       19073486328125 *
 * Random Number Adder      =                  0 *
 * Random Number Bits Used  =                 48 *
 * Random Number Stride     =             152917 *
 ************************************************


         3 warning messages so far.
```

N151physical constants print table 98

name	value	description
huge	1.0000000000000E+36	infinity
pie	3.1415926535898E+00	pi
euler	5.7721566490153E-01	euler constant
avogad	6.0220434469282E+23	avogadro number (molecules/mole)
aneut	1.0086649670000E+00	neutron mass (amu)
avgdn	5.9703109000000E-01	avogadro number/neutron mass (1.e-24*molecules/mole/amu)
slite	2.9979250000000E+02	speed of light (cm/shake)
planck	4.1357320000000E-13	planck constant (mev shake)
fscon	1.3703930000000E+02	inverse fine structure constant h*c/(2*pi*e**2)
gpt(1)	9.3958000000000E+02	neutron mass (mev)
gpt(3)	5.1100800000000E-01	electron mass (mev)

fission q-values:

nuclide	q(mev)	nuclide	q(mev)
90232	171.91	91233	175.57
92233	180.84	92234	179.45
92235	180.88	92236	179.50
92237	180.40	92238	181.31
92239	180.40	92240	180.40
93237	183.67	94238	186.65
94239	189.44	94240	186.36
94241	188.99	94242	185.98
94243	187.48	95241	190.83
95242	190.54	95243	190.25
96242	190.49	96244	190.49
other	180.00		

the following compilation options were used:

```
    unix
    dec
    plot
    mcplot
    gkssim
    xlib
    default datapath: /usr/projects/data/nuclear/mc/type1
```

N161cross-section tables print table 100

table	length

tables from file actia

```
  1001.62c    5588  1-h-1 at 293.6K from endf-vi.8 njoy99.50                          mat 125      12/05/01
  8016.62c  213844  8-o-16 at 293.6K from endf-vi.8 njoy99.50                        mat 825      12/05/01
 11023.62c   63912  11-na-23 at 293.6K from endf-vi.8 njoy99.50                      mat1125      12/06/01
 12000.62c   61241  12-mg-0 at 293.6K from endf/b-vi.8 njoy99.50                     mat1200      12/06/01
 13027.62c  120773  13-al-27 at 293.6K from endf-vi.8 njoy99.50                      mat1325      12/17/01
 19000.62c   43014  19-k-0 at 293.6K from endf/b-vi.8 njoy99.50                      mat1900      12/06/01
 20000.62c  111384  20-ca-0 at 293.6K from endf-vi.8 njoy99.50                       mat2000      12/05/01
 26054.62c  227396  26-fe-54 at 293.6K from endf-vi.8 njoy99.50                      mat2625      12/20/01
 26056.62c  354822  26-fe-56 at 293.6K from endf-vi.8 njoy99.50                      mat2631      12/20/01
 26057.62c  235169  26-fe-57 at 293.6K from endf-vi.8 njoy99.50                      mat2634      12/20/01
 26058.62c  146288  26-fe-58 at 293.6K from endf-vi.8 njoy99.50                      mat2637      12/20/01

                       tables from file endf60

 14000.60c  100118  14-si-nat from endf/b-vi                                        mat1400      11/25/93

                       tables from file mcplib02

  1000.02p     623                                                                                01/15/93

comment.   1000.02p lacks Compton profile data for photon energy broadening.
  8000.02p     623                                                                                01/15/93

comment.   8000.02p lacks Compton profile data for photon energy broadening.
 11000.02p     635                                                                                01/15/93

comment.  11000.02p lacks Compton profile data for photon energy broadening.
 12000.02p     643                                                                                01/15/93

comment.  12000.02p lacks Compton profile data for photon energy broadening.
 13000.02p     643                                                                                01/15/93

comment.  13000.02p lacks Compton profile data for photon energy broadening.
 14000.02p     643                                                                                01/15/93

comment.  14000.02p lacks Compton profile data for photon energy broadening.
 19000.02p     643                                                                                01/15/93

comment.  19000.02p lacks Compton profile data for photon energy broadening.
 20000.02p     651                                                                                01/15/93

comment.  20000.02p lacks Compton profile data for photon energy broadening.
 26000.02p     651                                                                                01/15/93

comment.  26000.02p lacks Compton profile data for photon energy broadening.

 total     1689304
```

N17 any neutrons with energy greater than emax = 1.50000E+01 from the source or from a collision will be resampled.

N18 neutron cross sections outside the range from 0.0000E+00 to 1.5000E+01 mev are expunged.

```
 maximum photon energy set to  100.0 mev (maximum electron energy)

                       tables from file el03

   1000.03e    2329                                                                  6/6/98
   8000.03e    2333                                                                  6/6/98
  11000.03e    2337                                                                  6/6/98
  12000.03e    2337                                                                  6/6/98
  13000.03e    2337                                                                  6/6/98
  14000.03e    2339                                                                  6/6/98
  19000.03e    2343                                                                  6/6/98
  20000.03e    2343                                                                  6/6/98
  26000.03e    2345                                                                  6/6/98
x 1range table for material    1 (condensed)                                    print table 85

 electron substeps per energy step =   4,  default =   4.  mean ionization energy = 1.41099E+02 ev.
```

N19 density effect data

```
 non-conductor
   z =   1
    occ no, be(ev) pairs
       1.     13.600
   z =   8
    occ no, be(ev) pairs
       2.    538.000       2.     28.480       4.     13.620
   z =  11
    occ no, be(ev) pairs
       2.   1075.000       2.     66.000       2.     34.000       4.     34.000      -1.      5.139
   z =  12
    occ no, be(ev) pairs
       2.   1308.000       2.     92.000       2.     54.000       4.     54.000      -2.      7.646
   z =  13
    occ no, be(ev) pairs
       2.   1564.000       2.    121.000       2.     77.000       4.     77.000      -3.      9.075
   z =  14
    occ no, be(ev) pairs
       2.   1844.000       2.    154.000       2.    104.000       4.    104.000       2.     13.460      -2.      8.151
   z =  19
    occ no, be(ev) pairs
       2.   3610.000       2.    381.000       2.    299.000       4.    296.000       2.     37.000       2.     19.000
       4.     18.700      -1.      4.341
   z =  20
    occ no, be(ev) pairs
       2.   4041.000       2.    441.000       2.    353.000       4.    349.000       2.     46.000       2.     28.000
       4.     28.000      -2.      6.113
```

```
    z =  26
     occ no, be(ev) pairs
        2.    7117.000       2.     851.000       2.     726.000       4.     713.000       2.      98.000       2.      61.000
        4.      59.000       6.       9.000      -2.       7.870
    z =  26
     occ no, be(ev) pairs
        2.    7117.000       2.     851.000       2.     726.000       4.     713.000       2.      98.000       2.      61.000
        4.      59.000       6.       9.000      -2.       7.870
    z =  26
     occ no, be(ev) pairs
        2.    7117.000       2.     851.000       2.     726.000       4.     713.000       2.      98.000       2.      61.000
        4.      59.000       6.       9.000      -2.       7.870
    z =  26
     occ no, be(ev) pairs
        2.    7117.000       2.     851.000       2.     726.000       4.     713.000       2.      98.000       2.      61.000
        4.      59.000       6.       9.000      -2.       7.870
        plas(ev)       wt       tmin(mev)
        30.57106     2.35209     0.36478

N20     energy           stopping power            range   radiation   beta**2   density   rad/col   drange    dyield
    n              collision radiation   total               yield               corr
          mev      mev cm2/g mev cm2/g mev cm2/g   g/cm2                        mev cm2/g             g/cm2

  133  1.0790E-03  7.975E+01 3.695E-03 7.976E+01 7.021E-06 3.708E-06  4.210E-03 0.000E+00 4.633E-05 1.098E-06 4.000E-09
  132  1.1766E-03  7.605E+01 3.798E-03 7.605E+01 8.276E-06 7.395E-06  4.589E-03 0.000E+00 4.994E-05 1.254E-06 4.700E-09
  131  1.2831E-03  7.241E+01 3.900E-03 7.242E+01 9.711E-06 1.109E-05  5.003E-03 0.000E+00 5.386E-05 1.435E-06 5.527E-09
  130  1.3992E-03  6.886E+01 4.003E-03 6.887E+01 1.136E-05 1.482E-05  5.454E-03 0.000E+00 5.813E-05 1.645E-06 6.502E-09
  129  1.5259E-03  6.540E+01 4.105E-03 6.541E+01 1.324E-05 1.860E-05  5.945E-03 0.000E+00 6.276E-05 1.888E-06 7.655E-09
  128  1.6640E-03  6.205E+01 4.207E-03 6.205E+01 1.541E-05 2.248E-05  6.481E-03 0.000E+00 6.780E-05 2.169E-06 9.015E-09
  127  1.8146E-03  5.880E+01 4.308E-03 5.881E+01 1.791E-05 2.646E-05  7.064E-03 0.000E+00 7.327E-05 2.494E-06 1.062E-08
SKIP 122 LINES OF OUTPUT
    4  7.7111E+01  1.906E+00 2.563E+00 4.469E+00 2.757E+01 3.582E-01  1.000E+00 4.644E-01 1.344E+00 1.471E+00 3.600E+00
    3  8.4090E+01  1.914E+00 2.814E+00 4.728E+00 2.909E+01 3.769E-01  1.000E+00 4.770E-01 1.471E+00 1.518E+00 4.079E+00
    2  9.1700E+01  1.921E+00 3.089E+00 5.010E+00 3.065E+01 3.960E-01  1.000E+00 4.898E-01 1.608E+00 1.564E+00 4.613E+00
    1  1.0000E+02  1.928E+00 3.390E+00 5.318E+00 3.226E+01 4.152E-01  1.000E+00 5.025E-01 1.759E+00 1.608E+00 5.206E+00

N211electron secondary production for material    1                                                            print table 86

        energy           stopping power            brems   thick tgt   k x-ray   knock-on
    n              collision radiation   total               brems
          mev      mev barn  mev barn  mev barn    barn                   barn      barn
  133  1.0790E-03  2.496E+03 1.157E-01 2.496E+03 1.398E+03 5.031E-05  0.000E+00 0.000E+00
  132  1.1766E-03  2.380E+03 1.189E-01 2.381E+03 1.327E+03 1.049E-04  0.000E+00 0.000E+00
  131  1.2831E-03  2.267E+03 1.221E-01 2.267E+03 1.259E+03 1.642E-04  0.000E+00 0.000E+00
  130  1.3992E-03  2.155E+03 1.253E-01 2.156E+03 1.193E+03 2.286E-04  0.000E+00 0.000E+00
  129  1.5259E-03  2.047E+03 1.285E-01 2.047E+03 1.130E+03 2.987E-04  0.000E+00 0.000E+00
  128  1.6640E-03  1.942E+03 1.317E-01 1.942E+03 1.070E+03 3.749E-04  0.000E+00 0.000E+00
  127  1.8146E-03  1.841E+03 1.349E-01 1.841E+03 1.012E+03 4.578E-04  0.000E+00 0.000E+00
```

```
SKIP 122 LINES OF OUTPUT
     4  7.7111E+01   5.967E+01  8.022E+01  1.399E+02  2.275E+01  1.986E+01   1.596E+00  2.409E+03
     3  8.4090E+01   5.990E+01  8.808E+01  1.480E+02  2.275E+01  2.097E+01   1.613E+00  2.409E+03
     2  9.1700E+01   6.012E+01  9.670E+01  1.568E+02  2.274E+01  2.210E+01   1.629E+00  2.409E+03
     1  1.0000E+02   6.035E+01  1.061E+02  1.665E+02  2.274E+01  2.327E+01   1.645E+00  2.409E+03

 ********************************************************************************************************************************
N22 dump no.     1 on file test1.r      nps =          0      coll =          0      ctm =     0.00      nrn =          0

      3 warning messages so far.
 x 1  starting mcrun.        cp0 =  0.33          print table 110

N23   test1: 100 cm thick concrete disk with 15 splitting surfaces

      nps     x           y           z        cell   surf      u           v           w           energy      weight      time
        1  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        2  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        3  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        4  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        5  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        6  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        7  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        8  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
        9  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       10  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       11  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       12  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       13  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       14  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       15  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       16  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       17  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       18  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       19  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       20  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       21  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       22  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       23  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       24  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       25  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       26  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       27  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       28  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       29  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
       30  0.000E+00   0.000E+00   0.000E+00     2      2   0.000E+00   1.000E+00   0.000E+00   1.419E+01   1.000E+00   0.000E+00
```

31	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
32	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
33	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
34	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
35	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
36	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
37	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
38	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
39	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
40	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
41	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
42	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
43	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
44	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
45	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
46	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
47	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
48	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
49	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00
50	0.000E+00	0.000E+00	0.000E+00	2	2	0.000E+00	1.000E+00	0.000E+00	1.419E+01	1.000E+00	0.000E+00

1problem summary

run terminated when 10000 particle histories were done.

+ 01/08/03 17:42:32

test1: 100 cm thick concrete disk with 15 splitting surfaces probid = 01/08/03 17:40:43

0

N24 neutron creation	tracks	weight (per source particle)	energy	neutron loss	tracks	weight (per source particle)	energy
source	10000	1.0000E+00	1.4190E+01	N27 escape	13484	4.0886E-01	9.6818E-01
				energy cutoff	0	0.	0.
				time cutoff	0	0.	0.
weight window	0	0.	0.	weight window	0	0.	0.
N25 cell importance	35686	2.5352E-01	9.6418E-02	N28 cell importance	23830	2.5620E-01	9.9262E-02
N26 weight cutoff	0	8.2987E-02	5.1344E-02	N29 weight cutoff	8628	8.0664E-02	4.5217E-02
e or t importance	0	0.	0.	e or t importance	0	0.	0.
dxtran	0	0.	0.	dxtran	0	0.	0.
forced collisions	0	0.	0.	forced collisions	0	0.	0.
exp. transform	0	0.	0.	exp. transform	0	0.	0.
upscattering	0	0.	1.1129E-07	N30 downscattering	0	0.	8.4086E+00
photonuclear	0	0.	0.	N31 capture	0	6.0569E-01	4.6845E+00
(n,xn)	512	2.9813E-02	7.4844E-02	loss to (n,xn)	256	1.4907E-02	2.0684E-01
prompt fission	0	0.	0.	loss to fission	0	0.	0.
delayed fission	0	0.	0.				
total	46198	1.3663E+00	1.4413E+01	N32 total	46198	1.3663E+00	1.4413E+01

```
    number of neutrons banked                    35942
    neutron tracks per source particle     4.6198E+00
    neutron collisions per source particle 1.1536E+02
    total neutron collisions                   1153552
N34 net multiplication              1.0149E+00 0.0010
0
 photon creation      tracks      weight        energy
                                  (per source particle)

 source                    0    0.            0.

 weight window             0    0.            0.
 cell importance        9728    1.5656E-01    1.6238E-01
 weight cutoff             0    5.1129E-02    5.0508E-03
 e or t importance         0    0.            0.
 dxtran                    0    0.            0.
 forced collisions         0    0.            0.
 exp. transform            0    0.            0.
 from neutrons         14445    1.9920E+00    6.4524E+00
 bremsstrahlung        20435    9.2325E-01    1.0884E-01
N35 p-annihilation      1932    2.9063E-01    1.4852E-01
 photonuclear              0    0.            0.
 electron x-rays           0    0.            0.
 1st fluorescence          0    0.            0.
 2nd fluorescence          0    0.            0.
     total             46540    3.4136E+00    6.8771E+00

  number of photons banked                    45574
  photon tracks per source particle     4.6540E+00
  photon collisions per source particle 1.7153E+01
  total photon collisions                   171528

 computer time so far in this run     1.72 minutes
 computer time in mcrun               1.39 minutes
 source particles per minute            7.1789E+03
 random numbers generated                 20894669

 range of sampled source weights = 1.0000E+00 to 1.0000E+00
1neutron  activity in each cell                                    print table 126

                tracks      population    collisions    collisions      number        flux         average       average
       cell     entering                                  * weight      weighted     weighted   track weight   track mfp
                                                       (per history)    energy       energy     (relative)       (cm)

     2     2       18462         10482         43742    2.9001E+00   4.2127E-03   6.6554E+00   7.3202E-01   6.4169E+00
     3     3       22154          9119         66582    4.0724E+00   1.6993E-03   4.2611E+00   6.5801E-01   5.4144E+00
```

```
N33 average time of (shakes)              cutoffs
 escape            6.3959E+03            tco   1.0000E+33
 capture           1.7093E+04            eco   0.0000E+00
 capture or escape 1.2782E+04            wc1  -5.0000E-01
 any termination   1.8089E+04            wc2  -2.5000E-01

  photon loss         tracks      weight        energy
                              (per source particle)

  escape                7065    5.1894E-01    1.0939E+00
  energy cutoff            0    0.            1.9439E-04
  time cutoff              0    0.            0.
  weight window            0    0.            0.
  cell importance       6109    1.4720E-01    1.4820E-01
  weight cutoff        32400    5.1533E-02    5.1175E-03
  e or t importance        0    0.            0.
  dxtran                   0    0.            0.
  forced collisions        0    0.            0.
  exp. transform           0    0.            0.
  compton scatter          0    0.            4.6578E+00
  capture                  0    2.5506E+00    1.5280E-01
  pair production        966    1.4532E-01    8.1907E-01
  photonuclear abs         0    0.            0.

      total            46540    3.4136E+00    6.8771E+00

N36 average time of (shakes)              cutoffs
 escape            6.6000E+03            tco   1.0000E+33
 capture           1.2856E+04            eco   1.0000E-03
 capture or escape 1.1798E+04            wc1  -5.0000E-01
 any termination   1.2100E+04            wc2  -2.5000E-01

 maximum number ever in bank        27
 bank overflows to backup file       0

 most random numbers used was    42929 in history     4668
```

4	4	22670	8110	76234	4.3753E+00	9.6498E-04	3.0650E+00	6.0980E-01	4.8516E+00
5	5	21174	7357	76298	4.1556E+00	6.1800E-04	2.3716E+00	5.7362E-01	4.4834E+00
6	6	18884	7053	72593	3.7823E+00	4.1831E-04	1.8063E+00	5.4446E-01	4.1574E+00
7	7	16296	7830	64281	3.2101E+00	3.0361E-04	1.4709E+00	5.1931E-01	3.9280E+00
8	8	26906	13245	108157	2.5988E+00	2.2913E-04	1.1970E+00	4.9749E-01	3.7466E+00
9	9	21120	8908	86103	2.0189E+00	1.8693E-04	1.0208E+00	4.8320E-01	3.6178E+00
10	10	16247	8212	67060	1.5232E+00	1.5713E-04	8.9890E-01	4.6712E-01	3.5316E+00
11	11	24675	12410	103125	1.1405E+00	1.3226E-04	7.6617E-01	4.5420E-01	3.4429E+00
12	12	18158	7712	76071	8.2707E-01	1.1583E-04	6.5418E-01	4.4588E-01	3.3636E+00
13	13	12902	6676	55244	5.9016E-01	9.7220E-05	5.7255E-01	4.3590E-01	3.2668E+00
14	14	18310	10217	78818	4.1300E-01	8.2226E-05	5.0106E-01	4.2902E-01	3.2038E+00
15	15	12516	6996	53411	2.7657E-01	7.7348E-05	4.7917E-01	4.2223E-01	3.1813E+00
16	16	15552	11034	66669	1.7149E-01	8.1345E-05	4.9070E-01	4.1924E-01	3.2045E+00
17	17	14260	11922	59164	7.6058E-02	1.0005E-04	6.0959E-01	4.1936E-01	3.3331E+00
total		300286	147283	1153552	3.2132E+01				

N37 **N38** **N39** **N40** **N41** **N42** **N43** **N44**

1photon activity in each cell print table 126

cell		tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
2	2	679	1402	3238	1.8850E+00	1.8744E+00	1.8744E+00	7.6679E+00	7.8232E+00
3	3	1121	1747	4989	2.7041E+00	1.6590E+00	1.6590E+00	7.0810E+00	7.2705E+00
4	4	1360	1804	5696	2.8920E+00	1.4907E+00	1.4907E+00	6.4765E+00	6.8526E+00
5	5	1395	1765	5375	2.4735E+00	1.4768E+00	1.4768E+00	5.8538E+00	6.7685E+00
6	6	1311	1601	4990	2.0132E+00	1.4306E+00	1.4306E+00	5.1193E+00	6.7149E+00
7	7	1196	1644	4754	1.6475E+00	1.3471E+00	1.3471E+00	4.3867E+00	6.4870E+00
8	8	2205	2989	8311	1.2388E+00	1.4486E+00	1.4486E+00	3.7469E+00	6.8062E+00
9	9	2079	2587	7107	8.8797E-01	1.4371E+00	1.4371E+00	3.0539E+00	6.7756E+00
10	10	2038	2824	7488	7.5264E-01	1.4003E+00	1.4003E+00	2.4416E+00	6.6894E+00
11	11	3845	5283	14101	6.0434E-01	1.3070E+00	1.3070E+00	1.9941E+00	6.4424E+00
12	12	3419	4345	11766	4.0238E-01	1.3423E+00	1.3423E+00	1.5960E+00	6.4944E+00
13	13	2970	4155	10259	2.9540E-01	1.3425E+00	1.3425E+00	1.2908E+00	6.4989E+00
14	14	5181	7708	18611	2.1517E-01	1.2874E+00	1.2874E+00	1.0048E+00	6.3947E+00
15	15	4241	6790	15338	1.3926E-01	1.3113E+00	1.3113E+00	7.8359E-01	6.4278E+00
16	16	6631	11317	23251	8.8534E-02	1.3775E+00	1.3775E+00	6.4904E-01	6.6175E+00
17	17	8272	15302	26254	4.6040E-02	1.4522E+00	1.4522E+00	6.0271E-01	6.8816E+00
total		47943	73263	171528	1.8286E+01				

N45

x 1neutron weight balance in each cell print table 130

N46 cell index	2	3	4	5	6	7	8	9	10
cell number	2	3	4	5	6	7	8	9	10
external events:									
entering	5.1477E-01	1.5747E+00	1.4653E+00	1.2700E+00	1.0632E+00	8.7244E-01	6.8637E-01	5.2105E-01	3.8661E-01

source	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
energy cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
time cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exiting	-1.3949E+00	-1.4745E+00	-1.3822E+00	-1.2038E+00	-1.0110E+00	-8.2659E-01	-6.5263E-01	-4.9497E-01	-3.6813E-01
total	1.1985E-01	1.0019E-01	8.3094E-02	6.6248E-02	5.2285E-02	4.5858E-02	3.3737E-02	2.6079E-02	1.8480E-02

variance reduction events:

weight window	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
cell importance	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-3.1048E-03	0.0000E+00	0.0000E+00	7.8973E-04
weight cutoff	2.0177E-04	2.4995E-04	-5.8698E-04	1.4282E-03	6.1319E-04	1.8838E-04	2.4003E-04	-1.6652E-04	3.9420E-05
e or t importance	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
dxtran	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
forced collisions	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exp. transform	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
total	2.0177E-04	2.4995E-04	-5.8698E-04	1.4282E-03	6.1319E-04	-2.9165E-03	2.4003E-04	-1.6652E-04	8.2915E-04

physical events:

capture	-1.2610E-01	-1.0404E-01	-8.4888E-02	-6.8489E-02	-5.3516E-02	-4.3503E-02	-3.4328E-02	-2.6112E-02	-1.9460E-02
(n,xn)	1.2105E-02	7.2022E-03	4.7636E-03	1.6252E-03	1.2352E-03	1.1234E-03	7.0208E-04	3.9989E-04	3.0104E-04
loss to (n,xn)	-6.0526E-03	-3.6011E-03	-2.3818E-03	-8.1259E-04	-6.1758E-04	-5.6169E-04	-3.5104E-04	-1.9995E-04	-1.5052E-04
fission	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
loss to fission	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
photonuclear	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
total	-1.2005E-01	-1.0044E-01	-8.2507E-02	-6.7676E-02	-5.2898E-02	-4.2941E-02	-3.3977E-02	-2.5912E-02	-1.9310E-02

cell index	11	12	13	14	15	16	17	
cell number	11	12	13	14	15	16	17	total

external events:

entering	2.8472E-01	2.0530E-01	1.4310E-01	9.9186E-02	6.6824E-02	4.1167E-02	1.8876E-02	9.2137E+00
source	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00
energy cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
time cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exiting	-2.7006E-01	-1.9452E-01	-1.3532E-01	-9.3900E-02	-6.3281E-02	-3.8923E-02	-1.7842E-02	-9.6226E+00
total	1.4657E-02	1.0775E-02	7.7845E-03	5.2857E-03	3.5430E-03	2.2442E-03	1.0340E-03	5.9114E-01

variance reduction events:

weight window	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
cell importance	0.0000E+00	0.0000E+00	-4.3460E-04	0.0000E+00	4.4900E-05	2.7124E-05	0.0000E+00	-2.6777E-03
weight cutoff	1.7459E-04	-1.7922E-04	1.8217E-05	1.1633E-04	4.2030E-05	-4.0861E-05	-1.4870E-05	2.3237E-03
e or t importance	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
dxtran	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
forced collisions	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exp. transform	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

total	1.7459E-04	-1.7922E-04	-4.1638E-04	1.1633E-04	8.6930E-05	-1.3736E-05	-1.4870E-05	-3.5404E-04
physical events:								
capture	-1.4876E-02	-1.0661E-02	-7.3881E-03	-5.4219E-03	-3.6397E-03	-2.2441E-03	-1.0232E-03	-6.0569E-01
(n,xn)	8.9720E-05	1.3079E-04	3.9989E-05	3.9772E-05	1.9515E-05	2.7230E-05	8.2037E-06	2.9813E-02
loss to (n,xn)	-4.4860E-05	-6.5393E-05	-1.9994E-05	-1.9886E-05	-9.7577E-06	-1.3615E-05	-4.1019E-06	-1.4907E-02
fission	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
loss to fission	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
photonuclear	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
total	-1.4831E-02	-1.0596E-02	-7.3681E-03	-5.4020E-03	-3.6299E-03	-2.2305E-03	-1.0191E-03	-5.9079E-01

X 1photon weight balance in each cell print table 130

cell index	2	3	4	5	6	7	8	9	10
cell number	2	3	4	5	6	7	8	9	10
external events:									
entering	4.7130E-01	7.4703E-01	8.7442E-01	8.1628E-01	6.7374E-01	5.2554E-01	4.2272E-01	3.3127E-01	2.6750E-01
source	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
energy cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
time cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exiting	-8.0313E-01	-9.5654E-01	-9.3016E-01	-8.3377E-01	-6.5255E-01	-5.2920E-01	-4.1924E-01	-3.1970E-01	-2.5007E-01
total	-3.3183E-01	-2.0951E-01	-5.5742E-02	-1.7488E-02	2.1182E-02	-3.6551E-03	3.4778E-03	1.1569E-02	1.7425E-02
variance reduction events:									
weight window	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
cell importance	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0109E-02	0.0000E+00	0.0000E+00	-1.9210E-04
weight cutoff	6.8973E-04	-5.6751E-04	-5.2323E-04	1.4002E-04	7.1491E-05	-2.2086E-04	5.3950E-04	-4.3822E-04	9.0507E-05
e or t importance	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
dxtran	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
forced collisions	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exp. transform	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
total	6.8973E-04	-5.6751E-04	-5.2323E-04	1.4002E-04	7.1491E-05	9.8880E-03	5.3950E-04	-4.3822E-04	-1.0160E-04
physical events:									
from neutrons	4.5778E-01	4.0662E-01	2.8784E-01	2.1478E-01	1.5833E-01	1.4095E-01	9.7172E-02	7.0637E-02	4.7593E-02
bremsstrahlung	1.2450E-01	1.6451E-01	1.3732E-01	1.3005E-01	8.4304E-02	7.4897E-02	5.7556E-02	3.5016E-02	3.5619E-02
capture	-2.6623E-01	-3.8694E-01	-3.8899E-01	-3.5036E-01	-2.7949E-01	-2.3701E-01	-1.6711E-01	-1.2053E-01	-1.0710E-01
p-annihilation	3.0193E-02	5.1774E-02	4.0188E-02	4.5781E-02	3.1194E-02	2.9855E-02	1.6732E-02	7.4985E-03	1.3132E-02
pair production	-1.5097E-02	-2.5887E-02	-2.0094E-02	-2.2890E-02	-1.5597E-02	-1.4927E-02	-8.3660E-03	-3.7493E-03	-6.5659E-03
photonuclear	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
photonuclear abs	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
electron x-rays	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
flourescence	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
total	3.3114E-01	2.1008E-01	5.6265E-02	1.7348E-02	-2.1254E-02	-6.2329E-03	-4.0173E-03	-1.1131E-02	-1.7323E-02

cell index	11	12	13	14	15	16	17	
cell number	11	12	13	14	15	16	17	total
external events:								
entering	2.0738E-01	1.4878E-01	1.0642E-01	7.4219E-02	4.9887E-02	3.2226E-02	1.8583E-02	5.7673E+00
source	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
energy cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
time cutoff	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exiting	-1.9456E-01	-1.3899E-01	-9.6981E-02	-6.8514E-02	-4.5442E-02	-2.9742E-02	-1.7625E-02	-6.2862E+00
	---	---	---	---	---	---	---	---
total	1.2819E-02	9.7937E-03	9.4364E-03	5.7045E-03	4.4443E-03	2.4833E-03	9.5808E-04	-5.1894E-01
variance reduction events:								
weight window	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
cell importance	0.0000E+00	0.0000E+00	-1.3446E-04	0.0000E+00	-3.5272E-04	-6.4991E-05	0.0000E+00	9.3646E-03
weight cutoff	1.8110E-05	-4.0144E-04	4.3357E-05	7.4486E-05	5.9061E-05	8.2137E-05	-6.1327E-05	-4.0419E-04
e or t importance	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
dxtran	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
forced collisions	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
exp. transform	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	---	---	---	---	---	---	---	---
total	1.8110E-05	-4.0144E-04	-9.1099E-05	7.4486E-05	-2.9366E-04	1.7145E-05	-6.1327E-05	8.9604E-03
physical events:								
from neutrons	3.8502E-02	2.5194E-02	1.7770E-02	1.2730E-02	8.4260E-03	5.1560E-03	2.5023E-03	1.9920E+00
bremsstrahlung	2.5622E-02	1.7201E-02	1.3995E-02	9.8857E-03	6.4686E-03	3.9997E-03	2.3163E-03	9.2325E-01
capture	-8.1380E-02	-5.4113E-02	-4.3485E-02	-2.9777E-02	-1.9829E-02	-1.2143E-02	-6.0853E-03	-2.5506E+00
p-annihilation	8.8383E-03	4.6537E-03	4.7504E-03	2.7632E-03	1.5677E-03	9.7427E-04	7.4012E-04	2.9063E-01
pair production	-4.4191E-03	-2.3268E-03	-2.3752E-03	-1.3816E-03	-7.8384E-04	-4.8713E-04	-3.7006E-04	-1.4532E-01
photonuclear	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
photonuclear abs	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
electron x-rays	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
flourescence	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	---	---	---	---	---	---	---	---
total	-1.2837E-02	-9.3923E-03	-9.3453E-03	-5.7790E-03	-4.1507E-03	-2.5004E-03	-8.9675E-04	5.0998E-01

x 1neutron activity of each nuclide in each cell, per source particle print table 140

N47

cell index	cell name	nuclides	atom fraction	total collisions	collisions * weight	wgt. lost to capture	wgt. gain by fission	wgt. gain by (n,xn)	photons produced	photon wgt produced	avg photon energy
2	2	1001.62c	8.48E-02	10729	6.1932E-01	2.2951E-03	0.0000E+00	0.0000E+00	2	2.0000E-03	2.2233E+00
		8016.62c	6.04E-01	22302	1.5210E+00	5.8326E-02	0.0000E+00	0.0000E+00	181	1.8100E-01	4.8237E+00
		11023.62c	9.47E-03	515	3.4295E-02	1.1800E-03	0.0000E+00	0.0000E+00	6	6.0000E-03	2.0094E+00
		12000.62c	3.00E-03	114	7.7258E-03	3.4855E-04	0.0000E+00	0.0000E+00	1	1.0000E-03	1.7968E+00
		13027.62c	2.48E-02	803	5.7665E-02	2.6595E-03	0.0000E+00	0.0000E+00	16	1.6000E-02	1.9294E+00
		14000.60c	2.42E-01	7902	5.6359E-01	5.0113E-02	0.0000E+00	5.7060E-03	217	2.1678E-01	2.6088E+00
		19000.62c	6.86E-03	250	1.8396E-02	3.4303E-03	0.0000E+00	0.0000E+00	10	1.0000E-02	2.1887E+00
		20000.62c	2.05E-02	769	5.5148E-02	6.5305E-03	0.0000E+00	0.0000E+00	15	1.5000E-02	2.7539E+00
		26054.62c	2.74E-04	26	1.8352E-03	1.2245E-04	0.0000E+00	0.0000E+00	0	0.0000E+00	0.0000E+00

		26056.62c	4.26E-03	326	2.0749E-02	1.0617E-03	0.0000E+00	3.4662E-04	10	1.0000E-02	3.4545E+00
		26057.62c	9.76E-05	6	4.2317E-04	3.3896E-05	0.0000E+00	0.0000E+00	0	0.0000E+00	0.0000E+00
		26058.62c	1.30E-05	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0	0.0000E+00	0.0000E+00
SKIP 183 LINES OF OUTPUT											
17	17	1001.62c	8.48E-02	22883	2.8818E-02	2.1773E-04	0.0000E+00	0.0000E+00	348	2.1750E-04	2.2233E+00
		8016.62c	6.04E-01	26763	3.4738E-02	6.7659E-05	0.0000E+00	0.0000E+00	216	1.5937E-04	5.1790E+00
		11023.62c	9.47E-03	464	6.2719E-04	3.6858E-05	0.0000E+00	0.0000E+00	212	1.5577E-04	2.0413E+00
		12000.62c	3.00E-03	111	1.4407E-04	1.8838E-06	0.0000E+00	0.0000E+00	8	6.4356E-06	1.7043E+00
		13027.62c	2.48E-02	554	7.5146E-04	4.3362E-05	0.0000E+00	0.0000E+00	179	1.2107E-04	3.0834E+00
		14000.60c	2.42E-01	6688	8.8240E-03	3.4287E-04	0.0000E+00	4.1019E-06	1374	9.9674E-04	3.4224E+00
		19000.62c	6.86E-03	278	3.5206E-04	1.2401E-04	0.0000E+00	0.0000E+00	251	4.3691E-04	2.0577E+00
		20000.62c	2.05E-02	749	9.6295E-04	8.4530E-05	0.0000E+00	0.0000E+00	308	2.1024E-04	3.1815E+00
		26054.62c	2.74E-04	18	2.1555E-05	5.6167E-06	0.0000E+00	0.0000E+00	11	9.0667E-06	4.5905E+00
		26056.62c	4.26E-03	652	8.1308E-04	9.6017E-05	0.0000E+00	0.0000E+00	277	1.8181E-04	4.3618E+00
		26057.62c	9.76E-05	3	4.0786E-06	1.7524E-06	0.0000E+00	0.0000E+00	3	5.3094E-06	3.8873E+00
		26058.62c	1.30E-05	1	1.5247E-06	9.3031E-07	0.0000E+00	0.0000E+00	1	2.0432E-06	5.7081E-01
total				1153552	3.2132E+01	6.0569E-01	0.0000E+00	1.4907E-02	14445	1.9920E+00	3.2392E+00

N48 total over all cells by nuclide

	total collisions	collisions * weight	wgt. lost to capture	wgt. gain by fission	wgt. gain by (n,xn)	photons produced	photon wgt produced	avg photon energy
1001.62c	413735	1.0093E+01	5.7144E-02	0.0000E+00	0.0000E+00	1198	5.9052E-02	2.2233E+00
8016.62c	535266	1.5570E+01	1.8905E-01	0.0000E+00	0.0000E+00	1487	5.2859E-01	4.7496E+00
11023.62c	11260	3.5735E-01	1.2778E-02	0.0000E+00	7.7727E-05	926	6.8461E-02	1.5109E+00
12000.62c	2665	8.1920E-02	1.4858E-03	0.0000E+00	1.9322E-04	35	3.7199E-03	2.6436E+00
13027.62c	13369	4.5764E-01	1.9131E-02	0.0000E+00	1.7574E-04	775	9.1215E-02	2.6219E+00
14000.60c	144907	4.6562E+00	2.2524E-01	0.0000E+00	1.2855E-02	6167	9.6022E-01	2.8006E+00
19000.62c	5570	1.5948E-01	3.6860E-02	0.0000E+00	6.7260E-05	1627	1.2191E-01	2.3052E+00
20000.62c	15447	4.6756E-01	3.9167E-02	0.0000E+00	0.0000E+00	1220	9.7648E-02	2.7834E+00
26054.62c	341	1.1305E-02	1.2653E-03	0.0000E+00	0.0000E+00	43	8.5360E-04	6.9631E+00
26056.62c	10846	2.7312E-01	2.3053E-02	0.0000E+00	1.4705E-03	933	5.8217E-02	3.5863E+00
26057.62c	128	3.3525E-03	4.7843E-04	0.0000E+00	6.6970E-05	31	1.4021E-03	7.0628E-01
26058.62c	18	7.9675E-04	4.7340E-05	0.0000E+00	0.0000E+00	3	6.9363E-04	5.4304E-01

x 1photoatomic activity of each nuclide in each cell, per source particle print table 140

cell index	cell name	nuclides	atom fraction	total collisions	collisions * weight	wgt. lost to capture
2	2	1000.02p	8.48E-02	16	1.2831E-02	2.5563E-08
		8000.02p	6.04E-01	1327	8.5833E-01	3.2705E-02
		11000.02p	9.47E-03	34	2.0875E-02	1.4099E-03
		12000.02p	3.00E-03	10	5.2013E-03	4.5928E-04
		13000.02p	2.48E-02	112	6.7051E-02	6.4151E-03
		14000.02p	2.42E-01	1282	7.0827E-01	1.3627E-01
		19000.02p	6.86E-03	81	3.5390E-02	1.1021E-02
		20000.02p	2.05E-02	272	1.2954E-01	5.0084E-02

		26000.02p	2.74E-04	10	5.4204E-03	2.5924E-03
		26000.02p	4.26E-03	90	3.9892E-02	2.3943E-02
		26000.02p	9.76E-05	4	2.1957E-03	1.3269E-03
		26000.02p	1.30E-05	0	0.0000E+00	0.0000E+00
SKIP 183 LINES OF OUTPUT						
17	17	1000.02p	8.48E-02	210	4.0562E-04	9.1318E-09
		8000.02p	6.04E-01	11588	2.1111E-02	7.5806E-04
		11000.02p	9.47E-03	293	5.1671E-04	5.5781E-05
		12000.02p	3.00E-03	107	2.0370E-04	1.7294E-05
		13000.02p	2.48E-02	916	1.5487E-03	2.1190E-04
		14000.02p	2.42E-01	9970	1.7291E-02	2.8167E-03
		19000.02p	6.86E-03	518	8.1238E-04	2.7335E-04
		20000.02p	2.05E-02	1848	2.8929E-03	1.1803E-03
		26000.02p	2.74E-04	33	7.8783E-05	5.5164E-05
		26000.02p	4.26E-03	757	1.1620E-03	7.0599E-04
		26000.02p	9.76E-05	12	1.7445E-05	1.0173E-05
		26000.02p	1.30E-05	2	8.0762E-07	7.0024E-07
total				171528	1.8286E+01	2.5506E+00

total over all cells by nuclide	total collisions	collisions * weight	wgt. lost to capture
N49			
1000.02p	1220	1.4140E-01	5.0327E-07
8000.02p	73574	8.3223E+00	3.0674E-01
11000.02p	1811	1.9631E-01	1.5044E-02
12000.02p	651	5.9774E-02	5.5093E-03
13000.02p	5993	6.5466E-01	9.5497E-02
14000.02p	66168	6.9292E+00	1.2269E+00
19000.02p	3655	3.3390E-01	1.1854E-01
20000.02p	12430	1.1574E+00	4.7198E-01
26000.02p	6026	4.9072E-01	3.1040E-01

N501summary of photons produced in neutron collisions

cell		number of photons	weight per source neut	energy per source neut	avg photon energy	mev/gm per source neut	weight/neut collision	energy/neut collision
1	1	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	2	458	4.57777E-01	1.58554E+00	3.46357E+00	6.37891E-06	1.57848E-01	5.46718E-01
3	3	452	4.06619E-01	1.35123E+00	3.32308E+00	5.43621E-06	9.98477E-02	3.31802E-01
4	4	360	2.87844E-01	8.69081E-01	3.01927E+00	3.49646E-06	6.57878E-02	1.98631E-01
5	5	307	2.14775E-01	7.31461E-01	3.40571E+00	2.94279E-06	5.16828E-02	1.76017E-01
6	6	264	1.58333E-01	4.81775E-01	3.04279E+00	1.93826E-06	4.18614E-02	1.27375E-01
7	7	282	1.40952E-01	4.19760E-01	2.97803E+00	1.68877E-06	4.39086E-02	1.30761E-01
8	8	486	9.71723E-02	2.99497E-01	3.08213E+00	1.20493E-06	3.73918E-02	1.15246E-01
9	9	471	7.06365E-02	2.15943E-01	3.05711E+00	8.68778E-07	3.49883E-02	1.06963E-01
10	10	476	4.75929E-02	1.47978E-01	3.10925E+00	5.95342E-07	3.12457E-02	9.71509E-02

11	11	906	3.85015E-02	1.23703E-01	3.21293E+00	4.97677E-07	3.37596E-02	1.08467E-01
12	12	719	2.51938E-02	8.06902E-02	3.20278E+00	3.24631E-07	3.04615E-02	9.75613E-02
13	13	709	1.77698E-02	5.55063E-02	3.12364E+00	2.23312E-07	3.01101E-02	9.40530E-02
14	14	1428	1.27303E-02	4.01346E-02	3.15269E+00	1.61468E-07	3.08236E-02	9.71773E-02
15	15	1545	8.42603E-03	2.64810E-02	3.14276E+00	1.06537E-07	3.04663E-02	9.57481E-02
16	16	2394	5.15596E-03	1.57306E-02	3.05095E+00	6.32869E-08	3.00652E-02	9.17277E-02
17	17	3188	2.50228E-03	7.84689E-03	3.13590E+00	3.15694E-08	3.28995E-02	1.03170E-01
total		14445	1.99198E+00	6.45236E+00	3.23916E+00			

energy interval	number of photons	number frequency	cum number distribution	weight of photons	weight frequency	cum weight distribution
20.000	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15.000	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10.000	56	3.87677E-03	3.87677E-03	1.98422E-02	9.96104E-03	9.96104E-03
9.000	37	2.56144E-03	6.43821E-03	6.56196E-03	3.29419E-03	1.32552E-02
8.000	101	6.99204E-03	1.34303E-02	1.59923E-02	8.02832E-03	2.12835E-02
7.000	805	5.57286E-02	6.91589E-02	9.99109E-02	5.01566E-02	7.14401E-02
6.000	1194	8.26584E-02	1.51817E-01	2.53922E-01	1.27472E-01	1.98912E-01
5.000	508	3.51679E-02	1.86985E-01	6.69176E-02	3.35935E-02	2.32505E-01
4.000	1687	1.16788E-01	3.03773E-01	1.71141E-01	8.59151E-02	3.18421E-01
3.000	2359	1.63309E-01	4.67082E-01	2.74669E-01	1.37887E-01	4.56308E-01
2.000	2908	2.01315E-01	6.68397E-01	2.86007E-01	1.43579E-01	5.99887E-01
1.000	2577	1.78401E-01	8.46798E-01	4.31631E-01	2.16684E-01	8.16572E-01
0.500	834	5.77362E-02	9.04534E-01	1.28351E-01	6.44337E-02	8.81005E-01
0.100	683	4.72828E-02	9.51817E-01	1.46349E-01	7.34690E-02	9.54474E-01
0.010	671	4.64521E-02	9.98269E-01	8.37645E-02	4.20508E-02	9.96525E-01
0.000	25	1.73070E-03	1.00000E+00	6.92214E-03	3.47500E-03	1.00000E+00
total	14445	1.00000E+00		1.99198E+00	1.00000E+00	

N51 1tally 11 nps = 10000
tally type 1 number of particles crossing a surface.
tally for neutrons

surface 18

energy		
1.0000E-04	4.77629E-03	0.0409
1.0000E-03	2.77044E-04	0.1113
1.0000E-02	2.84730E-04	0.0999
5.0000E-02	2.14883E-04	0.1044
1.0000E-01	1.09566E-04	0.1319
5.0000E-01	3.67009E-04	0.0890
1.0000E+00	3.34512E-04	0.0937
2.0000E+00	3.85410E-04	0.0980
3.0000E+00	4.70729E-04	0.0976
4.0000E+00	1.01474E-04	0.1648

```
   5.0000E+00   1.39429E-04 0.1753
   6.0000E+00   9.75997E-05 0.1802
   7.0000E+00   1.05532E-04 0.2210
   8.0000E+00   3.15291E-05 0.3090
   9.0000E+00   1.80565E-05 0.3767
   1.0000E+01   2.04469E-05 0.4711
   1.1000E+01   3.39812E-05 0.2599
   1.2000E+01   2.02660E-05 0.3112
   1.3000E+01   5.66043E-05 0.2044
   1.4000E+01   1.91146E-04 0.1625
   1.5000E+01   7.49294E-05 0.2935
     total      8.11117E-03 0.0386
```

N52 results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally 11

tfc bin	--mean--	---------relative error---------			----variance of the variance----			--figure of merit--		-pdf-
behavior	behavior	value	decrease	decrease rate	value	decrease	decrease rate	value	behavior	slope
desired	random	<0.10	yes	1/sqrt(nps)	<0.10	yes	1/nps	constant	random	>3.00
observed	random	0.04	yes	yes	0.00	yes	yes	constant	random	10.00
passed?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	N53	**N54**	**N55**	**N56**	**N57**	**N58**	**N59**	**N60**	**N61**	**N62**

N63 this tally meets the statistical criteria used to form confidence intervals: check the tally fluctuation chart to verify.
the results in other bins associated with this tally may not meet these statistical criteria.

----- estimated confidence intervals: -----

estimated asymmetric confidence interval(1,2,3 sigma): 7.8067E-03 to 8.4337E-03; 7.4931E-03 to 8.7472E-03; 7.1796E-03 to 9.0608E-03
estimated symmetric confidence interval(1,2,3 sigma): 7.7980E-03 to 8.4243E-03; 7.4848E-03 to 8.7375E-03; 7.1716E-03 to 9.0507E-03

1analysis of the results in the tally fluctuation chart bin (tfc) for tally 11 with nps = 10000 print table 160

N64 normed average tally per history = 8.11117E-03
estimated tally relative error = 0.0386
N67 relative error from zero tallies = 0.0277

number of nonzero history tallies = 1153
history number of largest tally = 5422
(largest tally)/(average tally) = 5.58601E+01

N65 unnormed average tally per history = 8.11117E-03
N66 estimated variance of the variance = 0.0045
N68 relative error from nonzero scores = 0.0269

N69 efficiency for the nonzero tallies = 0.1153
N70 largest unnormalized history tally = 4.53091E-01
(largest tally)/(avg nonzero tally)= 6.44067E+00

N71 (confidence interval shift)/mean = 0.0011 shifted confidence interval center = 8.12019E-03

N72 if the largest history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:

estimated quantities	value at nps	value at nps+1	value(nps+1)/value(nps)-1.
mean	8.11117E-03	8.15566E-03	0.005485
relative error	3.86105E-02	3.87816E-02	0.004432
variance of the variance	4.50432E-03	4.71222E-03	0.046156
shifted center	8.12019E-03	8.12045E-03	0.000031
figure of merit	4.81556E+02	4.77316E+02	-0.008805

N73 the estimated slope of the 57 largest tallies starting at 1.98897E-01 appears to be decreasing at least exponentially.
the large score tail of the empirical history score probability density function appears to have no unsampled regions.

fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (7.179E+03)*(2.590E-01)**2 = (7.179E+03)*(6.708E-02) = 4.816E+02

N74 1unnormed tally density for tally 11 nonzero tally mean(m) = 7.035E-02 nps = 10000 print table 161

abscissa tally	number	num den	ordinate log den:	log plot of tally probability density function in tally fluctuation chart bin(d=decade,slope=10.0)
7.94-03	6	3.67-01	-0.435	**********
1.00-02	59	2.87+00	0.458	**********
1.26-02	40	1.54+00	0.189	**********
1.58-02	58	1.78+00	0.250	**********
2.00-02	52	1.27+00	0.103	**********
2.51-02	73	1.41+00	0.150	**********
3.16-02	91	1.40+00	0.146	**********
3.98-02	88	1.07+00	0.031	**********
5.01-02	105	1.02+00	0.008	**********
6.31-02	110	8.48-01	-0.072	**********
7.94-02	107	6.55-01	-0.184	mmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmmm
1.00-01	106	5.15-01	-0.288	**********
1.26-01	81	3.13-01	-0.505	**********
1.58-01	72	2.21-01	-0.656	**********
2.00-01	49	1.19-01	-0.923	**********
2.51-01	28	5.42-02	-1.266	**********
3.16-01	17	2.61-02	-1.583	**********
3.98-01	8	9.77-03	-2.010	**********
5.01-01	3	2.91-03	-2.536	*
total	1153	1.15-01		

N75 cumulative tally number for tally 11 nonzero tally mean(m) = 7.035E-02 nps = 10000 print table 162

abscissa tally	cum number	ordinate cum pct	plot of the cumulative number of tallies in the tally fluctuation chart bin from 0 to 100 percent
		:--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100	
7.94328E-03	6	0.520	*
1.00000E-02	65	5.637	******
1.25893E-02	105	9.107	*********
1.58489E-02	163	14.137	**********
1.99526E-02	215	18.647	**********
2.51189E-02	288	24.978	**********
3.16228E-02	379	32.871	**********
3.98107E-02	467	40.503	**********
5.01187E-02	572	49.610	**********
6.30957E-02	682	59.150	**********
7.94328E-02	789	68.430	**********
1.00000E-01	895	77.624	**********
1.25893E-01	976	84.649	**********
1.58489E-01	1048	90.893	**********
1.99526E-01	1097	95.143	**********
2.51189E-01	1125	97.572	**********
3.16228E-01	1142	99.046	**********
3.98107E-01	1150	99.740	**********
5.01187E-01	1153	100.000	**********
total	1153	100.000	:--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100

1cumulative unnormed tally for tally 11 nonzero tally mean(m) = 7.035E-02 nps = 10000 print table 162

abscissa tally	cum tally/nps	ordinate cum pct	plot of the cumulative tally in the tally fluctuation chart bin from 0 to 100 percent
		:--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100	
7.943E-03	4.722E-06	0.058	
1.000E-02	5.676E-05	0.700	*
1.259E-02	1.015E-04	1.252	*
1.585E-02	1.850E-04	2.281	**
1.995E-02	2.780E-04	3.427	***
2.512E-02	4.449E-04	5.486	*****
3.162E-02	7.050E-04	8.692	*********
3.981E-02	1.016E-03	12.521	**********
5.012E-02	1.486E-03	18.322	**********
6.310E-02	2.109E-03	26.004	**********
7.943E-02	2.871E-03	35.400	**********
1.000E-01	3.823E-03	47.128	**********
1.259E-01	4.724E-03	58.242	**********
1.585E-01	5.741E-03	70.782	**********
1.995E-01	6.612E-03	81.514	**********
2.512E-01	7.228E-03	89.117	**********
3.162E-01	7.705E-03	94.995	**********
3.981E-01	7.981E-03	98.390	**********
5.012E-01	8.111E-03	100.000	**********
total	8.11117E-03	100.000	:--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100

SKIP 1254 LINES OF OUTPUT

N76 1status of the statistical checks used to form confidence intervals for the mean for each tally bin

```
tally   result of statistical checks for the tfc bin (the first check not passed is listed) and error magnitude check for all bins

   11   passed the 10 statistical checks for the tally fluctuation chart bin result
        missed all bin error check:    22 tally bins had     0 bins with zeros and    15 bins with relative errors exceeding 0.10

   16   passed the 10 statistical checks for the tally fluctuation chart bin result
        missed all bin error check:    22 tally bins had     0 bins with zeros and    12 bins with relative errors exceeding 0.10

   34   passed the 10 statistical checks for the tally fluctuation chart bin result
        missed all bin error check:    22 tally bins had     0 bins with zeros and    12 bins with relative errors exceeding 0.10

    1   missed  1 of 10 tfc bin checks: the variance of the variance appears not to decrease as 1/nps for the last half of problem
        missed all bin error check:    22 tally bins had     6 bins with zeros and     9 bins with relative errors exceeding 0.10

   12   passed the 10 statistical checks for the tally fluctuation chart bin result
        passed all bin error check:     1 tally bins all have relative errors less than 0.10 with no zero bins

   26   missed  1 of 10 tfc bin checks: the slope of decrease of largest tallies is less than the minimum acceptable value of 3.0
        missed all bin error check:    22 tally bins had     4 bins with zeros and     9 bins with relative errors exceeding 0.10

    6   missed  2 of 10 tfc bin checks: the variance of the variance appears not to decrease as 1/nps for the last half of problem
        missed all bin error check:    23 tally bins had     0 bins with zeros and    10 bins with relative errors exceeding 0.10


the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

warning.      3 of the   7 tally fluctuation chart bins did not pass all 10 statistical checks.
warning.      6 of the   7 tallies had bins with relative errors greater than recommended.
```

N77 1tally fluctuation charts

	tally 11					tally 16					tally 34				
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom	mean	error	vov	slope	fom
1000	6.0293E-03	0.1312	0.0350	0.0	439	7.0926E-09	0.2430	0.1801	0.0	128	1.5962E-08	0.2430	0.1801	0.0	128
2000	7.2398E-03	0.0870	0.0196	0.0	487	9.4142E-09	0.1733	0.0864	0.0	123	2.1187E-08	0.1733	0.0864	0.0	123
3000	7.2005E-03	0.0738	0.0143	0.0	460	9.1372E-09	0.1473	0.0690	0.0	115	2.0563E-08	0.1473	0.0690	0.0	115
4000	7.3340E-03	0.0634	0.0123	0.0	460	9.1690E-09	0.1252	0.0502	0.0	118	2.0635E-08	0.1252	0.0502	0.0	118
5000	7.4462E-03	0.0560	0.0095	10.0	468	9.3345E-09	0.1075	0.0380	10.0	127	2.1007E-08	0.1075	0.0380	10.0	127
6000	7.8013E-03	0.0505	0.0083	10.0	475	1.0079E-08	0.0974	0.0318	10.0	128	2.2682E-08	0.0974	0.0318	10.0	128
7000	7.7051E-03	0.0471	0.0073	10.0	469	9.6335E-09	0.0911	0.0276	10.0	125	2.1680E-08	0.0911	0.0276	10.0	125
8000	7.9450E-03	0.0430	0.0058	10.0	488	1.0081E-08	0.0818	0.0224	10.0	135	2.2688E-08	0.0818	0.0224	10.0	135
9000	8.0559E-03	0.0407	0.0050	10.0	481	1.0271E-08	0.0770	0.0190	10.0	134	2.3115E-08	0.0770	0.0190	10.0	134
10000	8.1112E-03	0.0386	0.0045	10.0	482	1.0302E-08	0.0733	0.0180	10.0	134	2.3184E-08	0.0733	0.0180	10.0	134

	tally 1	tally 12	tally 26

nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom	mean	error	vov	slope	fom
1000	1.0592E-02	0.1770	0.1674	0.0	241	9.2139E-07	0.1647	0.1157	0.0	279	4.8014E-08	0.1842	0.2942	0.0	223
2000	1.1069E-02	0.1274	0.1097	0.0	227	9.5799E-07	0.1270	0.1633	0.0	229	5.2389E-08	0.1321	0.1685	0.0	212
3000	1.0812E-02	0.1027	0.0693	0.0	238	9.5580E-07	0.1035	0.0941	0.0	234	4.9731E-08	0.1053	0.1092	0.0	226
4000	1.0338E-02	0.0861	0.0540	0.0	249	9.1583E-07	0.0866	0.0732	0.0	246	4.9071E-08	0.0871	0.0798	0.0	244
5000	1.0623E-02	0.0752	0.0423	3.4	259	9.5291E-07	0.0744	0.0507	4.5	265	5.1827E-08	0.0792	0.0728	3.0	234
6000	1.0873E-02	0.0674	0.0322	3.7	266	9.7081E-07	0.0660	0.0385	6.5	278	5.3710E-08	0.0704	0.0531	3.0	244
7000	1.0876E-02	0.0611	0.0262	3.5	279	9.7074E-07	0.0597	0.0315	4.8	293	5.3623E-08	0.0645	0.0434	2.9	251
8000	1.1106E-02	0.0587	0.0223	5.4	263	1.0005E-06	0.0581	0.0274	4.6	268	5.4710E-08	0.0612	0.0347	2.9	242
9000	1.1486E-02	0.0536	0.0183	4.7	277	1.0381E-06	0.0528	0.0222	5.4	286	5.6240E-08	0.0558	0.0288	2.9	255
10000	1.1458E-02	0.0538	0.0361	3.2	248	1.0345E-06	0.0517	0.0279	3.6	268	5.6642E-08	0.0560	0.0452	2.5	229

tally 6

nps	mean	error	vov	slope	fom
1000	5.5106E-08	0.1680	0.2464	0.0	268
2000	6.1803E-08	0.1193	0.1324	0.0	259
3000	5.8868E-08	0.0962	0.0826	0.0	271
4000	5.8240E-08	0.0799	0.0587	4.0	289
5000	6.1161E-08	0.0722	0.0553	3.1	281
6000	6.3789E-08	0.0644	0.0391	3.5	292
7000	6.3256E-08	0.0593	0.0323	3.4	296
8000	6.4791E-08	0.0557	0.0263	3.4	291
9000	6.6512E-08	0.0513	0.0214	3.3	303
10000	6.6944E-08	0.0511	0.0359	2.9	275

N78 1neutron weight-window lower bounds from the weight-window generator print table 190

energy: 1.000E+02

cell	
1	-1.000E+00
2	5.000E-01
3	3.922E-01
4	3.130E-01
5	2.475E-01
6	1.984E-01
7	1.626E-01
8	1.287E-01
9	1.010E-01
10	7.914E-02
11	6.129E-02
12	4.599E-02
13	3.698E-02
14	2.989E-02
15	2.475E-02
16	2.320E-02
17	2.915E-02

1photon weight-window lower bounds from the weight-window generator print table 190

energy: 1.000E+02

```
  cell
     1    -1.000E+00
     2     8.809E+01
     3     1.981E+01
     4     1.686E+01
     5     8.031E+00
     6     3.644E+00
     7     2.282E+00
     8     1.338E+00
     9     7.626E-01
    10     5.013E-01
    11     2.949E-01
    12     1.639E-01
    13     9.683E-02
    14     5.539E-02
    15     3.086E-02
    16     1.720E-02
    17     9.638E-03
```

N79 1weight-window cards from the weight-window generator print table 200

```
          each card has ten leading blanks that must be removed by a text editor.

          wwp:n 5 3 5 0 0 0
          wwe:n  1.0000E+02
          wwn1:n   -1.0000E+00  5.0000E-01  3.9217E-01  3.1303E-01  2.4752E-01
                    1.9838E-01  1.6262E-01  1.2870E-01  1.0098E-01  7.9136E-02
                    6.1293E-02  4.5990E-02  3.6979E-02  2.9887E-02  2.4748E-02
                    2.3198E-02  2.9147E-02
          wwp:p 5 3 5 0 0 0
          wwe:p  1.0000E+02
          wwn1:p   -1.0000E+00  8.8090E+01  1.9808E+01  1.6860E+01  8.0314E+00
                    3.6442E+00  2.2823E+00  1.3383E+00  7.6262E-01  5.0125E-01
                    2.9486E-01  1.6394E-01  9.6828E-02  5.5386E-02  3.0862E-02
                    1.7199E-02  9.6381E-03
1the following cells are bounded by cells with generated photon
 weight-window bounds that are a factor of four or more different.


 photon   window group  1     upper energy = 1.0000E+02

            window        maximum       window                minimum       window
  cell      weight       neighbor       weight     ratio     neighbor       weight     ratio

     2    8.80903E+01            3    1.98081E+01      0.2            3    1.98081E+01      4.4
     3    1.98081E+01            2    8.80903E+01      4.4            4    1.68602E+01      1.2

 ****************************************************************************************************************************
```

N80 dump no. 2 on file test1.r nps = 10000 coll = 1325080 ctm = 1.39 nrn = 20894669

```
      8 warning messages so far.

N81run terminated when    10000 particle histories were done.

 computer time =    1.73 minutes

 mcnp    version 5    12212002                01/08/03 17:42:32     probid =  01/08/03 17:40:43
```

Notes:

N1: The first line of the output file identifies the code name and version. LD=xx identifies the code version date. The last two entries are the date and time the run was made.

N2: This is an echo of the execution line. The "name" option is being used so that the output file will be test1.o and the RUNTPE file will be test1.r.

N3: The numbers in this first column are sequential line numbers for the input file. They may be useful if you make changes to the file with an editor.

N4: The SDEF card defines a neutron (by default) source at the point 0,0,0 on surface 2. The neutrons will enter cell 2. The entry CEL=2 is not needed, but if you choose to use it and type in the wrong cell number, MCNP will give you an error message. The weight of each source neutron is 1 (also the default). VEC and DIR determine the starting direction. In this problem, the source is monodirectional in the *y* direction. All source neutrons have a starting energy of 14.19 MeV.

N5: The PWT card controls the number and weight of neutron–induced photons produced at neutron collisions for each cell. More neutron-induced photons will be generated as the cell number increases; i.e., photons created near the source are unlikely to contribute to the photon tally, so they should be sampled less often.

N6: The E0 card defines energy bins for all tallies except F6 and F12, which have their own En card. 13I means put 13 interpolates between 1 and 15 MeV. These energy bins are printed in Print Table 30.

– Print Table 10–

N7: All source variables defined explicitly or by default are printed. The order of sampling of the source variables is also printed, which is important for source variables that are dependent on other source variables.

–Print Table 30–

N8: This line identifies which tally type and particle type (neutron, photon, or electron) is used.

N9: This warning is generated because the upper limit of the E0 card of 20 MeV is higher than the maximum energy specified on the PHYS:N card.

N10: The energy bins for Tally 11 are specified by the E0 card. Tallies F1, F11, F16, F26, and F34 have energy bins specified by the E0 card tally. Tallies F6 and F12 have energy bins specified by the E6 and E12 cards. Only the upper bin limits are printed in the tally results section.

–Print Table 50–

N11: A cell can be composed of physically separate regions or pieces joined with the union operator. Improperly defined cells can be composed unintentionally of more than one piece (for example, a surface is extended unknowingly and forms a cell). If a cell is composed of more than one piece, a warning message is given and you should verify that the number of pieces is correct or incorrect.

–Print Table 60–

N12: If the mass or volume of a geometry or parts of it are known, you should compare the known volume or mass with what MCNP calculates in order to verify the correctness of your geometry. Be careful, however, that volumes or masses that MCNP cannot calculate (but supplies a value such as unity) do not affect the totals. Cell volumes that are not calculated by MCNP can be entered on the VOL card.

–Print Table 70–

N13: These entries are the surface coefficients used by MCNP and are not necessarily the entries on the surface cards.

–Print Table 72–

N14: This is the temperature calculated by MCNP for cells 2 through 17. Because there was not a TMPn:N card in the input file, room temperature (2.53×10^{-8} MeV) is assumed. Cell 1 has zero importance and is therefore not affected. The minimum and maximum source weights are also printed here because they are sometimes dependent upon cell volumes and cannot be printed earlier. When the source is biased in any way, there will be a fluctuation in starting source weights. The minimum source weight is used in the weight cutoff game when negative weight cutoffs are entered on the CUT cards. By playing the weight cutoff game relative to the minimum source weight, the weight cutoff in each cell is the same regardless of starting source wight. Note that if the source weight can go to zero, the minimum source weight is set to 10^{-10} times the value of the WGT parameter on the SDEF card. Information about the random number generator and its settings are then listed.

–Print Table 98–

N15: The physical constants (located in parameter statements in mcnp_params.F90) and units used in MCNP are listed here. The compilation options are also listed. Knowing how the code was compiled is very useful if it runs slowly, runs out of space, does not plot (plot option is wrong for your machine or run–time libraries for plotting are located differently on your machine), or cannot find the data libraries (wrong datapath–so you must use “setenv DATAPATH ...” on UNIX systems).

–Print Table 100–

N16: The cross-section table list shows the nuclear and atomic data used in the problem. The C appended to the neutron data indicates Continuous energy, a D indicates discrete reaction data, a P indicates photon data, and an E indicates electron data. Note that photon and electron data are all elemental (1000.02P) rather than isotopic (1001.62C). Warnings are printed in MODE N P problems if the photon production cross sections are unavailable or are in the less accurate equiprobable bin format. Note that electron data are loaded even though electrons are not transported in this MODE N P problem. The electron data are used for the thick target bremsstrahlung (TTB) model.

N17: If a neutron is born at an energy greater than E_{max} as set by the first entry on the PHYS:N card, that neutron is rejected and the event (such as fission) is resampled until an energy below E_{max} is obtained.

N18: Any neutron cross sections outside the energy range of the problem as specified by the PHYS:N and CUT:N cards are deleted.

–Print Table 85–

N19: The “Density Effect Data” Table contains the material data necessary to correct the stopping power term for the polarization of the media. If a fast electron passes through an equal areal density (mass density times length) of two materials, it will lose more energy in a sparse (rather than dense) material. This effect is very small for heavier particles, but for electrons with relativistic velocities transversing dielectrics media, it can be significant. For 1-MeV electrons in water, this correction can be as large as 5%.

N20: This is the electron range and straggling table for material 1 (Los Alamos concrete). It lists 133 electron energies in ascending order (only some are shown in this listing) and gives the respective stopping powers due to collision and radiation and the range of the electron in the material. Radiation yield is the fraction of the electron's kinetic energy which is converted into bremsstrahlung energy. The electron physics is turned on in this MODE N P problem for the TTB model.

–Print Table 86–

N21: The table entitled “electron secondary production for material 1” contains a list of 133 electron energies in ascending order (only some are shown in this listing) and gives the respective stopping powers due to collision and radiation and the range of the secondary electron created in the electron in the material.

N22: At the end of the cross-section processing, and before histories are started, the first dump is made to the RUNTPE file test1.r. This dump contains all the fixed information about the problem, namely the problem specification and all nuclear data. Subsequent dumps to test1.r will contain only information that accumulates as histories are run, such as tally information and particle statistics for summary and ledger tables.

–Print Table 110–

N23: This table gives starting information about the first 50 source particles. X, Y, and Z specify the initial position. CELL identifies what cell the particle started in or was directed into. SURF identifies what surface the particle started on, if any. U, V, and W identify the starting direction cosines. The starting time, weight and energy of the particles are also given.

–Problem Summary Tables–

N24: This is the neutron summary page for the problem. Each particle type has a summary balance sheet: the left side showing how particle tracks, weight, and energy were created and the right side showing how they were lost. The problem summary is for accounting only, because most entries, such as "tracks," have no physical meaning, and trying to give physical interpretation to these numerical quantities may be dangerous. The weight and energy columns contain the physical results. Because the summary contains net creation and loss, physical interpretation must be done with care. This table is useful in determining the major particle production and loss mechanisms, including time and energy cutoffs.

N25: The 35,686 represents the increased number of tracks obtained and banked from cell splitting, which occurs when the ratio of importances of the cell entered to the cell exited is greater than one. If the ratio is less than one, Russian roulette is played. If the track survives the roulette, its weight and weight times energy increases are recorded as gains. If it loses, it is recorded as a loss in all three categories on the loss side of the table. (See **N28**.)

N26: The creation of particle weight and energy from weight cutoff represents the weight and weight times energy gained from winning the weight cutoff Russian roulette game. No tracks are created because the original track continues with an increased weight at the same energy. (See **N29**.)

N27: Any tracks that enter a cell of zero importance are considered to have escaped the geometry and are recorded here. This category is the physical leakage from the system. The precision of this result is unknown because no relative error is calculated as it is with a tally. If the statistical error is required, the escapes can be tallied with an F1 tally over all surfaces adjacent to zero importance cells.

N28: Loss to importance sampling results from losing the Russian roulette game played when a particle crosses a surface into a cell of lower importance. With perfect sampling, the weight and energy losses should agree with gains in **N25**.

N29: Loss to weight cutoff comes from losing the weight cutoff Russian roulette game. With perfect sampling, the weight and energy lost here should equal the weight and energy gained in **N26**. Accumulations in the three loss entries include the number, weight, and weight times energy of the tracks lost to weight cutoff. The weight entry in the table is normalized by the number of source particles, and the weight times energy entry is

normalized by the total weight of source particles. Thus, the average weight of each track lost to the weight cutoff is: weight entry ∗ NPS/number of tracks lost: 0.080664 * 10000 / 8628 = 0.093491. The small average track weight is caused by the scaling of the weight cutoff criteria by the ratio of the source cell importance to the collision cell importance. The average energy of a particle lost to weight cutoff per source particle is: energy entry/ (weight entry) ∗ average source starting weight: (0.045217/0.080664) ∗ 1.0 = 0.56056. The same normalizing procedure applies to all energy entries in both the creation and loss columns of this table.

N30: In a scattering event, only the particle energy is changed. Energy difference = energy in – energy out. If this difference is positive, it is entered as downscattering on the loss side; if it is negative, as in a thermal neutron upscatter, it is entered on the creation side as upscattering. Thermal neutron scatter always results in a small energy gain or loss. (Elastic collisions in the center–of–mass system gain or lose energy in the laboratory system.) Higher energy scatter is usually an energy loss mechanism. This energy is only for the track being followed. If the collision is a fission or (x,xn), the tracks in addition to one outgoing track are recorded in the three creation columns of the fission and (x,xn) rows.

N31: Tracks are lost to capture only if the analog capture option is used (PHYS or CUT card). In this problem, implicit capture was used to remove a fraction of each particle's weight at each collision. The energy lost was the incident energy of the particle times the weight lost to capture. The weight lost to capture (n,0n) is a physically meaningful quantity. No relative error is calculated.

N32: Note that the total gain and the total loss of each of the three quantities balance exactly in all problems.

N33: Since all neutrons in this problem started at time zero (see **N23**), the average time of escape is also the prompt neutron escape lifespan, and the average time of capture is also the prompt capture (n,0n) lifespan. Since there is no fission in the problem, escape and capture are the only two physical removal mechanisms; thus, the average time to capture or escape is both the prompt removal lifespan and the prompt removal lifetime. See Chapter 2, page 2-170. These quantities are absorption estimates averaged over all histories: F4 track length estimates can be calculated with the FM card. The “average time of” is always measured relative to time zero and is mostly of use in setting a time cutoff, time bins, or getting a better feel for what is happening in the problem.

N34: The second entry of the net multiplication is the relative error: the estimated standard deviation of the tally mean divided by the estimated tally mean. In this problem, the net multiplication, which is the sum of the source weight and the weight gain from (n,xn) reactions, is 1.0149 ±0.1 %. The net multiplication is not the criticality eigenvalue k_{eff} of the system. See Neutron Tallies and the MCNP Net Multiplication Factor on page 2-184 for further discussion of this subject.

N35: Pair production caused the loss of 966 tracks with a weight of 0.14532. The electron from pair production is assumed to immediately annihilate and lose all its energy in the cell,

unless it is transported in MODE P E. The positron is annihilated (p–annihilation), producing two photons (1932 tracks with weight 0.29063), each with energy 0.511 MeV (0.14852*1./0.29063) emitted isotropically.

N36: For a MODE N P problem, the "average time of" for a photon is relative to zero time, and not the time when the photon was produced. Thus the "average time of" escape or capture includes the mean time to creation.

–Print Table 126–

N37: "Tracks entering" a cell refers to all tracks entering a cell, including source particles. If a track leaves a cell and later reenters that same cell, it is counted again. Tracks entering does not include particles from the bank (from variance reduction events at collisions or physical events at collisions).

N38: "Population" in a cell is the number of tracks entering a cell plus source particles plus particles from the bank (from variance reduction or physical events at collisions). Population does not include reentrant tracks. Comparing **N37** to **N38** will indicate the amount of back scattering in the problem. An often successful rule of thumb for choosing importances is to select them so that population is kept roughly constant in all cells between the source and tally regions. Information, once lost, cannot be regained. The 13,245 particles in cell 8 can contain no more information than the 7,053 particles in cell 6 because all particles in cell 8 are progeny of the particles in cell 6. Oversplitting or undersplitting has occurred between cell 6 and cell 8.

N39: The number of "collisions" in a cell is important for a detector tally or anything involving collision rate. A lack of collisions may indicate a need to force them. This quantity is not normalized by cell volume. In some problems, most of the computer time is spent modeling collisions. Cells with excessive numbers of collisions are possibly oversampled. This often happens when many thermal neutrons diffuse and contribute little of significance to the problem solution. In such cases, energy–dependent weight windows are most effective, followed by energy roulette, exponential transform analog capture, time cutoff, or energy cutoff. Note that the last two methods may introduce a bias into the problem. Subdividing the cell into smaller cells with different importances also is effective.

N40: The number of "collisions times the weight" of the particles having the collisions is an indication of how important the collisions were.

N41: The next four items are determined from the distance D to the next collision or surface. The time DT to traverse this distance is determined from DT=D/VEL where VEL is the speed of the particle. WGT is the weight of the particle and ERG is its energy. Furthermore, the flux $\Phi(E)$ is equal to the number density n(E) times the speed.

The energy ERG averaged over the number density of particles WGT*DT is determined by

$$\frac{\int\int n(E,t)\cdot E dE dt}{\int\int n(E,t) dE dt} \quad \text{or} \quad \frac{\sum(WGT*DT*ERG)}{\sum(WGT*DT)}$$

N42: The energy averaged over the flux density is

$$\frac{\int\int \Phi(E,t)\cdot E dE dt}{\int\int \Phi(E,t) dE dt} \quad \text{or} \quad \frac{\sum(WGT*D*ERG)}{\sum(WGT*D)}$$

It is very difficult, and perhaps meaningless, to determine an average energy because a large spectrum involving several orders of magnitude is frequently involved leading to the problem of representing this spectrum by one number. That is why an average energy has been calculated by the two methods of items **N41** and **N42**. If the number–averaged neutron energy is significantly lower than the flux–averaged neutron energy (as is true in this problem), it indicates a large number of low-energy neutrons with large DTs. As the neutron energy cutoff in this problem is raised, these two average energies come into closer agreement. Note that the two average energies are identical for constant velocity photons.

N43: The relative average track weight is $I_c\Sigma(WGT*D)/(I_s\Sigma D)$, where I_c and I_s are the importances of the cell and the source cell. By making the average track weight relative to the cell importance, the weight reduction from importance splitting is removed. For most problems with proper cell importances, the average track weight is constant from cell to cell and deviations indicate a poor importance function. The variation in average track weight for the photons in Print Table 126 suggests that the photon importances (same as neutrons) are poor. With weight windows, the average track weight should be within the weight window bounds.

N44: The average flux weighted track mean free path is

$$\frac{\int \Phi(E)/\Sigma_t(E) dE}{\int \Phi(E) dE} = \frac{\sum WGT*D/TOTM}{\sum WGT*D} \quad ,$$

where $TOTM = \Sigma_t(E)$ is the total macroscopic cross section. The mean free path is strongly dependent upon energy and so this average mean free path may be meaningless. A rule of thumb for guessing at importances is that importances should double approximately every mean free path. This is usually a very poor rule, but it is sometimes better than nothing. The average track mean free path is thus useful for making poor guesses at cell importances. It is also useful for determining the fictitious radius of point detectors, the outer radius of DXTRAN spheres, exponential transform stretching parameters, the necessity of forced collisions, etc. Occasionally this quantity may even provide physical insight into your problem.

N45: For photons, the number–weighted energy and flux–weighted energy are equal because a photon has a constant velocity regardless of energy. See **N37 – N44**.

–Print Table 130–

N46: The next six tables of Print Table 130 (three for neutrons and three for photons) show all possible ways a particle's weight may be changed in each cell. In addition to telling you what is happening to the particle and where, this information can be useful in debugging a problem. The category totals agree with the problem summary.

Note that the neutron weight entering cell 17 is 0.018876, whereas in Print Table 126 the average relative track weight in cell 17 is 0.41936. This apparent discrepancy is resolved by realizing that the average weight in Table 126 is for a track, while it is for a history in Print Table 130. Furthermore, in Table 126 the weight is relative, whereas it is absolute here in Table 130. If the average track weight is multiplied by the tracks entering cell 17 (14,260) and then divided by both the number of source particles (10,000) and the importance ratio (32), the two weights are in close agreement. Most of the totals over the cells can be compared directly with the weight gain, loss, or difference in the Problem Summary. The average value of ν in a problem with fissionable material can be obtained by taking the ratio of fission neutrons to fission loss in the neutron physical events table.

–Print Table 140–

N47: The activity of each nuclide per source particle in each cell can tell you how important various nuclides, such as trace elements, are to the problem and may aid in selecting cross-section libraries when memory is limited. Neutron-induced photon production is also listed for MODE N P or MODE N P E problems. This chapter only shows a partial listing of this table.

N48: This table is the nuclide activity per source particle for neutrons summed over all cells in the problem.

N49: This table shows the photoatomic nuclide activity per source particle summed over all cells in the problem.

N50: This table is printed only for MODE N P or MODE N P E problems. It tells you how many photons were produced in each cell and the energy spectrum of the photons averaged over the problem. Because photons are produced only at neutron collisions, there is a correlation between the number of collisions in a cell, the PWT card, and this table. A previous table (**N47**) showing the photon activity for the problem includes isotope–dependent neutron–induced photon production information.

Tally Results and Tally Fluctuation Charts (TFC)

N51: All tallies here are created by the F1, F11, F12, F6, F16, F26, and F34 cards in the input file. Only the F11 results are shown. The F11 tally gives the neutron current summed in all directions integrated over a surface. Since surface 18 bounds a zero importance cell, the F11 tally is the leakage current leaving the concrete. This tally estimates that between 13 and 14 MeV, the current is $1.91146 \times 10^{-4} \pm 16.25\%$ within one standard deviation. The large relative error reduces the likelihood that this confidence interval is valid.

N52: This is the TFC statistical check table which provides the results of ten checks that are used to test the tally fluctuation chart answer for reliability. MCNP checks the behavior of the mean, relative error, VOV, FOM, and the high score region of the history probability density function. The table presents the desired, observed, and actual results along with the pass/no pass message for each test. The TFC bin for this problem is the last (total) energy result (see the TFn card in Chapter 3, page 3-111). All checks were passed, implying that confidence intervals for this tally will be valid.

N53: This column shows the desired, observed, and actual behavior of the estimated mean. Random behavior of the mean is desired because an ideal random quantity should exhibit a normal distribution of values around an average value. MCNP checks for non-monotonic (no increasing or decreasing trend) behavior of the mean for the last half of the problem. If the behavior of the mean meets this criteria, then it passes this test. The tally appeared to be random over the last half of the problem, so it passed this test.

N54: This column checks if the relative error (RE) is below a limit usually required to provide a reliable confidence interval (0.05 for detector tallies and 0.10 for all other tallies).

N55: This column checks if the RE is monotonically decreasing over the last half of the problem.

N56: This column checks for the decrease rate of the RE as a function of the number of histories (NPS). If the RE is decreasing at the desired rate ($\sim 1/\sqrt{\text{NPS}}$) for the last half of the problem, then it passes this check.

N57: This column checks if the VOV is below the prescribed value of 0.1.

N58: This column checks for a monotonically decreasing VOV for the last half of the problem.

N59: This column is the check for the rate of decrease (~1/NPS) of the VOV for the last half of the problem.

N60: This column checks for a statistically constant value of the figure of merit (FOM) for the last half of the problem.

N61: This column checks the FOM for random behavior.

N62: This column checks the slope of the history score probability density function (PDF) for the 25 to 200 largest history scores. At least the second large history score moment should exist for all valid MCNP tallies. If the slope is greater than 3, then the second moment of the sampled PDF exists and the requirements of the central limit theorem appear to be satisfied. As the slope increases, a more reliable confidence interval is formed because the tally PDF appears to be more completely sampled.

N63: All of the statistical checks were passed and, therefore, a range of confidence intervals for the shifted asymmetric distribution is provided. Three ranges are given for the confidence intervals of 1, 2, and 3 standard deviations. The second line displays the ranges for the unshifted symmetric confidence intervals. If the checks had not been satisfied, a warning would have been provided.

N64: The normed average tally per history describes the average tally normalized over the tally surface or volume for the TFC bin. It includes energy- and time-dependent multipliers and some constant multipliers, but excludes most constant multipliers.

N65: The unnormed average tally per history does not always include all multipliers. It is the tally used for statistical analysis and is for the same TFC bin as the normed tally.

N66: The estimated variance of the variance (VOV) checks the tally history scores for any effects of inadequately sampled problems. It can detect tally errors due to insufficient sampling of high weight scores that can cause an underestimated mean and relative error. If high scores are possible, but unsampled, the VOV is not an effective diagnostic. The typical acceptable VOV is 0.1 or less in order to provide a reliable confidence interval.

N67: This is the relative error component from histories which do not contribute to the tally (zero history scores). If this quantity is nearly equal to the tally error, then methods should be applied to enable more histories to contribute to the tally.

N68: This is the relative error from only the nonzero history scores. If this quantity is nearly equal to the tally error, problem efficiency can be improved by reducing the weight spread in the history scores.

N69: This is the fraction of total NPS that resulted in nonzero score tallies. The user should strive to make this quantity as close to unity as possible.

N70: If there is a great difference between the largest and average tally, the large weight tallies would represent important regions of physical phase space that have been undersampled (possibly caused by poor variance reduction technique selection). To understand what causes the large weight tallies, the history number of the largest weight tally is printed so that this history can be rerun to get its event log. When the undersampled event is identified, the variance reduction methods should be modified and the problem rerun. Improved variance reduction usually causes fewer source histories to be run per minute because more time is spent sampling the formerly undersampled important phenomena outside the source. The final result will be an improved (higher) FOM and a lower largest/average tally ratio. As the largest/average tally ratio approaches unity, the problem

approaches an ideal zero variance solution. In practice, performing the steps discussed above is an art often beyond all but the most experienced users: it can be difficult, time-consuming, frustrating, and sometimes unsuccessful. An alternative is to let MCNP determine the better importance function for the next run with the weight window generator, as has been done in this problem. Use of the generated weight windows printed in Print Table 190 caused a factor of three improvement in problem efficiency when the problem was rerun.

N71: This ratio expresses the confidence interval shift as a fraction of the mean. The confidence interval is shifted in the case of an asymmetric confidence interval.

N72: This table provides the user with the information on how the TFC bin would be affected by the largest sampled history score occurring on the next history. This table can reveal the impact of an infrequent high weight score distorting the TFC bin quantities. The three columns show the value at the current NPS, the value at the next NPS (which is the value of the highest past score), and the ratio of the highest value over the previous lower value. If the mean should increase a significant fraction of the original estimated standard deviation of the mean, the confidence interval may not be valid.

N73: These two lines summarize briefly the behavior of the large score tail of the history score probability density function. MCNP checks the slope of the high score tail in order to discern whether the tally appears to have been sampled well. If the tail of the probability density function is not decreasing at a fast enough rate so that at least the second history score moment appears to exist, then MCNP will flag this as an insufficiently sampled problem.

The third line prints the FOM as the product of the source histories per minute times the TFC bin signal-to-noise ratio squared. This ratio is defined to be the estimated mean divided by the estimated population standard deviation (see the FOM section in Chapter 2 on page 2-117). This FOM interpretation separates it into a computational rate term and a term dependent solely on the characteristics of the history score probability density function.

–Print Table 161–

N74: This plot is the unnormed empirical history score probability density for the tally fluctuation chart bin of Tally 11. The probability density is the number of history scores (horizontal) plotted against the value of the score (vertical). The nonzero mean is denoted by the horizontal line of m's. If a problem has been undersampled, this plot will often show “holes,” or unsampled regions of the PDF at the high scores. If the slope is less than 10, this plot will also show a curve of S's which represent the Pareto curve fit to the PDF at the high scores. This allows the user to visually compare the fit of the high weight tally scores to the calculated distribution. The total 0.115 is from 1,153 non-zero history scores out of 10,000 histories.

–Print Table 162–

N75: This plot is the cumulative number of tallies in the tally fluctuation chart bin of tally 11. It is simply the cumulative version of Print Table 161; i.e., the cumulative probability density function. The ordinate and abscissa values are printed in the left-hand columns and are read as, "789 scores were made with a value of 0.0794328 or less and these 789 scores accounted for 68.430% of the total tally." This plot is followed by a plot of the cumulative tally in the tally fluctuation chart bin. These entries are read as "Of the total tally value 8.11117×10^{-3}, 2.871×10^{-3} (or 35.4%) was from tallies with values less than 0.0794328."

N76: Only Tally 11 was shown to save space. After all the tallies are printed, a summary of statistical checks for all of the tallies is given, followed by warning messages if required.

N77: The tally fluctuation charts always should be studied to see how stable or reliable the tally mean, relative error, VOV, slope, and FOM are, indicating how the problem is converging as a function of history number, NPS. The FOM is defined as $1/\sigma^2 t$, where σ is the relative error and t is the computer time in minutes. In a well-behaved problem, t is proportional to the number of histories run, NPS, and σ is proportional to $1/\sqrt{\text{NPS}}$. Thus the FOM should rapidly approach a statistically constant value as it does in this problem. Big changes in the FOM indicate sampling problems that need attention. A large drop in the FOM means a large history score occurred. A monotonically increasing FOM indicates the tally is recovering from a large history score. In this case, expect a series of large scores to occur as the problem continues.

The order of printing tallies is: neutron, photon, combined neutron/photon, electron, and combined photon/electron. Notice that the combined heating Tally F6 is exactly the sum of the neutron, F16, and photon, F26, heating tallies.

–Print Table 190–

N78: These two tables are a list of the lower weight window energy bounds generated by the WWG card. These window bounds are themselves estimated quantities and must be well converged or they can cause more harm than good. When well converged, they can improve efficiency dramatically. Use of these printed weight window values results in an increase of three in the FOM for Tally 12 when the problem was rerun. Note that the number of histories per minute is often lower in the more efficient problem because more time is spent sampling important regions of the problem phase space.

These weight windows were chosen to optimize Tally 12 as specified on the WWG card. In the subsequent run using these weight windows, the FOM of Tally 12 improved by three as did the other photon tallies, and Tallies 16 and 34 were slightly degraded. The weight window generator optimizes the importance function for one tally at the expense of all others, if necessary.

Sometimes the calculated lower bound for the photon weight window in a cell is zero, meaning that no photons in that cell ever contributed to the tally of interest in that run. If

the zero is unchanged in the run using these windows, the weight cutoff game will be played in that cell, sometimes with disastrous consequences. Thus, a guess should be made for a lower bound rather than leaving the zero value. A good guess is 10, which is several times higher than the weight window generated for its nearest neighboring cell.

The generated weight windows may be thought of as a forward adjoint solution and thus can provide considerable insight into the physics of a problem. Low weight windows indicate important regions. A low window on a cell bounding the outside world often indicates that the geometry was truncated and more cells need to be added outside the present geometry. Weight windows that differ greatly between adjacent cells indicate poor weight window convergence or, more likely, a need to subdivide the geometry into smaller phase space units that will have different importances.

Time-dependent weight windows are also available.

–Print Table 200–

N79: The weight window cards from the weight window generator can, with some file editing, be used instead of the IMP:N and IMP:P cards in the next run of this problem. Zero windows should be replaced with a good guess. Windows differing greatly from those in neighboring cells should be replaced. The table following Print Table 200 indicates that the photon group 1 windows for adjacent cells 2 and 3 differ by more than a factor of 4.

We suggest the user read these generated window values from the WWOUT file rather than the editing method just discussed (WWG card, WWINP=WWOUT on the execute line).

N80: With this initial run, there are two dumps on the RUNTPE. The first dump occurs at the end of XACT. The second dump is done at the problem end. A continue–run will pick up from this second dump and add a third dump to the RUNTPE when it finishes.
CTM = 1.39 is the computer time in minutes used in the transport portion of the problem. Note the number of warning messages to make sure they are all understood.

N81: One or more reasons are always given as to why the run was terminated. If there are no errors, most runs terminate after the desired number of particles are run or by a time limit. Computer time =1.73 minutes is the total time for the problem, including initiation, output, etc.

III. CONC PROBLEM AND OUTPUT

This simple, but pathological, problem illustrates how to use and interpret results from point and ring detectors. It also shows how the statistical checks can reveal deficiencies in the tallies of an otherwise well–behaved problem. The problem consists of a spherical shell of concrete with a 390-cm outer radius and a 360–cm inner radius (see Chapter 2 Reference 122). A 14 MeV point isotropic neutron source is at 0,0,0, the center of the void region. It is a neutron–only problem (MODE N - this is the default mode and thus the mode card does not appear in the CONC input file), with a neutron lower energy cutoff at 12 MeV. A surface flux tally is used in addition to point and ring detectors.

Even though this is a simple problem, it is difficult, and even inappropriate, for the F65 point detector. Detectors are usually inappropriate when particles can be transported readily to the region of interest and another type of tally, such as the F2 surface flux tally, can be used. Also, detectors do not generally work well close to or in scattering regions. This problem is especially difficult for point detectors because the largest history scores occur for neutrons that not only have several collisions near the detector point but also stay above the 12 MeV energy cutoff. These histories are extremely rare. A detailed discussion of this problem is presented in Chapter 2, page 2-134.

The following notes on the output describe the pertinent details dealing with the point detector results. The notes will provide a description of the Tally Fluctuation Chart (TFC) bin checks that test the tally for its reliability. This problem dramatically illustrates the importance of the Variance of the Variance (VOV) and the history score Probability Density Function (PDF) slope checks in determining the reliability of the results.

The following notes apply to the CONC problem output file. Only the default print tables appear because there is no PRINT card.

```
                                  _
          ._ _    _  ._   ._   |_
          | | |  (_  | |  |_)   _)
                        |
 +--------------------------------------------------------------------+
 |   This program was prepared by the Regents of the University of    |
 |California at Los Alamos National Laboratory (the University) under |
 |  contract number W-7405-ENG-36 with the U.S. Department of Energy  |
 |(DoE).  The University has certain rights in the program pursuant to|
 |  the contract and the program should not be copied or distributed  |
 | outside your organization.  All rights in the program are reserved |
 |by the DoE and the University.  Neither the U.S. Government nor the |
 | University makes any warranty, express or implied, or assumes any  |
 |     liability or responsibility for the use of this software.      |
 +--------------------------------------------------------------------+

1mcnp     version 5     ld=12212002                    01/08/03 17:43:02
 ***********************************************************************                probid =  01/08/03 17:43:02
```

N1 `i=conc n=conc.`

```
    1-       conc: 30 cm thick concrete shell with point 14 MeV source in center
    2-       c
    3-       1    0 -1
    4-       2    1 -2.3 1 -2
    5-       3    0  2 -3
    6-       4    0  3 -4
    7-       5    0  4
    8-
    9-       1    so 360
   10-       2    so 390
   11-       3    so 420
   12-       4    so 4000
   13-
   14-       sdef
   15-       imp:n  1 3r 0
   16-       m1     1001 1.68765e-01
   17-              8016 5.62493e-01
   18-             11023 1.18366e-02
   19-             12000 1.39951e-03
   20-             13027 2.14316e-02
   21-             14000 2.04076e-01
   22-             19000 5.65495e-03
   23-             20000 1.86720e-02
   24-             26054 2.47295e-04
   25-             26056 3.91067e-03
   26-             26057 9.38014e-05
   27-             26058 1.19384e-05
   28-              6012 1.41730e-03
```

```
   29-       c
   30-       c     surface, point, and ring detector tallies
   31-       f2:n   4
   32-       e2     12.5 2i 14. c
   33-       f12:n  3
   34-       f22:n  2
   35-       f25:n  0 -4000 0 0
   36-       f35:n  0  4000 0 0
   37-       f45:n  0  -420 0 0
   38-       f55:n  0   420 0 0
N2 39-       f65:n  0  -390 0 -0.5
   40-       f75:n  0   390 0 -0.5
   41-       f85y:n  0 4000 0
N3 42-       f95y:n  0  420 0
   43-       f105y:n 0  390 -0.5
   44-       e0      12.5 2i 14.
N4 45-       dd      0.1 1e100
   46-       c
   47-       c    cutoff the neutrons at 12 MeV
N5 48-       cut:n   j 12.0
   49-       nps     40000
   50-
1cells                                                                  print table 60

                      atom        gram                                      neutron
        cell  mat     density     density     volume       mass     pieces importance

     1     1    0  0.00000E+00 0.00000E+00 1.95432E+08 0.00000E+00     1  1.0000E+00
     2     2    1  8.14389E-02 2.30000E+00 5.30427E+07 1.21998E+08     1  1.0000E+00
     3     3    0  0.00000E+00 0.00000E+00 6.18642E+07 0.00000E+00     1  1.0000E+00
     4     4    0  0.00000E+00 0.00000E+00 2.67772E+11 0.00000E+00     1  1.0000E+00
     5     5    0  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00     0  0.0000E+00

 total                                    2.68083E+11 1.21998E+08

    minimum source weight = 1.0000E+00    maximum source weight = 1.0000E+00

 ************************************************
 * Random Number Generator  =                   1 *
 * Random Number Seed       =       19073486328125 *
 * Random Number Multiplier =       19073486328125 *
 * Random Number Adder      =                    0 *
 * Random Number Bits Used  =                   48 *
 * Random Number Stride     =               152917 *
 ************************************************

1cross-section tables                                                   print table 100
```

```
      table    length

                          tables from file actia

   1001.62c     1670  1-h-1 at 293.6K from endf-vi.8 njoy99.50                                  mat 125       12/05/01
   8016.62c    63850  8-o-16 at 293.6K from endf-vi.8 njoy99.50                                 mat 825       12/05/01
  11023.62c     2073  11-na-23 at 293.6K from endf-vi.8 njoy99.50                               mat1125       12/06/01
  12000.62c     6718  12-mg-0 at 293.6K from endf/b-vi.8 njoy99.50                              mat1200       12/06/01
  13027.62c    42233  13-al-27 at 293.6K from endf-vi.8 njoy99.50                               mat1325       12/17/01
  19000.62c     4162  19-k-0 at 293.6K from endf/b-vi.8 njoy99.50                               mat1900       12/06/01
  20000.62c    33833  20-ca-0 at 293.6K from endf-vi.8 njoy99.50                                mat2000       12/05/01
  26054.62c    43143  26-fe-54 at 293.6K from endf-vi.8 njoy99.50                               mat2625       12/20/01
  26056.62c    86372  26-fe-56 at 293.6K from endf-vi.8 njoy99.50                               mat2631       12/20/01
  26057.62c    41673  26-fe-57 at 293.6K from endf-vi.8 njoy99.50                               mat2634       12/20/01
  26058.62c    16954  26-fe-58 at 293.6K from endf-vi.8 njoy99.50                               mat2637       12/20/01

                          tables from file rmccs

   6012.50c     3844  njoy                                                                 (  1306)      79/07/31.

                          tables from file endf60

  14000.60c     7846  14-si-nat from endf/b-vi                                                  mat1400       11/25/93

  total       354371

 neutron cross sections outside the range from 1.2000E+01 to 1.0000E+36 mev are expunged.

 ************************************************************************************************************************
 dump no.    1 on file conc.r       nps =         0     coll =              0     ctm =    0.00     nrn =              0
```

N6 1problem summary

```
      run terminated when     40000 particle histories were done.
+                                                                                        01/08/03 17:43:42
      conc: 30 cm thick concrete shell with point 14 MeV source in center                probid =  01/08/03 17:43:02
0
 neutron creation    tracks      weight        energy           neutron loss        tracks      weight        energy
                                 (per source particle)                                         (per source particle)

 source               40000    1.0000E+00    1.4000E+01        escape               4564    8.9431E-02    1.2287E+00
                                                                 energy cutoff       36072    6.7612E-01    3.5342E+00
                                                                 time cutoff             0    0.            0.
 weight window            0    0.            0.                weight window           0    0.            0.
 cell importance          0    0.            0.                cell importance         0    0.            0.
 weight cutoff            0    2.0177E-04    2.5423E-03        weight cutoff          39    2.1885E-04    2.7877E-03
 e or t importance        0    0.            0.                e or t importance       0    0.            0.
 dxtran                   0    0.            0.                dxtran                  0    0.            0.
 forced collisions        0    0.            0.                forced collisions       0    0.            0.
```

```
 exp. transform           0    0.            0.                  exp. transform           0    0.            0.
 upscattering             0    0.            0.                  downscattering           0    0.            5.7459E+00
 photonuclear             0    0.            0.                  capture                  0    2.4634E-01    3.3837E+00
 (n,xn)                1350    2.3811E-02    5.7280E-02          loss to (n,xn)         675    1.1905E-02    1.6458E-01
 prompt fission           0    0.            0.                  loss to fission          0    0.            0.
 delayed fission          0    0.            0.
     total            41350    1.0240E+00    1.4060E+01              total            41350    1.0240E+00    1.4060E+01

   number of neutrons banked                        0        average time of (shakes)              cutoffs
   neutron tracks per source particle     1.0337E+00          escape            7.9567E+01          tco   1.0000E+33
   neutron collisions per source particle 1.8927E+00          capture           7.3068E+00          eco   1.2000E+01
   total neutron collisions                    75707          capture or escape 2.6553E+01          wc1  -5.0000E-01
   net multiplication              1.0119E+00 0.0005          any termination   1.3464E+01          wc2  -2.5000E-01

 computer time so far in this run     0.63 minutes            maximum number ever in bank         0
 computer time in mcrun               0.31 minutes            bank overflows to backup file       0
 source particles per minute            1.3015E+05
 random numbers generated                  1221320            most random numbers used was      184 in history    16044

 range of sampled source weights = 1.0000E+00 to 1.0000E+00
1neutron  activity in each cell                                                                          print table 126

                tracks     population   collisions   collisions     number        flux        average      average
        cell    entering                             * weight     weighted     weighted   track weight   track mfp
                                                   (per history)    energy       energy     (relative)      (cm)

     1     1       40456        40000            0    0.0000E+00   1.3988E+01   1.3989E+01   9.9690E-01   0.0000E+00
     2     2       40456        40000        75707    1.6751E+00   1.3741E+01   1.3751E+01   8.8592E-01   8.1252E+00
     3     3        4564         4564            0    0.0000E+00   1.3668E+01   1.3676E+01   7.6640E-01   0.0000E+00
     4     4        4564         4564            0    0.0000E+00   1.3728E+01   1.3735E+01   7.8271E-01   0.0000E+00

     total         90040        89128        75707    1.6751E+00

1tally   2        nps =    40000
           tally type 2    particle flux averaged over a surface.       units   1/cm**2
           tally for  neutrons
N7         energy bins are cumulative.

           areas
                surface:       4
                         2.01062E+08

 surface  4
      energy
    1.2500E+01   1.73171E-11 0.0687
    1.3000E+01   3.54585E-11 0.0488
    1.3500E+01   7.03849E-11 0.0345
    1.4000E+01   4.45131E-10 0.0143
SKIP 697 LINES OF OUTPUT
```

```
1tally  65        nps =    40000
          tally type 5    particle flux at a point detector.          units   1/cm**2
          tally for  neutrons

 detector located at x,y,z = 0.00000E+00-3.90000E+02 0.00000E+00
      energy
    1.2500E+01   1.01897E-09 0.4927
    1.3000E+01   7.06975E-10 0.4303
    1.3500E+01   1.58041E-09 0.7556
    1.4000E+01   3.35508E-08 0.4864
      total      3.68571E-08 0.4449

 detector located at x,y,z = 0.00000E+00-3.90000E+02 0.00000E+00
 uncollided neutron flux
      energy
    1.2500E+01   0.00000E+00 0.0000
    1.3000E+01   0.00000E+00 0.0000
    1.3500E+01   0.00000E+00 0.0000
    1.4000E+01   1.31819E-08 0.0000
      total      1.31819E-08 0.0000
```

N8 detector score diagnostics

	times average score	transmissions	cumulative fraction of transmissions	tally per history	cumulative fraction of total tally
a	1.00000E-01	11834	0.22682	2.14003E-11	0.00058
	1.00000E+00	39918	0.99191	1.31328E-08	0.35690
	2.00000E+00	34	0.99256	2.07582E-11	0.35746
	5.00000E+00	37	0.99327	5.54181E-11	0.35896
	1.00000E+01	24	0.99373	6.65746E-11	0.36077
	1.00000E+02	42	0.99454	5.26167E-10	0.37505
	1.00000E+03	15	0.99483	2.37024E-09	0.43936
b	1.00000E+38	7	0.99496	2.05977E-08	0.99821
1st 200 histories		263	1.00000	6.60082E-11	1.00000

```
 average tally per history = 3.68571E-08            largest score = 3.61172E-04
 (largest score)/(average tally) = 9.79925E+03      nps of largest score =    39949

 score contributions by cell
        cell    misses      hits    tally per history    weight per hit
     1     1         0 *c* 40000       1.31819E-08         1.31819E-08
     2     2     55944 *d* 12174       2.36752E-08         7.77895E-08
       total     55944 *e* 52174       3.68571E-08         2.82571E-08

 score misses
   russian roulette on pd                  0
   psc=0.                               5349
   russian roulette in transmission     1803
   underflow in transmission               0
   hit a zero-importance cell              0
```

energy cutoff 48792

N9 results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally 65

tfc bin behavior	--mean-- behavior	---------relative error--------- value	decrease	decrease rate	----variance of the variance---- value	decrease	decrease rate	--figure of merit-- value	behavior	-pdf- slope
desired	random	<0.05	yes	1/sqrt(nps)	<0.10	yes	1/nps	constant	random	>3.00
observed	random	0.44	no	no	0.96	no	no	decrease	random	1.38
passed?	yes	no	no	no	no	no	no	no	yes	no

warning. the tally in the tally fluctuation chart bin did not pass 8 of the 10 statistical checks.

1analysis of the results in the tally fluctuation chart bin (tfc) for tally 65 with nps = 40000 print table 160

normed average tally per history = 3.68571E-08
estimated tally relative error = 0.4449
relative error from zero tallies = 0.0000

unnormed average tally per history = 3.68571E-08
estimated variance of the variance = 0.9596
relative error from nonzero scores = 0.4449

number of nonzero history tallies = 40000
history number of largest tally = 39949
(largest tally)/(average tally) = 1.76155E+04

efficiency for the nonzero tallies = 1.0000
largest unnormalized history tally = 6.49258E-04
(largest tally)/(avg nonzero tally)= 1.76155E+04

(confidence interval shift)/mean = 0.2160

shifted confidence interval center = 4.48174E-08

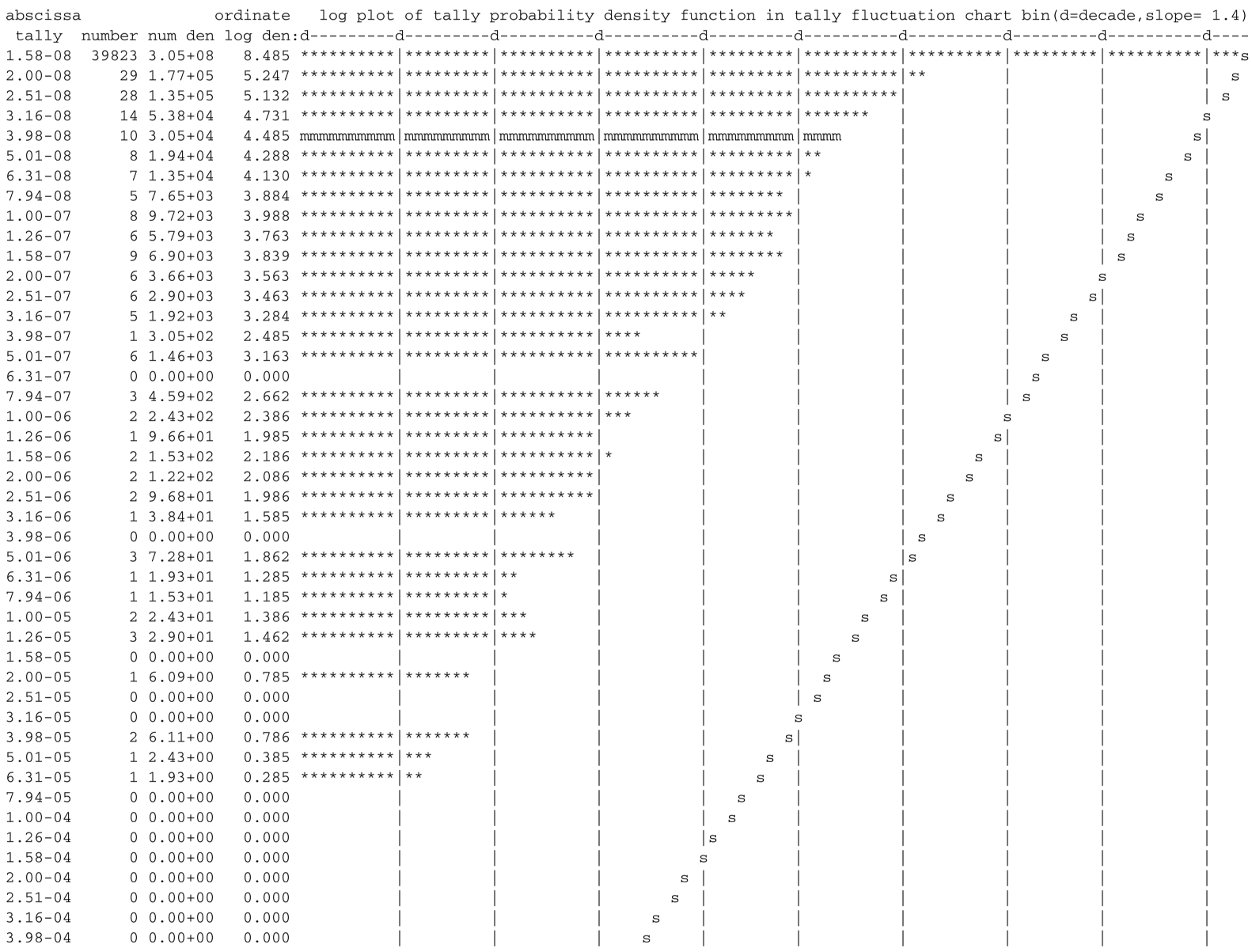
N10 if the largest history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:

estimated quantities	value at nps	value at nps+1	value(nps+1)/value(nps)-1.
mean	3.68571E-08	5.30873E-08	0.440352
relative error	4.44930E-01	4.34606E-01	-0.023204
variance of the variance	9.59635E-01	4.89697E-01	-0.489705
shifted center	4.48174E-08	4.48935E-08	0.001696
figure of merit	1.64360E+01	1.72261E+01	0.048075

the estimated inverse power slope of the 200 largest tallies starting at 1.48726E-08 is 1.3778
the history score probability density function appears to have an unsampled region at the largest history scores:
please examine. see print table 161.

fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (1.301E+05)*(1.124E-02)**2 = (1.301E+05)*(1.263E-04) = 1.644E+01

N11 1unnormed tally density for tally 65 nonzero tally mean(m) = 3.686E-08 nps = 40000 print table 161



```
 5.01-04      0 0.00+00   0.000           |         |          |  s       |         |          |          |         |          |
 6.31-04      0 0.00+00   0.000           |         |          | s        |         |          |          |         |          |
 7.94-04      1 1.53-01  -0.815 *         |         |          |s         |         |          |          |         |          |
  total   40000 1.00+00          d---------d---------d----------d----------d---------d----------d----------d---------d----------d----
SKIP 554 LINES OF OUTPUT
```

N12 1tally fluctuation charts

	tally 2					tally 12					tally 22				
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom	mean	error	vov	slope	fom
2000	4.4261E-10	0.0636	0.0036	0.0	15896	4.4815E-08	0.0640	0.0044	0.0	15725	5.5556E-08	0.0704	0.0302	0.0	13005
4000	4.6220E-10	0.0439	0.0017	0.0	16670	4.6729E-08	0.0440	0.0020	0.0	16578	5.7188E-08	0.0467	0.0098	0.0	14723
6000	4.5349E-10	0.0363	0.0012	10.0	16281	4.5567E-08	0.0364	0.0013	10.0	16221	5.5507E-08	0.0383	0.0055	4.0	14676
8000	4.4063E-10	0.0320	0.0009	10.0	15724	4.4346E-08	0.0321	0.0010	10.0	15637	5.4026E-08	0.0337	0.0038	6.1	14255
10000	4.4454E-10	0.0286	0.0007	10.0	15902	4.4543E-08	0.0286	0.0008	10.0	15867	5.3970E-08	0.0297	0.0027	4.0	14696
12000	4.4881E-10	0.0260	0.0006	10.0	16112	4.5070E-08	0.0260	0.0007	10.0	16090	5.5423E-08	0.0289	0.0130	2.8	13026
14000	4.4531E-10	0.0241	0.0005	10.0	15963	4.4745E-08	0.0242	0.0006	10.0	15930	5.4979E-08	0.0266	0.0102	3.2	13088
16000	4.4006E-10	0.0227	0.0005	10.0	15758	4.4258E-08	0.0228	0.0005	10.0	15724	5.4342E-08	0.0249	0.0083	3.5	13104
18000	4.4153E-10	0.0214	0.0004	10.0	15816	4.4494E-08	0.0214	0.0005	10.0	15762	5.4745E-08	0.0234	0.0067	3.2	13163
20000	4.3353E-10	0.0205	0.0004	10.0	15516	4.3837E-08	0.0205	0.0004	10.0	15429	5.4304E-08	0.0228	0.0062	2.7	12528
22000	4.3805E-10	0.0194	0.0003	10.0	15638	4.4241E-08	0.0195	0.0004	10.0	15573	5.4639E-08	0.0215	0.0053	2.6	12849
24000	4.3762E-10	0.0186	0.0003	10.0	15617	4.4194E-08	0.0187	0.0004	10.0	15533	5.4572E-08	0.0205	0.0046	2.6	12875
26000	4.3931E-10	0.0179	0.0003	10.0	15681	4.4297E-08	0.0179	0.0003	10.0	15618	5.4584E-08	0.0196	0.0040	2.6	13080
28000	4.4265E-10	0.0171	0.0003	10.0	15818	4.4653E-08	0.0172	0.0003	10.0	15748	5.4985E-08	0.0187	0.0035	2.8	13290
30000	4.4426E-10	0.0165	0.0002	10.0	15873	4.4828E-08	0.0166	0.0003	10.0	15801	5.5348E-08	0.0184	0.0055	2.7	12837
32000	4.4453E-10	0.0160	0.0002	10.0	15882	4.4861E-08	0.0160	0.0003	10.0	15811	5.5384E-08	0.0178	0.0050	2.7	12889
34000	4.4423E-10	0.0155	0.0002	10.0	15873	4.4815E-08	0.0156	0.0002	10.0	15802	5.5299E-08	0.0172	0.0045	2.7	12951
36000	4.4198E-10	0.0151	0.0002	10.0	15773	4.4617E-08	0.0152	0.0002	10.0	15713	5.5175E-08	0.0169	0.0047	2.7	12667
38000	4.4395E-10	0.0147	0.0002	10.0	15847	4.4763E-08	0.0147	0.0002	10.0	15789	5.5283E-08	0.0163	0.0043	2.8	12823
40000	4.4513E-10	0.0143	0.0002	10.0	15911	4.4871E-08	0.0143	0.0002	10.0	15860	5.5356E-08	0.0158	0.0039	3.0	12974

	tally 25					tally 35					tally 45				
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom	mean	error	vov	slope	fom
2000	4.9088E-10	0.1272	0.1182	2.1	3980	4.1538E-10	0.1177	0.1129	2.3	4649	2.6628E-08	0.3297	0.6246	1.2	593
4000	4.7484E-10	0.0894	0.0597	2.1	4018	4.6836E-10	0.0904	0.0853	2.1	3927	4.9621E-08	0.4977	0.8467	1.2	130
6000	4.4369E-10	0.0690	0.0453	2.5	4513	4.4833E-10	0.0697	0.0612	2.6	4424	3.8747E-08	0.4258	0.8403	1.2	119
8000	4.4541E-10	0.0597	0.0357	3.2	4523	4.4654E-10	0.0594	0.0415	3.3	4580	4.7146E-08	0.3953	0.4748	1.3	103
10000	4.2599E-10	0.0531	0.0301	3.3	4600	4.3926E-10	0.0525	0.0332	3.8	4719	4.0260E-08	0.3703	0.4748	1.4	95
12000	4.2208E-10	0.0480	0.0250	4.1	4709	4.5487E-10	0.0472	0.0245	4.3	4872	3.6122E-08	0.3442	0.4737	1.5	92
14000	4.2398E-10	0.0435	0.0206	4.9	4916	4.4500E-10	0.0441	0.0234	4.9	4779	3.4229E-08	0.3123	0.4676	1.4	95
16000	4.2399E-10	0.0407	0.0187	5.8	4911	4.3985E-10	0.0409	0.0205	5.7	4878	3.3614E-08	0.2811	0.4495	1.4	103
18000	4.3022E-10	0.0387	0.0161	7.9	4839	4.4160E-10	0.0393	0.0204	3.6	4689	3.2515E-08	0.2589	0.4455	1.4	108
20000	4.3434E-10	0.0374	0.0146	7.5	4640	4.3870E-10	0.0373	0.0180	4.1	4666	3.3559E-08	0.2308	0.4088	1.4	122
22000	4.3331E-10	0.0360	0.0131	9.4	4561	4.4336E-10	0.0353	0.0165	5.2	4743	3.2337E-08	0.2183	0.4048	1.4	124
24000	4.3371E-10	0.0349	0.0122	10.0	4465	4.3463E-10	0.0335	0.0156	5.5	4831	3.3095E-08	0.2001	0.3702	1.4	136
26000	4.4139E-10	0.0342	0.0134	7.4	4290	4.3168E-10	0.0327	0.0150	5.3	4690	3.1996E-08	0.1914	0.3674	1.5	137
28000	4.4135E-10	0.0332	0.0134	6.8	4229	4.3681E-10	0.0313	0.0133	6.3	4742	3.1526E-08	0.1825	0.3517	1.5	140
30000	4.4107E-10	0.0320	0.0124	6.8	4233	4.5447E-10	0.0309	0.0111	4.9	4547	3.3546E-08	0.1682	0.2914	1.6	153
32000	4.3582E-10	0.0308	0.0118	8.0	4282	4.5273E-10	0.0298	0.0104	5.7	4566	3.2262E-08	0.1640	0.2913	1.6	151

```
 34000  4.3539E-10  0.0299  0.0109  10.0      4290  4.5322E-10  0.0289  0.0096   6.8      4576  3.1259E-08  0.1594  0.2910   1.6       151
 36000  4.3246E-10  0.0288  0.0104  10.0      4353  4.5195E-10  0.0279  0.0091   8.4      4641  3.6503E-08  0.2004  0.3857   1.7        90
 38000  4.3320E-10  0.0279  0.0099   9.8      4382  4.5496E-10  0.0276  0.0090   6.9      4503  3.6606E-08  0.1901  0.3797   1.7        95
 40000  4.3330E-10  0.0271  0.0094   7.5      4441  4.5462E-10  0.0268  0.0085   9.0      4545  4.1813E-08  0.2164  0.3252   1.7        69
1tally fluctuation charts

                tally   55                                tally   65                                tally   75
      nps        mean      error     vov     slope     fom        mean      error     vov     slope     fom        mean      error     vov     slope     fom
     2000  1.5719E-08  0.1646  0.5551   1.4      2377  1.4255E-08  0.0609  0.9534   1.7     17342  1.3564E-08  0.0183  0.5489   1.9    192681
     4000  1.9359E-08  0.1272  0.1582   1.4      1985  1.3963E-08  0.0325  0.8033   1.7     30406  1.5740E-08  0.1207  0.9406   1.6      2206
     6000  1.9354E-08  0.1128  0.1559   1.4      1690  1.4146E-08  0.0317  0.4240   1.6     21382  1.5235E-08  0.0855  0.8445   1.5      2944
     8000  2.1783E-08  0.1466  0.4769   1.3       752  1.6177E-08  0.1011  0.4999   1.5      1580  1.6091E-08  0.0953  0.4857   1.4      1779
    10000  2.1812E-08  0.1252  0.3716   1.3       829  1.5652E-08  0.0837  0.4983   1.4      1856  1.5735E-08  0.0785  0.4718   1.4      2106
    12000  2.3024E-08  0.1183  0.2208   1.3       776  1.5354E-08  0.0714  0.4903   1.4      2132  1.5640E-08  0.0681  0.4152   1.4      2337
    14000  2.2726E-08  0.1082  0.1851   1.4       794  1.5361E-08  0.0626  0.4484   1.4      2375  1.5324E-08  0.0596  0.4145   1.4      2613
    16000  2.3562E-08  0.1009  0.1365   1.4       799  1.6265E-08  0.0860  0.4654   1.3      1102  1.5403E-08  0.0533  0.3744   1.3      2866
    18000  2.3051E-08  0.0940  0.1254   1.4       818  1.6010E-08  0.0777  0.4640   1.3      1199  1.5203E-08  0.0480  0.3732   1.3      3135
    20000  2.5969E-08  0.1565  0.5824   1.4       265  1.9511E-08  0.1425  0.3682   1.3       320  1.5623E-08  0.0557  0.3035   1.3      2098
    22000  2.5312E-08  0.1468  0.5694   1.5       274  1.8973E-08  0.1332  0.3681   1.3       333  1.5529E-08  0.0514  0.2917   1.3      2235
    24000  2.4509E-08  0.1393  0.5647   1.5       280  1.8795E-08  0.1238  0.3619   1.3       354  1.5413E-08  0.0477  0.2878   1.3      2389
    26000  2.6217E-08  0.1449  0.3603   1.5       239  1.8396E-08  0.1167  0.3619   1.3       368  1.5278E-08  0.0444  0.2874   1.3      2542
    28000  2.9275E-08  0.1426  0.2213   1.5       229  1.8419E-08  0.1102  0.3379   1.3       383  1.7396E-08  0.1176  0.7970   1.3       336
    30000  4.6376E-08  0.3337  0.8377   1.5        39  1.8981E-08  0.1031  0.2981   1.3       408  2.5960E-08  0.3100  0.8616   1.3        45
    32000  4.5970E-08  0.3167  0.8258   1.5        41  1.8629E-08  0.0985  0.2981   1.3       418  2.5424E-08  0.2968  0.8609   1.3        46
    34000  4.4098E-08  0.3108  0.8258   1.5        40  1.8322E-08  0.0943  0.2981   1.4       430  2.4718E-08  0.2873  0.8609   1.4        46
    36000  4.3204E-08  0.2999  0.8220   1.5        40  2.0991E-08  0.1232  0.2303   1.4       238  2.4232E-08  0.2769  0.8603   1.3        47
    38000  4.2634E-08  0.2881  0.8198   1.5        41  2.1007E-08  0.1174  0.2245   1.4       248  2.4078E-08  0.2644  0.8550   1.3        49
    40000  4.2152E-08  0.2776  0.8111   1.6        42  3.6857E-08  0.4449  0.9596   1.4        16  2.3599E-08  0.2563  0.8548   1.3        50

                tally   85                                tally   95                                tally  105
      nps        mean      error     vov     slope     fom        mean      error     vov     slope     fom        mean      error     vov     slope     fom
     2000  4.7534E-10  0.0761  0.0474   3.5      11110  3.3129E-08  0.1957  0.5252   1.8      1682  7.5352E-08  0.5518  0.9363   1.3       211
     4000  4.9677E-10  0.0548  0.0270   3.2      10687  3.1202E-08  0.1197  0.3087   1.8      2240  5.1896E-08  0.4034  0.9120   1.4       197
     6000  4.8167E-10  0.0466  0.0221   4.1       9907  3.9034E-08  0.1345  0.3286   1.9      1189  4.6957E-08  0.3013  0.8646   1.5       237
     8000  4.5672E-10  0.0397  0.0181   4.4      10248  3.8177E-08  0.1110  0.2531   2.2      1311  4.6615E-08  0.2362  0.7475   1.7       289
    10000  4.4956E-10  0.0351  0.0145   4.8      10528  3.8273E-08  0.0961  0.1948   2.6      1407  5.1594E-08  0.2030  0.4280   1.9       315
    12000  4.5311E-10  0.0324  0.0120   6.4      10336  3.8350E-08  0.0843  0.1591   2.6      1529  5.1090E-08  0.1768  0.3759   2.0       347
    14000  4.4835E-10  0.0297  0.0103  10.0      10558  3.8945E-08  0.0751  0.1301   2.9      1647  4.8569E-08  0.1606  0.3648   2.1       360
    16000  4.4734E-10  0.0276  0.0087  10.0      10728  3.9140E-08  0.0685  0.1091   3.1      1733  4.8581E-08  0.1436  0.3347   2.1       395
    18000  4.5435E-10  0.0262  0.0077  10.0      10525  4.0125E-08  0.0663  0.0919   2.9      1645  4.8462E-08  0.1303  0.3120   2.1       426
    20000  4.5568E-10  0.0248  0.0072  10.0      10569  4.3048E-08  0.0650  0.0593   2.7      1537  8.0763E-08  0.4210  0.9440   2.1        37
    22000  4.5719E-10  0.0237  0.0064  10.0      10556  4.2637E-08  0.0630  0.0561   2.7      1488  7.6071E-08  0.4063  0.9437   2.1        36
    24000  4.5593E-10  0.0227  0.0059  10.0      10562  4.2251E-08  0.0595  0.0520   2.7      1532  7.2957E-08  0.3887  0.9408   2.2        36
    26000  4.5630E-10  0.0218  0.0054  10.0      10509  4.3487E-08  0.0611  0.0564   2.6      1343  7.1810E-08  0.3650  0.9361   2.1        38
    28000  4.5751E-10  0.0210  0.0049  10.0      10511  4.4322E-08  0.0592  0.0489   2.6      1329  6.8940E-08  0.3531  0.9355   2.1        37
    30000  4.5783E-10  0.0204  0.0047  10.0      10384  4.3718E-08  0.0569  0.0460   2.6      1338  6.9463E-08  0.3279  0.9261   2.2        40
    32000  4.5589E-10  0.0197  0.0044  10.0      10446  4.3870E-08  0.0558  0.0420   2.5      1303  6.6897E-08  0.3192  0.9258   2.2        40
    34000  4.5191E-10  0.0191  0.0042  10.0      10539  4.3846E-08  0.0535  0.0393   2.8      1336  6.6268E-08  0.3035  0.9227   2.3        42
```

```
   36000   4.5162E-10 0.0185 0.0041 10.0   10559   4.3370E-08 0.0514 0.0383  2.9    1365   6.5224E-08 0.2915 0.9200  2.4    42
   38000   4.5010E-10 0.0181 0.0039 10.0   10432   4.3489E-08 0.0509 0.0356  3.0    1320   6.5079E-08 0.2783 0.8999  2.3    44
   40000   4.4945E-10 0.0177 0.0038 10.0   10380   4.3885E-08 0.0491 0.0327  3.3    1348   6.3161E-08 0.2724 0.8996  2.4    44
 ************************************************************************************************************************
 dump no.   2 on file conc.r      nps =    40000     coll =          75707     ctm =    0.31     nrn =       1221320

          7 warning messages so far.

 run terminated when    40000 particle histories were done.

 computer time =    0.63 minutes

 mcnp    version 5    12212002                    01/08/03 17:43:42                    probid =  01/08/03 17:43:02
```

Notes:

N1: MCNP was run with the name execute line option that renames the output file conc.o and the continue–run RUNTPE file conc.r.

N2: The point detector for Tally 65 is placed on surface 2 (at 0,-390,0) with a sphere of exclusion of .5 mean free paths. This tally is a good example of what NOT to do when using point detectors. First of all, the point detector (or ring detector) should not be placed directly on a surface, especially if the cell on one side has a zero importance and/or the cell material densities differ. As a rule of thumb, the point detector should lie just inside or outside a surface. Another significant item about this tally is that the radius of the sphere of exclusion is expressed as 0.5 mean free paths. It is generally not recommended to use a radius expressed in mean free paths because this increases the variance of the tally. However, the radius can be entered in mean free paths if the user does not know what other value to use. The fictitious sphere radius of 0.5 mean free paths (approximately 4.3 cm) assumes a uniform isotropic flux within the sphere. Although this assumption will smooth out the detector response, it is false. The fictitious sphere should never be in more than one material medium as it is here because the material is assumed to be uniform throughout the sphere. This point detector is included in the example to demonstrate how MCNP can detect supposedly accurate results that have not converged (the number of samples N has not gone to infinity in the sense of the central limit theorem). These remarks also apply to the F75 and F105 detector tallies that are also on surface 2.

N3: The ring detector for Tally 95 is about the y-axis centered at the origin. The radius of the ring is 420 cm and it is coincident with surface 3. The radius of the sphere of exclusion for this detector is set to 0. Because the detector lies in a void region, it will not produce erroneous results if coincident with a geometric surface not bounding the concrete shell.

N4: The DD card controls the Russian roulette games that are played for all detector problems unless explicitly turned off. The first entry of this card, 0.1, designates the level at which Russian roulette will be played. For the first 200 histories, all contributions to the detector are counted. The average contribution is then computed and updated whenever a tally fluctuation chart entry is computed. Russian roulette is played on all contributions below 0.1 times the computed average. This Russian roulette game is one of the few default MCNP variance reduction schemes and typically speeds up detector problems by an order of magnitude. The second entry on the DD card causes a detector diagnostic message to be printed if a tally greater than $0.1 * 10^{100}$ is reached (which in this case is never). If this second entry is too high, the diagnostic messages will never be printed. Conversely, if this number is too low, the output will be cluttered with these messages.

N5: The neutron cutoff card for this problem uses the default large time cutoff value and an energy cutoff of 12.0 MeV. If a neutron time is greater than the time entry or if the neutron energy is below 12 MeV, the particle is terminated. These cutoff parameters can reduce computational time, but they should be used with caution. In some applications, ignoring neutrons and photons beneath a certain energy cutoff will not significantly affect the tally. But, if these lower energy interactions are important (fission and photon

interactions) then the final result will be biased low because these contributions are not included in the calculation.

N6: The problem summary table provides an accounting of particle track, weight, and energy creation and loss. For this problem, the largest neutron loss was caused by energy cutoff. There are a total of 75,707 collisions for 40,000 source histories. The net multiplication of 1.0119 is caused by (n,xn) reactions; the system is clearly not critical because there is no fissionable material. The weight escaping per source particle is 0.089431, meaning that the flux on the shell of radius 4,000 cm is approximately $0.089431/(4*\pi*4000^2) = 4.448 \times 10^{-10}$ neutrons/cm^2 (see Tally 2). (Note: This problem is inefficient for escaping neutrons, since only 4,564 out of 40,000 escape.) The energy cutoff terminated 36,072 tracks out of 40,000 starting particles, increasing the number of neutrons per minute that are calculated.

N7: The energy bins for tally 2 are cumulative so that any particle with energy less than or equal to the energy of a bin scores in that bin.

N8: The letters *a*, etc., throughout the diagnostics table correspond to the notes, (a),(b), etc. There were 52,174 detector contributions (e). 40,000 were from the source (there were 40,000 hits from cell 1(c) and 12,174 from collisions inside cell 2 (d). According to the problem summary there were 75,707 collisions. Thus the DD card roulette game and the 12 MeV energy cutoff eliminated 84% of the collision contributions. Of the 12,174 collisions that did contribute to the tally, 11,834 (a) made a tally less than the 0.1 tally contribution level. These 11,834 transmissions to the detector contributed only 0.058% of the cumulative fraction of total tally (a). The majority of the total F65 tally was contributed by seven transmissions, each greater than 1,000 times the average tally (b). These seven scores contributed 55.9% of the total tally. Many more histories need to be run to further sample these large scores.

N9: This TFC bin passed only two of the ten TFC bin statistical checks, clearly a horrible sign. The relative error (RE) was much larger than 5%. The VOV was not below the required 0.1 maximum and is not decreasing as 1/NPS. The estimated history score probability density function (PDF) slope was not greater than 3. Both the VOV and slope indicate that the problem was not sampled adequately. Undersampling of infrequent high scoring tallies gives a result with an underpredicted mean, RE, and VOV. The VOV is more sensitive to large tally score fluctuations than the RE, and is one good indicator of confidence interval reliability when high scores have been sampled. The PDF slope check confirms whether the PDF function's high score tail is decreasing with at least a $1/x^3$ dependence. If the high score tail follows this criteria, then the Central Limit Theorem appears to apply and the tally distribution should behave as a normal distribution. If the estimated slope of 1.38 persisted, then the mean of the empirical PDF would not exist! These ten statistical checks do not ensure a totally reliable result; they do provide a more rigorous check of the tally reliability. The tally fluctuation chart bin (total bin) of Tally 65 is clearly not converged.

N10: This section describes how the TFC bin would be affected if the largest previously sampled score was encountered on the next history. The “value at nps” column shows the

TFC bin values of the current history, while the "value at nps+1" column shows the results after the largest previous history has been added to the tally. The last column shows the relative change of the TFC bin values from the NPS value to the NPS+1 value. The effect of having a very large score on the next history has an overall detrimental effect on these TFC values. The mean increased by 44%! Such a large increase in the mean also indicates that more histories need to be run. The history score PDF has a huge unsampled region for high scores.

N11: This plot is the unnormed probability density for Tally 65. It is a log–log plot of the empirical history score PDF for Tally 65 that is shown by asterisks, along with the central mean (denoted by the line of m's). The curve of S's denotes the Pareto curve fit to the PDF distribution. This S curve is included so that the user can see if the Pareto fit is fairly accurate when compared to the calculated distribution. The Pareto fit appears to be good since its slope matches the empirical PDF. To the left of the plot are the columns that show the abscissa, number, number density and the ordinate of the PDF. The line above the 10 statistical checks table says the PDF has unsampled large score regions. This fact is confirmed by the plot--many more histories are required!

N12: These are the TFC bin results of all the tallies. Note that at 14,000 histories, the TFC bin (total) for Tally 65 has an RE of 6.26%, almost acceptable. At 18,000 histories, Tally 75 has an acceptable RE of 4.80% Since both of these results have large VOVs and small slopes, these answers (~1.5×10^{-8}) are wrong! To ensure a reliable confidence interval, the acceptable value of the VOV is 0.1. As mentioned previously, the VOV checks the higher moments (3rd and 4th) of the PDF because they are more sensitive to any aberrations in the PDF caused by insufficient sampling. For these tallies, VOVs greater than 0.35 clearly does not fall below the acceptable limit of 0.1. To achieve a reliable confidence interval, the slope of the high-score (x) portion of the history score PDF must be greater than or equal to three in order to produce a distribution that has at least a $1/x^3$ behavior. The tallies also fail this criterion, indicating that the Central Limit Theorem cannot be applied. Tallies 65 and 75 appear to have converged to a flux of 1.5×10^{-8} at 14,000 and 18,000 histories respectively. However, surface Tally 22 at 390 cm is 5.54×10^{-8} and the still–unconverged ring detector Tally 105 at 390 cm is 6.32×10^{-8}. Tallies 65 and 75 appear close to convergence by RE, but they are actually low by a factor of 3.7! At 40,000 histories, Tallies 65 and 75 have increased, but now have terrible REs. See the CONC problem analysis in Chapter 2, page 2-134. Tallies 25 and 35 at 4,000 cm agree with the surface neutron flux in Tally 2; namely 4.45×10^{-10}.

COMMENTS:

How should the CONC problem be better specified? First, detectors are inappropriate for this problem and should not be used. Surface flux tallies are about a factor of 30,000 more efficient for this 1D problem for a fully converged point detector tally. The shell should be divided into four spherically concentric geometrical regions with outwardly increasing importances of 1, 2, 4, and 8. Then for every source particle, approximately one particle would cross the outer surface of the shell and score, instead of the present 4,564 out of 40,000.

How could detectors be made to work better in this problem? In any problem with symmetry, a ring detector rather than a point detector should be used to at least take advantage of the symmetry. The ring detector is about 200 times more efficient than a fully converged point detector tally. The source direction could be biased to direct particles at the ring, causing a lot more collisions in the vicinity of the ring detector.

IV. KCODE

The problem selected to illustrate the output from a criticality calculation is the one–dimensional model of the GODIVA critical assembly, composed of about 93.7% ^{235}U. This assembly is discussed by Raphael J. LaBauve in "Highly Enriched Uranium Systems."[1.]

An MCNP input file that models GODIVA and performs only the criticality calculation with no separate tallies would be only 11 lines long. The KCODE card indicates that the problem is a criticality calculation for the k_{eff} eigenvalue. To perform this same calculation with neutron-induced photon production, add the MODE N P card. Any tallies that are made in a criticality problem are normalized to the starting weight (one fission neutron in the problem) or number of particles as defined by the user (see Chapter 2 beginning on page 2-166 for details). Tallies should be scaled for the appropriate steady state fission neutron generation rate.

The following is a partial listing of the output from a KCODE calculation. The pages selected emphasize the criticality aspects of the problem.

```
                                  _
          ._ _    _  ._   ._    |_
          | | |  (_  | |  |_)    _)
                           |
 +--------------------------------------------------------------------+
 |   This program was prepared by the Regents of the University of    |
 |California at Los Alamos National Laboratory (the University) under |
 |  contract number W-7405-ENG-36 with the U.S. Department of Energy  |
 |(DoE).  The University has certain rights in the program pursuant to|
 |  the contract and the program should not be copied or distributed  |
 | outside your organization.  All rights in the program are reserved |
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 | University makes any warranty, express or implied, or assumes any  |
 |     liability or responsibility for the use of this software.      |
 +--------------------------------------------------------------------+

1mcnp     version 5     ld=12212002                    01/16/03 14:14:32
 ********************************************************************** probid =  01/16/03 14:14:32
 i=kcode n=kcode.

N1  1-       kcode godiva: bare u(94) sphere. ref. r.j. labauve, heu-met-fast-001
    2-       1    10 -18.74  -1
    3-       2    0           1
    4-
    5-       1    so 8.7407
    6-
    7-       imp:n 1 0
N2  8-       m10    92235 -93.71  92238 -5.27  92234 -1.02
N3  9-       kcode 5000 1. 30 130
N4 10-       ksrc  0 0 0
   11-       print
   12-       c
   13-       c   pertubations
N5 14-       pert1:n cell=1 rho=-20.0 method=-1 $ perturb density and give changes
   15-       c
   16-       c   tallies
   17-       c
   18-       f1:n 1
   19-       f14:n 1
   20-       fc14 total fission neutrons (track length keff), total loss to (n,xn)
   21-            total neutron captures, total fission and neutron heating (mev/gram)
   22-       fq14 e m
N6 23-       fm14 (134.2212 10 (-6 -7) (16:17) (-2) (-6)) (0.002560502 10 1 -4)
   24-       f6:n 1
```

```
   25-       f7:n 1
   26-       c
   27-       c    use the 16 group hansen-roach energy structure as the tally default
   28-       c
N7 29-       e0   1-7 4-7 1-6 3-6 1-5 3-5 1-4 5.5-4 3-3 1.7-2 0.1 0.4 0.9 1.4 3 20
N8 30-       f34:n 1
   31-       sd34 1
   32-       fq34 m f
   33-       fm34 (-1 10 -6 -7) (-1 10 16:17) (-1 10 -2) (-1 10 -6)
   34-            (-0.00001907672 10 1 -4)
   35-       e34  20 nt
   36-
1     initial source from ksrc card.                                                print table 90
N9
 original number of points                          1
    points not in any cell                    0
    points in cells of zero importance        0
    points in void cells                      0
    points in ambiguous cells                 0
 total points rejected                             0
 points remaining                                  1
 points after expansion or contraction          5000
 nominal source size                            5000

 initial guess for k(eff.)                   1.000000

 cycles to skip before tallying                   30

 number of keff cycles that can be stored       1500


 comment. total fission nubar data are being used.
SKIP 73 LINES OF OUTPUT
1tally  14                                                                         print table 30
+                                  total fission neutrons (track length keff), total loss to (n,xn)
                                   total neutron captures, total fission and neutron heating (mev/gram)
           tally type 4    track length estimate of particle flux.
           tally for  neutrons

N10 warning. perturbation may require negative fm constant.  tally  14

 warning. perturbation may require negative fm constant.  tally  14

 warning. perturbation may require negative fm constant.  tally  14

 warning. perturbation may require negative fm constant.  tally  14

 warning. perturbation may require negative fm constant.  tally  14
```

```
SKIP 49 LINES OF OUTPUT
1material composition                                                                                    print table 40

 the sum of the fractions of material   10 was 1.000000E+02

 material
  number     component nuclide, atom fraction

    10           92235, 9.37683E-01      92238, 5.20667E-02      92234, 1.02501E-02




 material
  number     component nuclide, mass fraction

    10           92235, 9.37100E-01      92238, 5.27000E-02      92234, 1.02000E-02
```

N11 warning. 1 materials had unnormalized fractions. print table 40.

N12 warning. perturbation correction not applied to tally 6

```
 warning. perturbation correction not applied to tally    7
1cell volumes and masses                                                                                 print table 50
```

N13

```
        cell     atom          gram         input       calculated                          reason volume
                density       density       volume        volume         mass       pieces    not calculated

     1      1  4.79838E-02   1.87400E+01   0.00000E+00   2.79722E+03   5.24200E+04      1
     2      2  0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00   0.00000E+00      0      infinite
SKIP 77 LINES OF OUTPUT
1cross-section tables                                                                                    print table 100
```

N14

```
     table    length

                         tables from file endf66c

  92234.66c  196257  92-u-234 at 293.6K from endf-vi.0 njoy99.50        total nu                 mat9225      08/13/01
                     probability tables used from 1.5000E-03 to 1.0000E-01 mev.
  92235.66c  583724  92-u-235 at 293.6K from endf-vi.5 njoy99.50        total nu                 mat9228      08/14/01
                     probability tables used from 2.2500E-03 to 2.5000E-02 mev.
  92238.66c  669744  92-u-238 at 293.6K from endf-vi.5 njoy99.50        total nu                 mat9237      08/14/01
                     probability tables used from 1.0000E-02 to 1.4903E-01 mev.

  total     1449725

 ****************************************************************************************************************************
```

N15 dump no. 1 on file kcode.r nps = 0 coll = 0 ctm = 0.00 nrn = 0

N16 source distribution written to file kcode.s cycle = 0

8 warning messages so far.

1 starting mcrun. cp0 = 0.22 print table 110

kcode godiva: bare u(94) sphere. ref. r.j. labauve, heu-met-fast-001

N17

nps	x	y	z	cell	surf	u	v	w	energy	weight	time
1	0.000E+00	0.000E+00	0.000E+00	1	0	5.085E-01	4.733E-01	7.193E-01	2.209E+00	1.000E+00	0.000E+00
2	0.000E+00	0.000E+00	0.000E+00	1	0	8.952E-01	-4.447E-01	-2.944E-02	4.904E+00	1.000E+00	0.000E+00
3	0.000E+00	0.000E+00	0.000E+00	1	0	-6.184E-01	-4.495E-01	6.446E-01	3.809E-01	1.000E+00	0.000E+00
4	0.000E+00	0.000E+00	0.000E+00	1	0	9.710E-01	-5.665E-02	-2.323E-01	1.331E+00	1.000E+00	0.000E+00
5	0.000E+00	0.000E+00	0.000E+00	1	0	5.861E-01	1.496E-01	-7.963E-01	1.902E+00	1.000E+00	0.000E+00
6	0.000E+00	0.000E+00	0.000E+00	1	0	-6.489E-02	-1.626E-01	9.845E-01	4.410E-01	1.000E+00	0.000E+00
7	0.000E+00	0.000E+00	0.000E+00	1	0	-7.068E-02	3.263E-02	-9.970E-01	4.750E-01	1.000E+00	0.000E+00
8	0.000E+00	0.000E+00	0.000E+00	1	0	-3.915E-01	4.664E-01	-7.932E-01	4.136E+00	1.000E+00	0.000E+00
9	0.000E+00	0.000E+00	0.000E+00	1	0	-2.368E-01	9.215E-01	-3.079E-01	7.453E-02	1.000E+00	0.000E+00
10	0.000E+00	0.000E+00	0.000E+00	1	0	1.946E-01	-3.204E-01	9.271E-01	3.128E+00	1.000E+00	0.000E+00
11	0.000E+00	0.000E+00	0.000E+00	1	0	-6.698E-01	-7.177E-01	-1.905E-01	1.014E+00	1.000E+00	0.000E+00
12	0.000E+00	0.000E+00	0.000E+00	1	0	-8.398E-01	-4.129E-01	3.524E-01	1.395E+00	1.000E+00	0.000E+00
13	0.000E+00	0.000E+00	0.000E+00	1	0	-1.714E-01	-8.572E-01	4.857E-01	7.748E-01	1.000E+00	0.000E+00
14	0.000E+00	0.000E+00	0.000E+00	1	0	-2.489E-01	-5.118E-01	-8.222E-01	1.101E+00	1.000E+00	0.000E+00
15	0.000E+00	0.000E+00	0.000E+00	1	0	-2.959E-01	2.119E-01	9.314E-01	1.951E+00	1.000E+00	0.000E+00
16	0.000E+00	0.000E+00	0.000E+00	1	0	1.395E-01	-9.829E-01	1.202E-01	2.186E+00	1.000E+00	0.000E+00
17	0.000E+00	0.000E+00	0.000E+00	1	0	6.909E-01	-7.110E-01	1.307E-01	1.865E+00	1.000E+00	0.000E+00
18	0.000E+00	0.000E+00	0.000E+00	1	0	-6.580E-01	5.320E-01	-5.329E-01	1.229E+00	1.000E+00	0.000E+00
19	0.000E+00	0.000E+00	0.000E+00	1	0	-9.903E-01	-1.380E-01	1.353E-02	1.305E+00	1.000E+00	0.000E+00
20	0.000E+00	0.000E+00	0.000E+00	1	0	7.462E-01	4.859E-01	-4.551E-01	1.000E+00	1.000E+00	0.000E+00
21	0.000E+00	0.000E+00	0.000E+00	1	0	-1.977E-01	9.797E-01	3.360E-02	3.990E+00	1.000E+00	0.000E+00
22	0.000E+00	0.000E+00	0.000E+00	1	0	-9.117E-01	-3.647E-01	-1.891E-01	2.665E-01	1.000E+00	0.000E+00
23	0.000E+00	0.000E+00	0.000E+00	1	0	-4.287E-01	8.361E-01	-3.423E-01	1.156E+00	1.000E+00	0.000E+00
24	0.000E+00	0.000E+00	0.000E+00	1	0	1.080E-01	3.412E-01	-9.338E-01	2.669E+00	1.000E+00	0.000E+00
25	0.000E+00	0.000E+00	0.000E+00	1	0	-9.111E-01	-9.012E-03	-4.122E-01	2.185E+00	1.000E+00	0.000E+00
26	0.000E+00	0.000E+00	0.000E+00	1	0	-2.568E-01	-6.391E-01	-7.249E-01	4.225E+00	1.000E+00	0.000E+00
27	0.000E+00	0.000E+00	0.000E+00	1	0	-2.912E-01	8.086E-01	5.113E-01	1.079E+00	1.000E+00	0.000E+00
28	0.000E+00	0.000E+00	0.000E+00	1	0	1.472E-01	-9.514E-01	2.705E-01	3.461E+00	1.000E+00	0.000E+00
29	0.000E+00	0.000E+00	0.000E+00	1	0	-6.135E-01	-7.645E-01	-1.978E-01	1.836E+00	1.000E+00	0.000E+00
30	0.000E+00	0.000E+00	0.000E+00	1	0	-5.702E-01	5.651E-01	-5.963E-01	4.556E-01	1.000E+00	0.000E+00
31	0.000E+00	0.000E+00	0.000E+00	1	0	-6.607E-01	5.373E-01	-5.242E-01	6.415E-01	1.000E+00	0.000E+00
32	0.000E+00	0.000E+00	0.000E+00	1	0	-9.742E-02	-3.639E-01	-9.263E-01	2.764E+00	1.000E+00	0.000E+00
33	0.000E+00	0.000E+00	0.000E+00	1	0	-1.965E-01	-3.145E-01	-9.287E-01	2.785E-01	1.000E+00	0.000E+00
34	0.000E+00	0.000E+00	0.000E+00	1	0	4.097E-01	8.465E-01	-3.399E-01	9.097E-01	1.000E+00	0.000E+00
35	0.000E+00	0.000E+00	0.000E+00	1	0	-4.048E-02	8.831E-01	4.675E-01	3.360E-01	1.000E+00	0.000E+00

36	0.000E+00	0.000E+00	0.000E+00	1	0	3.371E-01	-9.269E-01	-1.652E-01	6.376E-01	1.000E+00	0.000E+00
37	0.000E+00	0.000E+00	0.000E+00	1	0	-1.867E-01	9.756E-01	-1.155E-01	2.186E+00	1.000E+00	0.000E+00
38	0.000E+00	0.000E+00	0.000E+00	1	0	-2.616E-01	2.336E-01	-9.365E-01	7.314E-01	1.000E+00	0.000E+00
39	0.000E+00	0.000E+00	0.000E+00	1	0	9.780E-01	-7.641E-02	-1.939E-01	2.997E-01	1.000E+00	0.000E+00
40	0.000E+00	0.000E+00	0.000E+00	1	0	2.580E-01	-7.076E-01	6.578E-01	1.444E+00	1.000E+00	0.000E+00
41	0.000E+00	0.000E+00	0.000E+00	1	0	-3.212E-01	-7.678E-01	-5.543E-01	1.914E+00	1.000E+00	0.000E+00
42	0.000E+00	0.000E+00	0.000E+00	1	0	5.039E-01	-1.460E-01	8.513E-01	1.502E+00	1.000E+00	0.000E+00
43	0.000E+00	0.000E+00	0.000E+00	1	0	6.080E-01	5.487E-01	5.738E-01	5.971E+00	1.000E+00	0.000E+00
44	0.000E+00	0.000E+00	0.000E+00	1	0	-2.932E-01	9.304E-01	-2.199E-01	1.827E+00	1.000E+00	0.000E+00
45	0.000E+00	0.000E+00	0.000E+00	1	0	-8.475E-01	-3.993E-01	-3.497E-01	1.928E+00	1.000E+00	0.000E+00
46	0.000E+00	0.000E+00	0.000E+00	1	0	1.200E-01	-9.195E-01	-3.743E-01	1.351E+00	1.000E+00	0.000E+00
47	0.000E+00	0.000E+00	0.000E+00	1	0	7.085E-01	5.879E-01	3.904E-01	2.288E+00	1.000E+00	0.000E+00
48	0.000E+00	0.000E+00	0.000E+00	1	0	4.261E-01	9.046E-01	9.254E-03	1.230E+00	1.000E+00	0.000E+00
49	0.000E+00	0.000E+00	0.000E+00	1	0	5.431E-01	4.270E-01	-7.230E-01	1.433E+00	1.000E+00	0.000E+00
50	0.000E+00	0.000E+00	0.000E+00	1	0	-1.053E-01	-9.805E-01	1.658E-01	6.572E-01	1.000E+00	0.000E+00

1estimated keff results by cycle print table 175

N18

cycle	1	k(collision)	1.357781	prompt removal lifetime(abs)	9.2432E-01	source points generated	6878
cycle	2	k(collision)	1.137936	prompt removal lifetime(abs)	7.2370E-01	source points generated	4210
cycle	3	k(collision)	1.074601	prompt removal lifetime(abs)	6.8428E-01	source points generated	4729
cycle	4	k(collision)	1.015694	prompt removal lifetime(abs)	6.2956E-01	source points generated	4772
cycle	5	k(collision)	1.012679	prompt removal lifetime(abs)	6.3207E-01	source points generated	5017
cycle	6	k(collision)	1.005543	prompt removal lifetime(abs)	6.3156E-01	source points generated	5003
cycle	7	k(collision)	0.997368	prompt removal lifetime(abs)	6.1724E-01	source points generated	4968
cycle	8	k(collision)	1.015658	prompt removal lifetime(abs)	6.3166E-01	source points generated	5016
cycle	9	k(collision)	0.993955	prompt removal lifetime(abs)	6.1257E-01	source points generated	4934
cycle	10	k(collision)	0.983553	prompt removal lifetime(abs)	6.1586E-01	source points generated	4951
cycle	11	k(collision)	0.996647	prompt removal lifetime(abs)	6.3200E-01	source points generated	5012
cycle	12	k(collision)	1.009862	prompt removal lifetime(abs)	6.4865E-01	source points generated	5023
cycle	13	k(collision)	1.001332	prompt removal lifetime(abs)	6.2325E-01	source points generated	5008
cycle	14	k(collision)	1.009621	prompt removal lifetime(abs)	6.3693E-01	source points generated	5034
cycle	15	k(collision)	0.988114	prompt removal lifetime(abs)	6.1351E-01	source points generated	4960
cycle	16	k(collision)	0.981015	prompt removal lifetime(abs)	6.0661E-01	source points generated	4894

```
cycle    17    k(collision)  0.995968    prompt removal lifetime(abs)  6.0706E-01    source points generated   5144

cycle    18    k(collision)  0.998541    prompt removal lifetime(abs)  6.1252E-01    source points generated   5070

cycle    19    k(collision)  1.012155    prompt removal lifetime(abs)  6.3523E-01    source points generated   5106

cycle    20    k(collision)  1.005680    prompt removal lifetime(abs)  6.3389E-01    source points generated   5014

cycle    21    k(collision)  1.021934    prompt removal lifetime(abs)  6.2288E-01    source points generated   5064

cycle    22    k(collision)  1.001049    prompt removal lifetime(abs)  6.1975E-01    source points generated   4933

cycle    23    k(collision)  1.014237    prompt removal lifetime(abs)  6.4376E-01    source points generated   5078

cycle    24    k(collision)  0.991820    prompt removal lifetime(abs)  6.3556E-01    source points generated   4821

cycle    25    k(collision)  0.991832    prompt removal lifetime(abs)  6.1512E-01    source points generated   4895

cycle    26    k(collision)  1.000807    prompt removal lifetime(abs)  6.2594E-01    source points generated   5119

cycle    27    k(collision)  1.000663    prompt removal lifetime(abs)  6.2296E-01    source points generated   4961

cycle    28    k(collision)  1.004738    prompt removal lifetime(abs)  6.2925E-01    source points generated   4985

cycle    29    k(collision)  0.985507    prompt removal lifetime(abs)  6.1142E-01    source points generated   5005

cycle    30    k(collision)  1.011755    prompt removal lifetime(abs)  6.3483E-01    source points generated   5101

cycle    31    k(collision)  0.995226    prompt removal lifetime(abs)  6.2262E-01    source points generated   4924

 estimator     cycle    32   ave of     2 cycles      combination         simple average    combined average     corr
k(collision)      0.992374       0.993800 0.0014     k(col/abs)          0.000000 0.0000     0.000000 0.0000   0.0000
k(absorption)     0.990457       0.992463 0.0020     k(abs/tk ln)        0.000000 0.0000     0.000000 0.0000   0.0000
k(trk length)     0.992387       0.995619 0.0032     k(tk ln/col)        0.000000 0.0000     0.000000 0.0000   0.0000
rem life(col)   6.1203E-01     6.1668E-01 0.0075
rem life(abs)   6.1241E-01     6.1752E-01 0.0083     life(col/abs)     0.0000E+00 0.0000   0.0000E+00 0.0000   0.0000
source points generated   4934

 estimator     cycle    33   ave of     3 cycles      combination         simple average    combined average     corr
k(collision)      0.992185       0.993261 0.0010     k(col/abs)          0.993000 0.0010     0.993152 0.0015   0.6870
k(absorption)     0.993292       0.992739 0.0012     k(abs/tk ln)        0.994262 0.0015     0.988060 0.0021   0.9894
k(trk length)     0.996116       0.995785 0.0019     k(tk ln/col)        0.994523 0.0014     0.992497 0.0022   0.7854
rem life(col)   6.1555E-01     6.1630E-01 0.0044
rem life(abs)   6.1511E-01     6.1671E-01 0.0050     life(col/abs)     6.1651E-01 0.0047   6.1489E-01 0.0056   0.9920
source points generated   5025

 estimator     cycle    34   ave of     4 cycles      combination         simple average    combined average     corr
k(collision)      0.990454       0.992560 0.0010     k(col/abs)          0.992285 0.0010     0.992471 0.0014   0.8305
k(absorption)     0.989823       0.992010 0.0011     k(abs/tk ln)        0.994600 0.0011     0.993260 0.0020   0.0368
```

```
 k(trk length)      1.001404       0.997189 0.0019     k(tk ln/col)        0.994874 0.0010     0.993656 0.0016  -0.1375
 rem life(col)    6.2832E-01     6.1931E-01 0.0058     k(col/abs/tk ln)    0.993920 0.0009     0.993741 0.0025
 rem life(abs)    6.2808E-01     6.1955E-01 0.0058     life(col/abs/tl)  6.1975E-01 0.0055   6.2124E-01 0.0108
 source points generated   5090

  estimator     cycle    35   ave of     5 cycles      combination         simple average    combined average     corr
 k(collision)       1.004481       0.994944 0.0025     k(col/abs)          0.994733 0.0026     0.995396 0.0031   0.9830
 k(absorption)      1.004572       0.994522 0.0027     k(abs/tk ln)        0.996772 0.0023     0.997755 0.0042   0.7402
 k(trk length)      1.006347       0.999021 0.0024     k(tk ln/col)        0.996982 0.0023     0.997384 0.0039   0.7109
 rem life(col)    6.2895E-01     6.2124E-01 0.0054     k(col/abs/tk ln)    0.996162 0.0024     0.998345 0.0048
 rem life(abs)    6.2826E-01     6.2130E-01 0.0053     life(col/abs/tl)  6.2130E-01 0.0049   6.2148E-01 0.0055
 source points generated   5101
SKIP 745 LINES OF OUTPUT
  estimator     cycle   129   ave of    99 cycles      combination         simple average    combined average     corr
 k(collision)       1.002170       0.995378 0.0010     k(col/abs)          0.995472 0.0010     0.995432 0.0010   0.9920
 k(absorption)      1.003169       0.995566 0.0010     k(abs/tk ln)        0.996150 0.0008     0.996489 0.0008   0.5853
 k(trk length)      0.989952       0.996734 0.0008     k(tk ln/col)        0.996056 0.0008     0.996467 0.0008   0.6093
 rem life(col)    6.1230E-01     6.1905E-01 0.0016     k(col/abs/tk ln)    0.995893 0.0009     0.996664 0.0008
 rem life(abs)    6.1136E-01     6.1902E-01 0.0017     life(col/abs/tl)  6.1958E-01 0.0015   6.2149E-01 0.0013
 source points generated   5060
```

N19

```
  estimator     cycle   130   ave of   100 cycles      combination         simple average    combined average     corr
 k(collision)       0.994554       0.995369 0.0010     k(col/abs)          0.995466 0.0010     0.995426 0.0010   0.9920
 k(absorption)      0.995210       0.995563 0.0010     k(abs/tk ln)        0.996153 0.0008     0.996496 0.0008   0.5852
 k(trk length)      0.997695       0.996744 0.0008     k(tk ln/col)        0.996057 0.0008     0.996473 0.0008   0.6091
 rem life(col)    6.1293E-01     6.1899E-01 0.0016     k(col/abs/tk ln)    0.995892 0.0009     0.996674 0.0008
 rem life(abs)    6.1351E-01     6.1897E-01 0.0016     life(col/abs/tl)  6.1952E-01 0.0015   6.2144E-01 0.0013
 source points generated   4931

 source distribution written to file kcode.s         cycle =   130
1problem summary (active cycles only)              source particle weight for summary table normalization =   500000.00
```

N20

```
      run terminated when   130 kcode cycles were done.
+                                                                                          01/16/03 14:23:41
      kcode godiva: bare u(94) sphere. ref. r.j. labauve, heu-met-fast-001                probid =  01/16/03 14:14:32
0
 neutron creation    tracks      weight        energy            neutron loss        tracks      weight        energy
                                 (per source particle)                                          (per source particle)

 source              499004    1.0000E+00    2.0654E+00          escape              428685    5.7427E-01    9.2826E-01
                                                                 energy cutoff            0    0.            0.
                                                                 time cutoff              0    0.            0.
 weight window            0    0.            0.                weight window            0    0.            0.
 cell importance          0    0.            0.                cell importance          0    0.            0.
 weight cutoff            0    3.2759E-02    1.1963E-02        weight cutoff        72361    3.3000E-02    1.1928E-02
 e or t importance        0    0.            0.                e or t importance        0    0.            0.
 dxtran                   0    0.            0.                dxtran                   0    0.            0.
 forced collisions        0    0.            0.                forced collisions        0    0.            0.
```

```
 exp. transform           0    0.            0.                  exp. transform           0    0.            0.
 upscattering             0    0.            0.                  downscattering           0    0.            5.2470E-01
 photonuclear             0    0.            0.                  capture                  0    4.4732E-02    2.7501E-02
 (n,xn)                4079    5.0787E-03    3.5293E-03          loss to (n,xn)        2037    2.5362E-03    1.9874E-02
 prompt fission           0    0.            0.                  loss to fission          0    3.8330E-01    5.6863E-01
 delayed fission          0    0.            0.
     total           503083    1.0378E+00    2.0809E+00              total           503083    1.0378E+00    2.0809E+00

   number of neutrons banked                    2706        average time of (shakes)              cutoffs
   neutron tracks per source particle     1.0062E+00          escape            6.0576E-01          tco   1.0000E+33
   neutron collisions per source particle 4.0632E+00          capture           1.0087E+00          eco   0.0000E+00
   total neutron collisions                  2031596          capture or escape 6.3488E-01          wc1  -5.0000E-01
   net multiplication              1.0025E+00 0.0001          any termination   6.7357E-01          wc2  -2.5000E-01

 computer time so far in this run     8.96 minutes            maximum number ever in bank         2
 computer time in mcrun               8.72 minutes            bank overflows to backup file       0
 source particles per minute            7.4500E+04
 random numbers generated                 33602569            most random numbers used was      608 in history   137192

 range of sampled source weights = 7.2696E-01 to 1.1876E+00
1neutron  activity in each cell                                                                    print table 126

                tracks     population   collisions   collisions     number        flux        average      average
        cell    entering                             * weight     weighted     weighted   track weight   track mfp
                                                   (per history)    energy       energy     (relative)      (cm)

     1     1      499004       501046      2031596    2.6484E+00   8.5856E-01   1.4915E+00   6.7448E-01   2.6342E+00

     total        499004       501046      2031596    2.6484E+00
1neutron  weight balance in each cell                                                              print table 130

        cell index        1
       cell number        1       total

 external events:
          entering  0.0000E+00  0.0000E+00
            source  1.0000E+00  1.0000E+00
     energy cutoff  0.0000E+00  0.0000E+00
       time cutoff  0.0000E+00  0.0000E+00
           exiting -5.7427E-01 -5.7427E-01
                   ----------  ----------
             total  4.2573E-01  4.2573E-01

 variance reduction events:
     weight window  0.0000E+00  0.0000E+00
   cell importance  0.0000E+00  0.0000E+00
     weight cutoff -2.4095E-04 -2.4095E-04
 e or t importance  0.0000E+00  0.0000E+00
            dxtran  0.0000E+00  0.0000E+00
```

```
 forced collisions  0.0000E+00  0.0000E+00
    exp. transform  0.0000E+00  0.0000E+00
                    ----------  ----------
             total -2.4095E-04 -2.4095E-04

 physical events:
           capture -4.4732E-02 -4.4732E-02
            (n,xn)  5.0787E-03  5.0787E-03
    loss to (n,xn) -2.5362E-03 -2.5362E-03
           fission  0.0000E+00  0.0000E+00
   loss to fission -3.8330E-01 -3.8330E-01
      photonuclear  0.0000E+00  0.0000E+00
                    ----------  ----------
             total -4.2549E-01 -4.2549E-01
1neutron activity of each nuclide in each cell, per source particle                                    print table 140

   cell  cell   nuclides     atom       total  collisions   wgt. lost   wgt. gain   wgt. gain     photons  photon wgt  avg photon
  index  name             fraction  collisions    * weight  to capture  by fission   by (n,xn)    produced    produced      energy

      1     1  92235.66c 9.38E-01     1901962  2.4791E+00  4.2466E-02  3.7664E-01  2.3918E-03           0  0.0000E+00  0.0000E+00
               92238.66c 5.21E-02      107252  1.3985E-01  1.5473E-03  3.4316E-03  1.4380E-04           0  0.0000E+00  0.0000E+00
               92234.66c 1.03E-02       22382  2.9449E-02  7.1877E-04  3.2356E-03  6.9682E-06           0  0.0000E+00  0.0000E+00

        total                         2031596  2.6484E+00  4.4732E-02  3.8330E-01  2.5425E-03           0  0.0000E+00  0.0000E+00


  total over all cells by nuclide       total  collisions   wgt. lost   wgt. gain   wgt. gain     photons  photon wgt  avg photon
                                  collisions    * weight  to capture  by fission   by (n,xn)    produced    produced      energy

               92234.66c               22382  2.9449E-02  7.1877E-04  3.2356E-03  6.9682E-06           0  0.0000E+00  0.0000E+00
               92235.66c             1901962  2.4791E+00  4.2466E-02  3.7664E-01  2.3918E-03           0  0.0000E+00  0.0000E+00
               92238.66c              107252  1.3985E-01  1.5473E-03  3.4316E-03  1.4380E-04           0  0.0000E+00  0.0000E+00
1keff results for: kcode godiva: bare u(94) sphere. ref. r.j. labauve, heu-met-fast-001                 probid =  01/16/03 14:14:32
```

N21

```
 the initial fission neutron source distribution used the   1 source points that were input on the ksrc card.
 the criticality problem was scheduled to skip  30 cycles and run a total of  130 cycles with nominally     5000 neutrons per cycle.
 this problem has run  30 inactive cycles with   150604 neutron histories and  100 active cycles with      499004 neutron histories.


 this calculation has completed the requested number of keff cycles using a total of      649608 fission neutron source histories.
 all cells with fissionable material were sampled and had fission neutron source points.


 the results of the w test for normality applied to the individual collision, absorption, and track-length keff cycle values are:

          the k( collision) cycle values appear normally distributed at the 95 percent confidence level
          the k(absorption) cycle values appear normally distributed at the 95 percent confidence level
          the k(trk length) cycle values appear normally distributed at the 95 percent confidence level
```

```
 the final estimated combined collision/absorption/track-length keff = 0.99667 with an estimated standard deviation of 0.00079

 the estimated 68, 95, & 99 percent keff confidence intervals are 0.99588 to 0.99747, 0.99509 to 0.99825, and 0.99458 to 0.99877

 the final combined (col/abs/tl) prompt removal lifetime = 6.2144E-09 seconds with an estimated standard deviation of 8.1692E-12

 the average neutron energy causing fission = 1.4835E+00 mev
 the energy corresponding to the average neutron lethargy causing fission = 8.3104E-01 mev

 the percentages of fissions caused by neutrons in the thermal, intermediate, and fast neutron ranges are:
        (<0.625 ev):   0.00%         (0.625 ev - 100 kev):   5.34%          (>100 kev):  94.66%

 the average fission neutrons produced per neutron absorbed (capture + fission) in all cells with fission = 2.3254E+00
 the average fission neutrons produced per neutron absorbed (capture + fission) in all the geometry cells = 2.3254E+00

 the average number of neutrons produced per fission = 2.597
```

the estimated average keffs, one standard deviations, and 68, 95, and 99 percent confidence intervals are:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence	corr
collision	0.99537	0.00102	0.99435 to 0.99639	0.99334 to 0.99739	0.99268 to 0.99806	
absorption	0.99556	0.00102	0.99454 to 0.99658	0.99353 to 0.99759	0.99287 to 0.99826	
track length	0.99674	0.00079	0.99595 to 0.99753	0.99517 to 0.99832	0.99466 to 0.99883	
col/absorp	0.99543	0.00103	0.99439 to 0.99646	0.99337 to 0.99748	0.99270 to 0.99815	0.9920
abs/trk len	0.99650	0.00078	0.99571 to 0.99728	0.99494 to 0.99805	0.99444 to 0.99856	0.5852
col/trk len	0.99647	0.00079	0.99569 to 0.99726	0.99491 to 0.99804	0.99439 to 0.99855	0.6091
col/abs/trk len	0.99667	0.00079	0.99588 to 0.99747	0.99509 to 0.99825	0.99458 to 0.99877	

N22

if the largest of each keff occurred on the next cycle, the keff results and 68, 95, and 99 percent confidence intervals would be:

keff estimator	keff	standard deviation	68% confidence	95% confidence	99% confidence
collision	0.99566	0.00105	0.99461 to 0.99671	0.99357 to 0.99774	0.99289 to 0.99842
absorption	0.99588	0.00106	0.99482 to 0.99694	0.99377 to 0.99799	0.99308 to 0.99868
track length	0.99691	0.00080	0.99611 to 0.99771	0.99532 to 0.99850	0.99480 to 0.99902
col/abs/trk len	0.99685	0.00081	0.99604 to 0.99767	0.99523 to 0.99848	0.99470 to 0.99901

N23

the estimated average prompt removal lifetimes, one standard deviations, and 68, 95, and 99 percent confidence intervals are (sec):

estimator	lifetime	std. dev.	68% confidence	95% confidence	99% confidence	corr
collision	6.18989E-09	1.00188E-11	6.1799E-09 to 6.1999E-09	6.1699E-09 to 6.2098E-09	6.1634E-09 to 6.2164E-09	
absorption	6.18967E-09	1.01361E-11	6.1795E-09 to 6.1998E-09	6.1695E-09 to 6.2099E-09	6.1629E-09 to 6.2164E-09	
track length	6.20616E-09	7.93215E-12	6.1982E-09 to 6.2141E-09	6.1904E-09 to 6.2220E-09	6.1852E-09 to 6.2271E-09	
col/absorp	6.19053E-09	9.93048E-12	6.1806E-09 to 6.2005E-09	6.1708E-09 to 6.2103E-09	6.1643E-09 to 6.2168E-09	0.9983
abs/trk len	6.21478E-09	8.14817E-12	6.2066E-09 to 6.2229E-09	6.1986E-09 to 6.2310E-09	6.1933E-09 to 6.2363E-09	0.9092
col/trk len	6.21446E-09	8.19416E-12	6.2063E-09 to 6.2227E-09	6.1981E-09 to 6.2308E-09	6.1928E-09 to 6.2361E-09	0.9108
col/abs/trk len	6.21441E-09	8.16925E-12	6.2062E-09 to 6.2226E-09	6.1981E-09 to 6.2307E-09	6.1928E-09 to 6.2360E-09	

absorption estimates of prompt lifetimes (sec):

	escape	capture	fission	removal
fraction	5.72947E-01	4.46294E-02	3.82424E-01	1.00000E+00
lifetime(abs)	1.08032E-08	1.38690E-07	1.61854E-08	6.18967E-09
lifetime(c/a/t)	1.08464E-08	1.39245E-07	1.62501E-08	6.21441E-09

N24

```
=============================================================================================================================
=                                                                                                                           =
=     the following output gives the predicted changes in keff (track length estimator) for the perturbations.             =
=     the differential operator method was used to obtain these results (1st and/or 2nd order).                            =
=     warning:  fundamental eigenfunction (fission distribution) approximated as unperturbed.                              =
=                                                                                                                           =
=============================================================================================================================
```

perturbation	k(trk ln)	std. dev.
1	1.04902	0.00081

1average keff results summed over 2 cycles each to form 50 batch values of keff print table 178

N25

batch number	start cycle	end cycle	keff estimators by batch k(coll)	k(abs)	k(track)	average keff estimators and deviations k(coll)	st dev	k(abs)	st dev	k(track)	st dev	col/abs/tl keff k(c/a/t)	st dev
1	31	32	0.99380	0.99246	0.99562								
2	33	34	0.99132	0.99156	0.99876	0.99256	0.00124	0.99201	0.00045	0.99719	0.00157		
3	35	36	0.99969	1.00023	1.00396	0.99494	0.00248	0.99475	0.00275	0.99945	0.00243		
4	37	38	1.00241	1.00210	0.99982	0.99681	0.00256	0.99659	0.00268	0.99954	0.00172	1.00125	0.00170
5	39	40	0.99996	0.99991	0.99170	0.99744	0.00208	0.99725	0.00218	0.99797	0.00206	0.99816	0.00203
6	41	42	0.99912	1.00137	0.99481	0.99772	0.00172	0.99794	0.00191	0.99745	0.00176	0.99748	0.00165
7	43	44	0.98613	0.98726	0.99457	0.99606	0.00221	0.99641	0.00222	0.99704	0.00154	0.99687	0.00182
8	45	46	0.99280	0.99262	1.00020	0.99565	0.00195	0.99594	0.00198	0.99743	0.00139	0.99700	0.00156
9	47	48	0.99648	0.99795	0.99609	0.99575	0.00172	0.99616	0.00176	0.99728	0.00124	0.99698	0.00139
10	49	50	0.99417	0.99422	0.98861	0.99559	0.00155	0.99597	0.00159	0.99642	0.00141	0.99610	0.00140
11	51	52	0.98862	0.98787	0.99136	0.99496	0.00154	0.99523	0.00161	0.99596	0.00135	0.99541	0.00136

12	53	54	0.99981	1.00159	0.99637	0.99536	0.00146	0.99576	0.00156	0.99599	0.00124	0.99549 0.00127
13	55	56	0.99634	0.99709	1.00007	0.99543	0.00135	0.99586	0.00144	0.99630	0.00118	0.99563 0.00121
14	57	58	0.99799	0.99751	1.00466	0.99562	0.00126	0.99598	0.00134	0.99690	0.00124	0.99612 0.00123
15	59	60	0.98040	0.98077	0.98664	0.99460	0.00155	0.99497	0.00161	0.99622	0.00135	0.99557 0.00155
16	61	62	1.01157	1.01177	1.00785	0.99566	0.00180	0.99602	0.00183	0.99694	0.00145	0.99675 0.00172
17	63	64	1.00016	1.00011	1.00859	0.99593	0.00171	0.99626	0.00174	0.99763	0.00153	0.99715 0.00178
18	65	66	1.01162	1.01408	1.00136	0.99680	0.00183	0.99725	0.00192	0.99784	0.00145	0.99741 0.00176
19	67	68	0.98953	0.98842	1.00327	0.99642	0.00177	0.99678	0.00187	0.99812	0.00141	0.99755 0.00169
20	69	70	0.98266	0.98263	0.99416	0.99573	0.00182	0.99608	0.00191	0.99792	0.00135	0.99745 0.00168
21	71	72	0.99631	0.99665	0.99730	0.99576	0.00173	0.99610	0.00182	0.99790	0.00128	0.99743 0.00160
22	73	74	0.99235	0.99251	0.99461	0.99560	0.00166	0.99594	0.00174	0.99775	0.00123	0.99726 0.00154
23	75	76	0.99546	0.99437	0.99589	0.99560	0.00158	0.99587	0.00166	0.99767	0.00118	0.99716 0.00140
24	77	78	0.99296	0.99297	1.00029	0.99549	0.00152	0.99575	0.00160	0.99777	0.00114	0.99721 0.00136
25	79	80	1.00171	1.00108	0.99975	0.99573	0.00148	0.99596	0.00155	0.99785	0.00109	0.99743 0.00127
26	81	82	0.98982	0.99087	0.99747	0.99551	0.00144	0.99577	0.00150	0.99784	0.00105	0.99742 0.00125
27	83	84	0.99838	0.99862	0.99920	0.99561	0.00139	0.99587	0.00145	0.99789	0.00101	0.99749 0.00120
28	85	86	0.99513	0.99582	0.99470	0.99560	0.00134	0.99587	0.00139	0.99778	0.00098	0.99739 0.00117
29	87	88	1.00173	1.00153	1.00551	0.99581	0.00131	0.99607	0.00136	0.99804	0.00098	0.99767 0.00117
30	89	90	0.99524	0.99492	0.99584	0.99579	0.00126	0.99603	0.00131	0.99797	0.00095	0.99758 0.00112
31	91	92	0.99036	0.99023	0.99412	0.99561	0.00124	0.99584	0.00128	0.99784	0.00093	0.99744 0.00110
32	93	94	0.99454	0.99329	0.99667	0.99558	0.00120	0.99576	0.00125	0.99781	0.00090	0.99738 0.00104
33	95	96	0.99479	0.99479	0.98607	0.99556	0.00116	0.99573	0.00121	0.99745	0.00094	0.99683 0.00102
34	97	98	1.00187	1.00332	0.99846	0.99574	0.00114	0.99596	0.00119	0.99748	0.00091	0.99688 0.00100
35	99	100	1.00191	1.00284	1.00223	0.99592	0.00112	0.99615	0.00118	0.99762	0.00090	0.99699 0.00099
36	101	102	0.99216	0.99119	0.99994	0.99581	0.00109	0.99601	0.00115	0.99768	0.00088	0.99703 0.00096
37	103	104	0.99697	0.99746	0.99510	0.99585	0.00107	0.99605	0.00112	0.99761	0.00085	0.99698 0.00093
38	105	106	0.99200	0.99131	0.99289	0.99574	0.00104	0.99593	0.00110	0.99749	0.00084	0.99683 0.00091
39	107	108	0.97623	0.97640	0.99150	0.99524	0.00113	0.99543	0.00118	0.99733	0.00083	0.99685 0.00094
40	109	110	0.98573	0.98637	0.98478	0.99501	0.00113	0.99520	0.00117	0.99702	0.00087	0.99653 0.00098
41	111	112	1.00528	1.00534	1.00121	0.99526	0.00113	0.99545	0.00117	0.99712	0.00086	0.99673 0.00095
42	113	114	1.00896	1.00929	1.00328	0.99558	0.00115	0.99578	0.00119	0.99727	0.00085	0.99700 0.00094
43	115	116	0.97250	0.97272	0.98822	0.99505	0.00124	0.99524	0.00128	0.99706	0.00085	0.99699 0.00097
44	117	118	1.00061	1.00077	1.00165	0.99517	0.00122	0.99537	0.00126	0.99716	0.00084	0.99711 0.00095
45	119	120	0.98899	0.99002	0.99248	0.99504	0.00120	0.99525	0.00123	0.99706	0.00083	0.99706 0.00095
46	121	122	0.99384	0.99339	0.98494	0.99501	0.00118	0.99521	0.00121	0.99680	0.00085	0.99656 0.00094
47	123	124	1.00306	1.00239	1.00256	0.99518	0.00116	0.99536	0.00119	0.99692	0.00084	0.99675 0.00093
48	125	126	0.98931	0.98985	0.98735	0.99506	0.00115	0.99525	0.00117	0.99672	0.00085	0.99654 0.00093
49	127	128	1.00730	1.00711	1.00085	0.99531	0.00115	0.99549	0.00117	0.99680	0.00084	0.99670 0.00091
50	129	130	0.99836	0.99919	0.99382	0.99537	0.00113	0.99556	0.00115	0.99674	0.00082	0.99665 0.00089

average keff results summed over 4 cycles each to form 25 batch values of keff

batch number	start cycle	end cycle	keff estimators by batch k(coll)	k(abs)	k(track)	average keff estimators and deviations k(coll)	st dev	k(abs)	st dev	k(track)	st dev	col/abs/tl keff k(c/a/t)	st dev

1	31	34	0.99256	0.99201	0.99719									
2	35	38	1.00105	1.00117	1.00189	0.99681	0.00425	0.99659	0.00458	0.99954	0.00235			
3	39	42	0.99954	1.00064	0.99326	0.99772	0.00262	0.99794	0.00297	0.99745	0.00250			
4	43	46	0.98946	0.98994	0.99739	0.99565	0.00277	0.99594	0.00290	0.99743	0.00176	0.99789	0.00344	
5	47	50	0.99533	0.99608	0.99235	0.99559	0.00215	0.99597	0.00225	0.99642	0.00170	0.99726	0.00266	
6	51	54	0.99421	0.99473	0.99387	0.99536	0.00177	0.99576	0.00185	0.99599	0.00145	0.99696	0.00220	
7	55	58	0.99717	0.99730	1.00237	0.99562	0.00152	0.99598	0.00158	0.99690	0.00153	0.99737	0.00227	
8	59	62	0.99598	0.99627	0.99725	0.99566	0.00131	0.99602	0.00136	0.99694	0.00133	0.99740	0.00195	
9	63	66	1.00589	1.00710	1.00498	0.99680	0.00162	0.99725	0.00172	0.99784	0.00147	0.99617	0.00261	
10	67	70	0.98610	0.98552	0.99871	0.99573	0.00180	0.99608	0.00194	0.99792	0.00132	0.99605	0.00246	
11	71	74	0.99433	0.99458	0.99596	0.99560	0.00164	0.99594	0.00176	0.99775	0.00121	0.99584	0.00224	
12	75	78	0.99421	0.99367	0.99809	0.99549	0.00150	0.99575	0.00161	0.99777	0.00110	0.99627	0.00181	
13	79	82	0.99577	0.99598	0.99861	0.99551	0.00138	0.99577	0.00148	0.99784	0.00102	0.99633	0.00169	
14	83	86	0.99676	0.99722	0.99695	0.99560	0.00128	0.99587	0.00138	0.99778	0.00094	0.99629	0.00159	
15	87	90	0.99849	0.99822	1.00067	0.99579	0.00121	0.99603	0.00129	0.99797	0.00090	0.99696	0.00145	
16	91	94	0.99245	0.99176	0.99539	0.99558	0.00115	0.99576	0.00124	0.99781	0.00086	0.99665	0.00123	
17	95	98	0.99833	0.99905	0.99227	0.99574	0.00109	0.99596	0.00118	0.99748	0.00087	0.99628	0.00113	
18	99	102	0.99704	0.99702	1.00109	0.99581	0.00103	0.99601	0.00111	0.99768	0.00084	0.99642	0.00111	
19	103	106	0.99449	0.99439	0.99399	0.99574	0.00098	0.99593	0.00106	0.99749	0.00082	0.99619	0.00101	
20	107	110	0.98098	0.98139	0.98814	0.99501	0.00118	0.99520	0.00124	0.99702	0.00091	0.99663	0.00128	
21	111	114	1.00712	1.00732	1.00225	0.99558	0.00127	0.99578	0.00131	0.99727	0.00090	0.99735	0.00121	
22	115	118	0.98656	0.98675	0.99494	0.99517	0.00128	0.99537	0.00132	0.99716	0.00086	0.99739	0.00118	
23	119	122	0.99142	0.99170	0.98871	0.99501	0.00123	0.99521	0.00127	0.99680	0.00090	0.99678	0.00121	
24	123	126	0.99618	0.99612	0.99496	0.99506	0.00118	0.99525	0.00121	0.99672	0.00087	0.99664	0.00113	
25	127	130	1.00283	1.00315	0.99734	0.99537	0.00117	0.99556	0.00121	0.99674	0.00083	0.99675	0.00105	

average keff results summed over 5 cycles each to form 20 batch values of keff

batch number	start cycle	end cycle	keff estimators by batch k(coll)	k(abs)	k(track)	average keff estimators and deviations k(coll)	st dev	k(abs)	st dev	k(track)	st dev	col/abs/tl keff k(c/a/t)	st dev
1	31	35	0.99494	0.99452	0.99902								
2	36	40	0.99993	0.99999	0.99692	0.99744	0.00249	0.99725	0.00273	0.99797	0.00105		
3	41	45	0.99262	0.99415	0.99496	0.99583	0.00216	0.99622	0.00189	0.99697	0.00117		
4	46	50	0.99486	0.99522	0.99475	0.99559	0.00154	0.99597	0.00136	0.99642	0.00100	0.99695	0.00103
5	51	55	0.99212	0.99279	0.99258	0.99489	0.00138	0.99533	0.00123	0.99565	0.00109	0.99644	0.00129
6	56	60	0.99315	0.99314	0.99906	0.99460	0.00117	0.99497	0.00107	0.99622	0.00105	0.99652	0.00106
7	61	65	1.00444	1.00488	1.00552	0.99601	0.00172	0.99638	0.00168	0.99755	0.00160	0.99795	0.00247
8	66	70	0.99377	0.99392	1.00058	0.99573	0.00151	0.99608	0.00149	0.99792	0.00144	0.99794	0.00222
9	71	75	0.99631	0.99632	0.99927	0.99579	0.00134	0.99610	0.00131	0.99807	0.00128	0.99799	0.00195
10	76	80	0.99521	0.99470	0.99586	0.99573	0.00120	0.99596	0.00118	0.99785	0.00116	0.99726	0.00162
11	81	85	0.99516	0.99574	0.99809	0.99568	0.00108	0.99594	0.00107	0.99788	0.00105	0.99728	0.00150
12	86	90	0.99697	0.99697	0.99899	0.99579	0.00099	0.99603	0.00098	0.99797	0.00096	0.99737	0.00137

13	91	95	0.99308	0.99203	0.99453	0.99558	0.00094	0.99572	0.00095	0.99770	0.00093	0.99671 0.00127
14	96	100	1.00031	1.00176	0.99649	0.99592	0.00093	0.99615	0.00098	0.99762	0.00086	0.99690 0.00112
15	101	105	0.99356	0.99328	0.99626	0.99576	0.00088	0.99596	0.00093	0.99753	0.00081	0.99677 0.00106
16	106	110	0.98368	0.98381	0.98942	0.99501	0.00112	0.99520	0.00116	0.99702	0.00091	0.99684 0.00130
17	111	115	0.99946	0.99977	0.99861	0.99527	0.00108	0.99547	0.00112	0.99711	0.00086	0.99702 0.00120
18	116	120	0.99108	0.99149	0.99613	0.99504	0.00105	0.99525	0.00108	0.99706	0.00081	0.99703 0.00116
19	121	125	0.99802	0.99746	0.99284	0.99519	0.00100	0.99537	0.00103	0.99684	0.00080	0.99648 0.00098
20	126	130	0.99873	0.99931	0.99497	0.99537	0.00097	0.99556	0.00099	0.99674	0.00076	0.99641 0.00090

average keff results summed over 10 cycles each to form 10 batch values of keff

batch number	start cycle	end cycle	keff estimators by batch k(coll)	k(abs)	k(track)	average keff estimators and deviations k(coll)	st dev	k(abs)	st dev	k(track)	st dev	col/abs/tl keff k(c/a/t)	st dev
1	31	40	0.99744	0.99725	0.99797								
2	41	50	0.99374	0.99468	0.99486	0.99559	0.00185	0.99597	0.00129	0.99642	0.00156		
3	51	60	0.99263	0.99297	0.99582	0.99460	0.00145	0.99497	0.00125	0.99622	0.00092		
4	61	70	0.99911	0.99940	1.00305	0.99573	0.00152	0.99608	0.00142	0.99792	0.00183	0.99625	0.00441
5	71	80	0.99576	0.99551	0.99757	0.99573	0.00118	0.99596	0.00110	0.99785	0.00142	0.99556	0.00289
6	81	90	0.99606	0.99635	0.99854	0.99579	0.00097	0.99603	0.00090	0.99797	0.00116	0.99558	0.00235
7	91	100	0.99670	0.99689	0.99551	0.99592	0.00083	0.99615	0.00077	0.99762	0.00104	0.99643	0.00141
8	101	110	0.98862	0.98855	0.99284	0.99501	0.00116	0.99520	0.00116	0.99702	0.00108	0.99652	0.00209
9	111	120	0.99527	0.99563	0.99737	0.99504	0.00102	0.99525	0.00103	0.99706	0.00096	0.99655	0.00189
10	121	130	0.99837	0.99839	0.99390	0.99537	0.00097	0.99556	0.00097	0.99674	0.00091	0.99622	0.00121

average keff results summed over 20 cycles each to form 5 batch values of keff

batch number	start cycle	end cycle	keff estimators by batch k(coll)	k(abs)	k(track)	average keff estimators and deviations k(coll)	st dev	k(abs)	st dev	k(track)	st dev	col/abs/tl keff k(c/a/t)	st dev
1	31	50	0.99559	0.99597	0.99642								
2	51	70	0.99587	0.99618	0.99943	0.99573	0.00014	0.99608	0.00011	0.99792	0.00151		
3	71	90	0.99591	0.99593	0.99806	0.99579	0.00010	0.99603	0.00008	0.99797	0.00087		
4	91	110	0.99266	0.99272	0.99418	0.99501	0.00079	0.99520	0.00083	0.99702	0.00113	0.99333	0.00290
5	111	130	0.99682	0.99701	0.99564	0.99537	0.00071	0.99556	0.00074	0.99674	0.00092	0.99497	0.00172

average keff results summed over 25 cycles each to form 4 batch values of keff

batch number	start cycle	end cycle	keff estimators by batch k(coll)	k(abs)	k(track)	average keff estimators and deviations k(coll)	st dev	k(abs)	st dev	k(track)	st dev	col/abs/tl keff k(c/a/t)	st dev
1	31	55	0.99489	0.99533	0.99565								
2	56	80	0.99658	0.99659	1.00006	0.99573	0.00084	0.99596	0.00063	0.99785	0.00220		

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      3     81    105      0.99582  0.99596  0.99687       0.99576 0.00049   0.99596 0.00036   0.99753 0.00131
      4    106    130      0.99419  0.99437  0.99439       0.99537 0.00052   0.99556 0.00047   0.99674 0.00122       0.99457 0.00114


 average keff results summed over  50 cycles each to form  2 batch values of keff

  batch  start    end     keff estimators by batch             average keff estimators and deviations
 number  cycle  cycle     k(coll)  k(abs)  k(track)       k(coll)  st dev    k(abs)  st dev   k(track) st dev

      1     31     80      0.99573  0.99596  0.99785
      2     81    130      0.99500  0.99516  0.99563       0.99537 0.00037   0.99556 0.00040   0.99674 0.00111
1average individual and combined collision/absorption/track-length keff results for  7 different batch sizes
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N26

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 cycles per  number of    average keff estimators and deviations      normality  average k(c/a/t)    k(c/a/t) confidence intervals
 keff batch  k batches  k(col) st dev  k(abs) st dev  k(trk) st dev   co/ab/trk  k(c/a/t) st dev    95% confidence     99% confidence

       1        100   |  0.9954 0.0010  0.9956 0.0010  0.9967 0.0008  |95/95/95|  0.99667 0.00079   0.99509-0.99825   0.99458-0.99877
       2         50   |  0.9954 0.0011  0.9956 0.0012  0.9967 0.0008  |95/95/95|  0.99665 0.00089   0.99486-0.99844   0.99426-0.99904
       4         25   |  0.9954 0.0012  0.9956 0.0012  0.9967 0.0008  |95/95/95|  0.99675 0.00105   0.99456-0.99893   0.99378-0.99972
       5         20   |  0.9954 0.0010  0.9956 0.0010  0.9967 0.0008  |95/95/95|  0.99641 0.00090   0.99450-0.99831   0.99379-0.99903
      10         10   |  0.9954 0.0010  0.9956 0.0010  0.9967 0.0009  |95/95/95|  0.99622 0.00121   0.99337-0.99908   0.99200-1.00045
      20          5   |  0.9954 0.0007  0.9956 0.0007  0.9967 0.0009  |95/95/95|  0.99497 0.00172   0.98754-1.00239   0.97785-1.01208
      25          4   |  0.9954 0.0005  0.9956 0.0005  0.9967 0.0012  |95/95/95|  0.99457 0.00114   0.98003-1.00912   0.92170-1.06745
1individual and average keff estimator results by cycle
```

N27

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  keff     neutron    keff estimators by cycle          average keff estimators and deviations               average k(c/a/t)
 cycle   histories   k(coll)  k(abs)  k(track)     k(coll)  st dev    k(abs)  st dev   k(track) st dev    k(c/a/t)  st dev    fom

     1        5000 | 1.35778  1.35725  1.34730  |
     2        6878 | 1.13794  1.13693  1.14910  |
     3        4210 | 1.07460  1.07274  1.07515  |
     4        4729 | 1.01569  1.01547  1.02185  |
     5        4772 | 1.01268  1.01315  1.01677  |
     6        5017 | 1.00554  1.00819  1.00857  |
     7        5003 | 0.99737  0.99426  1.00240  |
     8        4968 | 1.01566  1.01310  1.00923  |
     9        5016 | 0.99396  0.99452  0.99040  |
    10        4934 | 0.98355  0.98043  0.99437  |
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    11        4951 | 0.99665  0.99965  1.00887  |
    12        5012 | 1.00986  1.01177  1.01113  |
    13        5023 | 1.00133  1.00237  0.99554  |
    14        5008 | 1.00962  1.00782  1.01163  |
    15        5034 | 0.98811  0.98660  0.98598  |
    16        4960 | 0.98102  0.97998  0.98266  |
    17        4894 | 0.99597  0.99490  0.98888  |
    18        5144 | 0.99854  0.99658  0.99280  |
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   19        5070 | 1.01216  1.01467  1.01042  |
   20        5106 | 1.00568  1.00638  1.00173  |
------------------------------------------------------------------------------------------------------------------
   21        5014 | 1.02193  1.02101  1.00430  |
   22        5064 | 1.00105  1.00097  0.99770  |
   23        4933 | 1.01424  1.01438  1.01305  |
   24        5078 | 0.99182  0.99236  0.99283  |
   25        4821 | 0.99183  0.99416  0.99160  |
   26        4895 | 1.00081  1.00214  1.00150  |
   27        5119 | 1.00066  0.99919  1.01072  |
   28        4961 | 1.00474  1.00576  0.99820  |
   29        4985 | 0.98551  0.98616  0.98279  |
   30        5005 | 1.01176  1.00986  1.00869  |
-----------------  begin active keff cycles  ---------------------------------------------------------------------
   31        5101 | 0.99523  0.99447  0.99885  |
   32        4924 | 0.99237  0.99046  0.99239  |  0.99380 0.00143   0.99246 0.00201   0.99562 0.00323  |
   33        4934 | 0.99218  0.99329  0.99612  |  0.99326 0.00098   0.99274 0.00119   0.99578 0.00187  |
   34        5025 | 0.99045  0.98982  1.00140  |  0.99256 0.00099   0.99201 0.00111   0.99719 0.00193  |  0.99374 0.00253    467361
   35        5090 | 1.00448  1.00457  1.00635  |  0.99494 0.00250   0.99452 0.00266   0.99902 0.00236  |  0.99834 0.00483    103791
   36        5101 | 0.99490  0.99590  1.00158  |  0.99494 0.00204   0.99475 0.00218   0.99945 0.00198  |  0.99828 0.00384    136390
   37        4907 | 1.00256  1.00342  1.00761  |  0.99603 0.00204   0.99599 0.00222   1.00061 0.00204  |  0.99939 0.00371    125972
   38        4974 | 1.00227  1.00079  0.99203  |  0.99681 0.00193   0.99659 0.00201   0.99954 0.00207  |  0.99910 0.00212    336212
   39        5009 | 0.99743  0.99650  0.99344  |  0.99687 0.00171   0.99658 0.00178   0.99886 0.00194  |  0.99878 0.00182    408110
   40        4984 | 1.00249  1.00333  0.98995  |  0.99744 0.00163   0.99725 0.00173   0.99797 0.00195  |  0.99794 0.00143    587546
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   41        4986 | 0.99678  0.99834  0.99865  |  0.99738 0.00147   0.99735 0.00156   0.99803 0.00177  |  0.99769 0.00128    667816
   42        4988 | 1.00145  1.00440  0.99097  |  0.99772 0.00139   0.99794 0.00154   0.99745 0.00172  |  0.99746 0.00120    698241
   43        4968 | 0.97663  0.97822  0.98897  |  0.99609 0.00206   0.99642 0.00208   0.99679 0.00171  |  0.99661 0.00171    318017
   44        4788 | 0.99564  0.99630  1.00018  |  0.99606 0.00191   0.99641 0.00192   0.99704 0.00160  |  0.99674 0.00159    340088
   45        5061 | 0.99259  0.99349  0.99604  |  0.99583 0.00179   0.99622 0.00180   0.99697 0.00149  |  0.99664 0.00150    358438
   46        4914 | 0.99300  0.99175  1.00437  |  0.99565 0.00169   0.99594 0.00171   0.99743 0.00147  |  0.99683 0.00141    380727
   47        4942 | 0.98741  0.99012  0.99192  |  0.99517 0.00166   0.99560 0.00164   0.99711 0.00142  |  0.99671 0.00139    365455
   48        4980 | 1.00555  1.00577  1.00026  |  0.99575 0.00167   0.99616 0.00165   0.99728 0.00135  |  0.99711 0.00134    373782
   49        5077 | 0.99565  0.99517  0.99003  |  0.99574 0.00158   0.99611 0.00156   0.99690 0.00133  |  0.99672 0.00128    387914
   50        5000 | 0.99270  0.99327  0.98719  |  0.99559 0.00150   0.99597 0.00149   0.99642 0.00135  |  0.99635 0.00127    375205
------------------------------------------------------------------------------------------------------------------
   51        4976 | 0.99254  0.99001  0.99981  |  0.99544 0.00144   0.99568 0.00144   0.99658 0.00130  |  0.99626 0.00118    411228
   52        4976 | 0.98470  0.98574  0.98291  |  0.99496 0.00145   0.99523 0.00145   0.99596 0.00138  |  0.99575 0.00127    339724
   53        4997 | 1.00583  1.00813  0.99847  |  0.99543 0.00147   0.99579 0.00149   0.99607 0.00133  |  0.99602 0.00127    324753
   54        5099 | 0.99378  0.99505  0.99428  |  0.99536 0.00141   0.99576 0.00143   0.99599 0.00127  |  0.99597 0.00122    334374
   55        4919 | 0.98372  0.98503  0.98745  |  0.99489 0.00143   0.99533 0.00144   0.99565 0.00127  |  0.99571 0.00125    307083
   56        4900 | 1.00896  1.00914  1.01269  |  0.99543 0.00147   0.99586 0.00148   0.99630 0.00138  |  0.99631 0.00138    244559
   57        5127 | 0.99190  0.99134  1.00404  |  0.99530 0.00142   0.99570 0.00143   0.99659 0.00136  |  0.99638 0.00133    251080
   58        4943 | 1.00409  1.00368  1.00529  |  0.99562 0.00141   0.99598 0.00141   0.99690 0.00135  |  0.99672 0.00132    249157
   59        5066 | 0.97574  0.97655  0.98328  |  0.99493 0.00152   0.99531 0.00152   0.99643 0.00138  |  0.99638 0.00141    208025
   60        4966 | 0.98505  0.98499  0.99001  |  0.99460 0.00151   0.99497 0.00150   0.99622 0.00135  |  0.99611 0.00140    204535
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   61        5088 | 1.01312  1.01183  1.00439  |  0.99520 0.00157   0.99551 0.00155   0.99648 0.00134  |  0.99662 0.00135    212729
   62        5133 | 1.01002  1.01171  1.01131  |  0.99566 0.00159   0.99602 0.00159   0.99694 0.00137  |  0.99699 0.00144    182878
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63	4858	0.99611	0.99701	1.00374	0.99568 0.00154	0.99605 0.00154	0.99715 0.00135	0.99710 0.00142	182540
64	4890	1.00420	1.00322	1.01345	0.99593 0.00152	0.99626 0.00151	0.99763 0.00139	0.99747 0.00143	173471
65	5120	0.99876	1.00065	0.99469	0.99601 0.00148	0.99638 0.00147	0.99755 0.00135	0.99749 0.00140	177103
66	5026	1.02448	1.02752	1.00803	0.99680 0.00164	0.99725 0.00167	0.99784 0.00135	0.99795 0.00146	156890
67	4944	1.00074	0.99828	1.01130	0.99691 0.00160	0.99728 0.00162	0.99820 0.00136	0.99830 0.00143	159344
68	4973	0.97832	0.97856	0.99523	0.99642 0.00163	0.99678 0.00166	0.99812 0.00133	0.99824 0.00142	157971
69	4786	0.98568	0.98519	0.99301	0.99614 0.00161	0.99649 0.00164	0.99799 0.00130	0.99807 0.00140	158617
70	4893	0.97964	0.98006	0.99531	0.99573 0.00162	0.99608 0.00165	0.99792 0.00127	0.99804 0.00139	158157
71	4914	1.00184	1.00195	1.00033	0.99588 0.00159	0.99622 0.00162	0.99798 0.00124	0.99811 0.00135	163202
72	5093	0.99077	0.99135	0.99428	0.99576 0.00156	0.99610 0.00158	0.99790 0.00121	0.99804 0.00132	165004
73	4978	0.99962	0.99904	1.00445	0.99585 0.00152	0.99617 0.00155	0.99805 0.00119	0.99817 0.00130	167551
74	5072	0.98508	0.98598	0.98477	0.99560 0.00151	0.99594 0.00153	0.99775 0.00120	0.99790 0.00131	160829
75	4896	1.00423	1.00330	1.01253	0.99579 0.00149	0.99610 0.00150	0.99807 0.00122	0.99818 0.00132	155411
76	5001	0.98669	0.98543	0.97924	0.99560 0.00147	0.99587 0.00149	0.99767 0.00126	0.99741 0.00134	147126
77	5000	0.99791	0.99645	1.00624	0.99564 0.00144	0.99588 0.00146	0.99785 0.00125	0.99754 0.00132	149194
78	4925	0.98801	0.98948	0.99435	0.99549 0.00142	0.99575 0.00143	0.99777 0.00122	0.99750 0.00130	149654
79	4898	1.00780	1.00671	1.00209	0.99574 0.00141	0.99597 0.00142	0.99786 0.00120	0.99766 0.00126	156522
80	5109	0.99561	0.99545	0.99740	0.99573 0.00138	0.99596 0.00139	0.99785 0.00118	0.99764 0.00123	159955
81	4977	0.99459	0.99635	0.99586	0.99571 0.00135	0.99597 0.00136	0.99781 0.00116	0.99764 0.00121	161641
82	4868	0.98506	0.98539	0.99909	0.99551 0.00134	0.99577 0.00135	0.99784 0.00113	0.99763 0.00120	162269
83	4917	1.00300	1.00297	1.00328	0.99565 0.00132	0.99590 0.00133	0.99794 0.00112	0.99776 0.00118	164571
84	5097	0.99376	0.99426	0.99512	0.99561 0.00130	0.99587 0.00131	0.99789 0.00110	0.99771 0.00116	166998
85	4852	0.99938	0.99970	0.99713	0.99568 0.00128	0.99594 0.00129	0.99788 0.00108	0.99772 0.00114	171154
86	5098	0.99088	0.99194	0.99228	0.99560 0.00126	0.99587 0.00127	0.99778 0.00106	0.99765 0.00112	172075
87	5013	1.00349	1.00287	1.00602	0.99573 0.00124	0.99599 0.00125	0.99792 0.00105	0.99780 0.00111	173333
88	5078	0.99998	1.00020	1.00500	0.99581 0.00122	0.99607 0.00123	0.99804 0.00104	0.99789 0.00110	173231
89	5000	0.99924	0.99937	0.99874	0.99587 0.00120	0.99612 0.00121	0.99805 0.00102	0.99791 0.00108	176828
90	5014	0.99125	0.99046	0.99294	0.99579 0.00119	0.99603 0.00119	0.99797 0.00101	0.99778 0.00106	178848
91	4928	0.99365	0.99295	1.00003	0.99575 0.00117	0.99598 0.00117	0.99800 0.00099	0.99778 0.00105	181471
92	5087	0.98707	0.98751	0.98820	0.99561 0.00116	0.99584 0.00116	0.99784 0.00099	0.99763 0.00104	179450
93	4930	0.99460	0.99262	1.00954	0.99560 0.00114	0.99579 0.00115	0.99803 0.00099	0.99770 0.00104	179148
94	5085	0.99448	0.99396	0.98381	0.99558 0.00112	0.99576 0.00113	0.99781 0.00100	0.99736 0.00102	180683
95	4996	0.99562	0.99310	0.99109	0.99558 0.00110	0.99572 0.00111	0.99770 0.00099	0.99716 0.00100	185763
96	5056	0.99396	0.99647	0.98105	0.99556 0.00109	0.99573 0.00109	0.99745 0.00101	0.99698 0.00099	185875
97	5033	0.98375	0.98542	0.99662	0.99538 0.00109	0.99558 0.00109	0.99744 0.00099	0.99696 0.00099	185753
98	4932	1.02000	1.02122	1.00029	0.99574 0.00113	0.99596 0.00114	0.99748 0.00098	0.99723 0.00097	187424
99	5284	1.00174	1.00186	1.00257	0.99583 0.00112	0.99604 0.00112	0.99756 0.00097	0.99731 0.00096	188857
100	4966	1.00208	1.00382	1.00190	0.99592 0.00110	0.99615 0.00111	0.99762 0.00096	0.99738 0.00096	188509
101	5039	0.98642	0.98633	0.99854	0.99578 0.00110	0.99601 0.00111	0.99763 0.00094	0.99736 0.00095	189434
102	4819	0.99791	0.99606	1.00134	0.99581 0.00108	0.99601 0.00109	0.99768 0.00093	0.99738 0.00093	193795
103	5051	0.99997	1.00039	0.99531	0.99587 0.00107	0.99607 0.00108	0.99765 0.00092	0.99738 0.00092	197438
104	4992	0.99398	0.99453	0.99490	0.99585 0.00105	0.99605 0.00106	0.99761 0.00091	0.99735 0.00091	199616
105	4996	0.98954	0.98911	0.99120	0.99576 0.00104	0.99596 0.00105	0.99753 0.00090	0.99724 0.00090	200205
106	4992	0.99446	0.99351	0.99457	0.99574 0.00103	0.99593 0.00104	0.99749 0.00089	0.99718 0.00088	203443
107	5172	0.97682	0.97776	0.98657	0.99550 0.00104	0.99569 0.00105	0.99735 0.00089	0.99709 0.00089	196856

108	4865	0.97564	0.97504	0.99642	0.99524	0.00106	0.99543	0.00107	0.99733	0.00088	0.99706	0.00089	195453
109	4993	0.97552	0.97618	0.98209	0.99499	0.00108	0.99518	0.00109	0.99714	0.00089	0.99692	0.00091	185784
110	5018	0.99593	0.99657	0.98746	0.99501	0.00106	0.99520	0.00107	0.99702	0.00088	0.99680	0.00090	187690
111	5027	1.00622	1.00623	1.00032	0.99514	0.00106	0.99534	0.00107	0.99706	0.00087	0.99688	0.00088	190647
112	5013	1.00434	1.00446	1.00211	0.99526	0.00105	0.99545	0.00106	0.99712	0.00087	0.99696	0.00088	192246
113	4854	1.00221	0.99961	0.99968	0.99534	0.00104	0.99550	0.00105	0.99715	0.00086	0.99697	0.00086	198016
114	4835	1.01572	1.01897	1.00688	0.99558	0.00106	0.99578	0.00107	0.99727	0.00085	0.99713	0.00087	190437
115	5117	0.96881	0.96958	0.98405	0.99527	0.00109	0.99547	0.00110	0.99711	0.00086	0.99705	0.00088	182346
116	4775	0.97619	0.97587	0.99239	0.99505	0.00110	0.99524	0.00112	0.99706	0.00085	0.99701	0.00088	181217
117	5074	0.99820	0.99787	0.99633	0.99508	0.00109	0.99527	0.00110	0.99705	0.00084	0.99700	0.00087	184145
118	5050	1.00302	1.00368	1.00698	0.99517	0.00108	0.99537	0.00109	0.99716	0.00084	0.99709	0.00087	181907
119	5043	0.99664	0.99531	0.99112	0.99519	0.00107	0.99537	0.00108	0.99710	0.00083	0.99698	0.00086	184806
120	4843	0.98134	0.98473	0.99385	0.99504	0.00107	0.99525	0.00108	0.99706	0.00082	0.99698	0.00085	184862
121	4919	0.98829	0.98799	0.99203	0.99496	0.00106	0.99517	0.00107	0.99700	0.00081	0.99692	0.00085	185677
122	4939	0.99939	0.99879	0.97785	0.99501	0.00105	0.99521	0.00106	0.99680	0.00083	0.99659	0.00085	183634
123	5032	1.00885	1.00684	1.00431	0.99516	0.00105	0.99533	0.00105	0.99688	0.00083	0.99670	0.00084	186169
124	5128	0.99726	0.99793	1.00081	0.99518	0.00104	0.99536	0.00104	0.99692	0.00082	0.99673	0.00083	187139
125	4931	0.99631	0.99575	0.98920	0.99519	0.00103	0.99537	0.00103	0.99684	0.00082	0.99664	0.00082	189020
126	4949	0.98231	0.98395	0.98551	0.99506	0.00103	0.99525	0.00103	0.99672	0.00082	0.99656	0.00082	186589
127	4862	1.01968	1.02036	1.00422	0.99531	0.00105	0.99551	0.00105	0.99680	0.00081	0.99672	0.00082	186166
128	5165	0.99493	0.99385	0.99747	0.99531	0.00104	0.99549	0.00104	0.99680	0.00080	0.99671	0.00081	188496
129	4921	1.00217	1.00317	0.98995	0.99538	0.00103	0.99557	0.00103	0.99673	0.00080	0.99666	0.00080	190786
130	5060	0.99455	0.99521	0.99769	0.99537	0.00102	0.99556	0.00102	0.99674	0.00079	0.99667	0.00079	192271

N28

the largest active cycle keffs by estimator are:

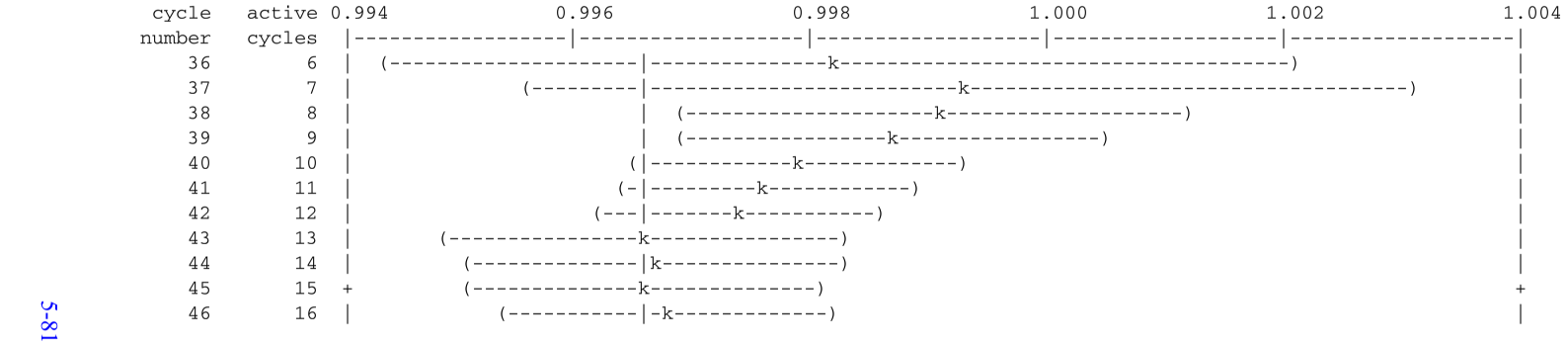
collision 1.02448 on cycle 66
absorption 1.02752 on cycle 66
track length 1.01345 on cycle 64

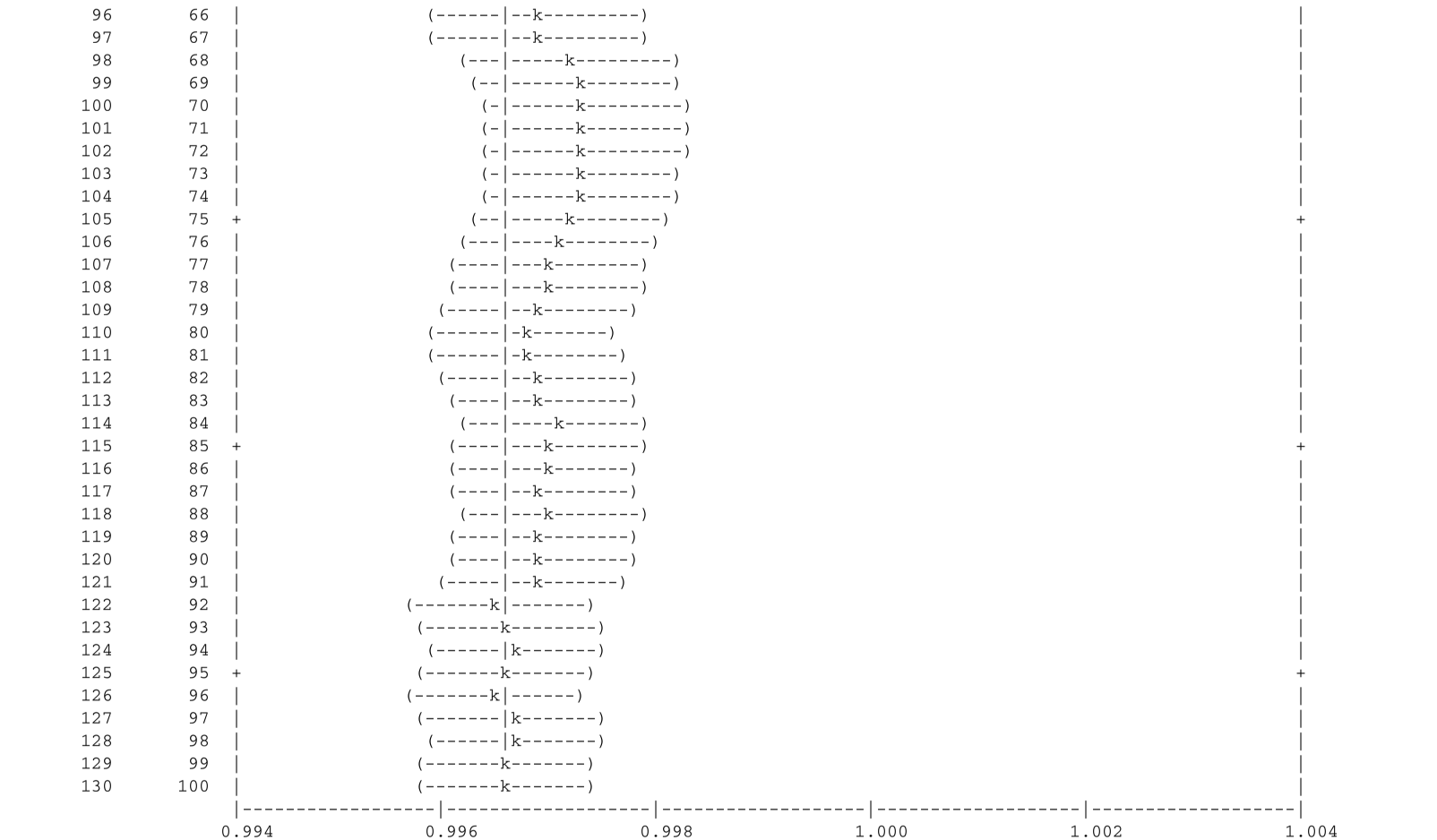
the smallest active cycle keffs by estimator are:

collision 0.96881 on cycle 115
absorption 0.96958 on cycle 115
track length 0.97785 on cycle 122

1plot of the estimated col/abs/track-length keff one standard deviation interval versus cycle number (| = final keff = 0.99667)

N29





1individual and collision/absorption/track-length keffs for different numbers of inactive cycles skipped for fission source settling

N30

skip cycles	active cycles	active neutrons	average keff estimators and deviations k(col)	st dev	k(abs)	st dev	k(trk)	st dev	normality co/ab/tl	average k(c/a/t) k(c/a/t)	st dev	k(c/a/t) confidence intervals 95% confidence	99% confidence
0	130	649608	1.0012	0.0032	1.0013	0.0032	1.0022	0.0031	no/no/no	1.00259	0.00311	0.99640-1.00879	0.99438-1.01081
1	129	644608	0.9984	0.0016	0.9985	0.0015	0.9995	0.0015	no/no/no	0.99928	0.00151	0.99627-1.00229	0.99529-1.00327
2	128	637730	0.9973	0.0011	0.9975	0.0011	0.9983	0.0010	no/no/no	0.99826	0.00098	0.99632-1.00021	0.99568-1.00084
3	127	633520	0.9967	0.0009	0.9969	0.0009	0.9977	0.0008	95/95/95	0.99758	0.00077	0.99604-0.99912	0.99554-0.99962
4	126	628791	0.9966	0.0009	0.9967	0.0009	0.9975	0.0008	95/95/95	0.99741	0.00076	0.99590-0.99891	0.99541-0.99940
5	125	624019	0.9965	0.0009	0.9966	0.0009	0.9974	0.0007	95/95/95	0.99727	0.00074	0.99578-0.99875	0.99530-0.99924
6	124	619002	0.9964	0.0009	0.9965	0.0009	0.9973	0.0007	95/95/95	0.99719	0.00074	0.99571-0.99867	0.99523-0.99915

7	123	613999	0.9964	0.0009	0.9965	0.0009	0.9972	0.0007	95/95/95	0.99717	0.00075	0.99567-0.99866	0.99519-0.99915
8	122	609031	0.9962	0.0009	0.9964	0.0009	0.9971	0.0007	95/95/95	0.99703	0.00075	0.99554-0.99853	0.99505-0.99902
9	121	604015	0.9962	0.0009	0.9964	0.0010	0.9972	0.0008	95/95/95	0.99708	0.00076	0.99558-0.99859	0.99508-0.99908
10	120	599081	0.9963	0.0009	0.9965	0.0010	0.9972	0.0008	95/95/95	0.99715	0.00076	0.99563-0.99866	0.99513-0.99916
11	119	594130	0.9963	0.0010	0.9965	0.0010	0.9971	0.0008	95/95/95	0.99710	0.00076	0.99558-0.99861	0.99509-0.99910
12	118	589118	0.9962	0.0010	0.9964	0.0010	0.9970	0.0008	95/95/95	0.99699	0.00075	0.99549-0.99849	0.99500-0.99898
13	117	584095	0.9962	0.0010	0.9963	0.0010	0.9970	0.0008	95/95/95	0.99699	0.00076	0.99547-0.99850	0.99498-0.99899
14	116	579087	0.9961	0.0010	0.9962	0.0010	0.9969	0.0008	95/95/95	0.99686	0.00076	0.99534-0.99837	0.99485-0.99886
15	115	574053	0.9961	0.0010	0.9963	0.0010	0.9970	0.0008	95/95/95	0.99698	0.00076	0.99546-0.99849	0.99497-0.99899
16	114	569093	0.9963	0.0010	0.9964	0.0010	0.9971	0.0008	95/95/95	0.99713	0.00076	0.99563-0.99864	0.99514-0.99913
17	113	564199	0.9963	0.0010	0.9965	0.0010	0.9972	0.0008	95/95/95	0.99722	0.00076	0.99571-0.99874	0.99522-0.99923
18	112	559055	0.9962	0.0010	0.9965	0.0010	0.9972	0.0008	95/95/95	0.99729	0.00077	0.99576-0.99882	0.99526-0.99932
19	111	553985	0.9961	0.0010	0.9963	0.0010	0.9971	0.0008	95/95/95	0.99719	0.00076	0.99568-0.99870	0.99518-0.99919
20	110	548879	0.9960	0.0010	0.9962	0.0010	0.9971	0.0008	95/95/95	0.99713	0.00076	0.99561-0.99865	0.99511-0.99915
22	108	538801	0.9957	0.0010	0.9959	0.0010	0.9970	0.0008	95/95/95	0.99699	0.00078	0.99544-0.99854	0.99494-0.99905
24	106	528790	0.9956	0.0010	0.9958	0.0010	0.9969	0.0008	95/95/95	0.99686	0.00077	0.99532-0.99841	0.99481-0.99891
26	104	519074	0.9956	0.0010	0.9957	0.0010	0.9969	0.0008	95/95/95	0.99683	0.00078	0.99527-0.99839	0.99476-0.99890
28	102	508994	0.9954	0.0010	0.9956	0.0010	0.9967	0.0008	95/95/95	0.99669	0.00079	0.99511-0.99827	0.99459-0.99878
30	100*	499004	0.9954	0.0010	0.9956	0.0010	0.9967	0.0008	95/95/95	0.99667	0.00079	0.99509-0.99825	0.99458-0.99877
32	98	488979	0.9954	0.0010	0.9956	0.0010	0.9968	0.0008	95/95/95	0.99675	0.00081	0.99514-0.99836	0.99461-0.99889
34	96	479020	0.9955	0.0011	0.9957	0.0011	0.9967	0.0008	95/95/95	0.99673	0.00082	0.99509-0.99837	0.99455-0.99891
36	94	468829	0.9954	0.0011	0.9956	0.0011	0.9966	0.0008	95/95/95	0.99659	0.00083	0.99494-0.99825	0.99439-0.99879
38	92	458948	0.9952	0.0011	0.9955	0.0011	0.9965	0.0008	95/95/95	0.99656	0.00084	0.99489-0.99824	0.99434-0.99879
40	90	448955	0.9951	0.0011	0.9954	0.0011	0.9966	0.0009	95/95/95	0.99667	0.00086	0.99495-0.99839	0.99439-0.99895
42	88	438981	0.9950	0.0011	0.9952	0.0011	0.9966	0.0009	95/95/95	0.99665	0.00088	0.99489-0.99840	0.99432-0.99897
44	86	429225	0.9953	0.0011	0.9954	0.0011	0.9967	0.0009	95/95/95	0.99666	0.00089	0.99489-0.99843	0.99431-0.99901
46	84	419250	0.9953	0.0012	0.9955	0.0012	0.9966	0.0009	95/95/95	0.99661	0.00091	0.99480-0.99841	0.99421-0.99900
48	82	409328	0.9953	0.0012	0.9954	0.0012	0.9966	0.0009	95/95/95	0.99656	0.00092	0.99472-0.99841	0.99412-0.99901
50	80	399251	0.9953	0.0012	0.9955	0.0012	0.9968	0.0009	95/95/95	0.99677	0.00094	0.99489-0.99865	0.99428-0.99926
52	78	389299	0.9955	0.0012	0.9957	0.0012	0.9970	0.0009	95/95/95	0.99693	0.00095	0.99503-0.99883	0.99442-0.99945
54	76	379203	0.9954	0.0013	0.9955	0.0013	0.9970	0.0010	95/95/95	0.99689	0.00097	0.99495-0.99883	0.99432-0.99947
56	74	369384	0.9953	0.0013	0.9955	0.0013	0.9969	0.0010	95/95/95	0.99679	0.00097	0.99487-0.99872	0.99424-0.99935
58	72	359314	0.9953	0.0013	0.9954	0.0013	0.9967	0.0010	95/95/95	0.99662	0.00098	0.99466-0.99857	0.99402-0.99922
60	70	349282	0.9957	0.0013	0.9958	0.0013	0.9970	0.0010	95/95/95	0.99688	0.00098	0.99492-0.99883	0.99428-0.99947
62	68	339061	0.9952	0.0013	0.9953	0.0013	0.9966	0.0010	95/99/95	0.99653	0.00097	0.99458-0.99847	0.99394-0.99911
64	66	329313	0.9951	0.0013	0.9952	0.0013	0.9963	0.0010	95/99/95	0.99623	0.00097	0.99430-0.99816	0.99366-0.99880
66	64	319167	0.9946	0.0013	0.9948	0.0013	0.9961	0.0010	95/95/95	0.99590	0.00096	0.99399-0.99781	0.99335-0.99844
68	62	309250	0.9947	0.0013	0.9948	0.0013	0.9959	0.0010	95/95/95	0.99577	0.00097	0.99384-0.99771	0.99321-0.99834
70	60	299571	0.9951	0.0013	0.9952	0.0013	0.9960	0.0010	95/95/95	0.99589	0.00099	0.99391-0.99787	0.99325-0.99852
72	58	289564	0.9951	0.0014	0.9952	0.0013	0.9959	0.0010	95/95/95	0.99583	0.00102	0.99378-0.99787	0.99311-0.99855
74	56	279514	0.9952	0.0014	0.9953	0.0014	0.9960	0.0010	95/95/95	0.99588	0.00103	0.99381-0.99795	0.99312-0.99863
76	54	269617	0.9952	0.0014	0.9953	0.0014	0.9960	0.0010	95/95/95	0.99598	0.00099	0.99399-0.99796	0.99334-0.99861
78	52	259692	0.9953	0.0015	0.9954	0.0015	0.9958	0.0010	95/95/95	0.99583	0.00101	0.99380-0.99786	0.99312-0.99854
80	50	249685	0.9950	0.0015	0.9952	0.0015	0.9956	0.0010	95/95/95	0.99566	0.00105	0.99356-0.99777	0.99285-0.99848

82	48	239840	0.9952	0.0016	0.9953	0.0016	0.9956	0.0011	95/95/95	0.99561	0.00109	0.99342-0.99779	0.99268-0.99853
84	46	229826	0.9951	0.0016	0.9952	0.0016	0.9954	0.0011	95/95/95	0.99544	0.00112	0.99318-0.99770	0.99242-0.99847
86	44	219876	0.9951	0.0017	0.9952	0.0017	0.9954	0.0012	95/95/95	0.99545	0.00117	0.99309-0.99781	0.99229-0.99861
88	42	209785	0.9948	0.0017	0.9949	0.0017	0.9950	0.0012	95/95/95	0.99500	0.00118	0.99261-0.99738	0.99180-0.99819
90	40	199771	0.9947	0.0018	0.9949	0.0018	0.9949	0.0012	95/95/95	0.99497	0.00124	0.99247-0.99747	0.99162-0.99833
92	38	189756	0.9950	0.0019	0.9951	0.0019	0.9949	0.0013	95/95/95	0.99503	0.00129	0.99242-0.99764	0.99153-0.99854
94	36	179741	0.9950	0.0020	0.9952	0.0020	0.9949	0.0012	95/95/95	0.99492	0.00128	0.99232-0.99753	0.99142-0.99842
96	34	169689	0.9950	0.0021	0.9952	0.0021	0.9954	0.0012	95/95/95	0.99538	0.00129	0.99276-0.99800	0.99185-0.99891
98	32	159724	0.9946	0.0021	0.9947	0.0021	0.9952	0.0013	95/95/95	0.99521	0.00135	0.99244-0.99797	0.99148-0.99893
100	30	149474	0.9941	0.0022	0.9942	0.0022	0.9947	0.0013	95/95/95	0.99475	0.00139	0.99189-0.99761	0.99089-0.99861
102	28	139616	0.9942	0.0024	0.9944	0.0023	0.9943	0.0014	95/95/95	0.99434	0.00147	0.99131-0.99738	0.99023-0.99846
104	26	129573	0.9940	0.0025	0.9942	0.0025	0.9943	0.0015	95/95/95	0.99429	0.00159	0.99100-0.99758	0.98983-0.99876
106	24	119585	0.9942	0.0027	0.9944	0.0027	0.9944	0.0016	95/95/95	0.99442	0.00174	0.99080-0.99803	0.98949-0.99934
108	22	109548	0.9958	0.0027	0.9960	0.0027	0.9947	0.0018	95/95/95	0.99459	0.00189	0.99063-0.99854	0.98918-0.99999
110	20	99537	0.9968	0.0028	0.9970	0.0028	0.9956	0.0018	95/95/95	0.99556	0.00191	0.99154-0.99958	0.99003-1.00109
112	18	89497	0.9959	0.0031	0.9961	0.0030	0.9950	0.0019	95/95/95	0.99496	0.00207	0.99055-0.99936	0.98887-1.00105
114	16	79808	0.9942	0.0031	0.9944	0.0031	0.9940	0.0020	95/95/95	0.99415	0.00213	0.98954-0.99876	0.98772-1.00058
116	14	69916	0.9974	0.0026	0.9975	0.0025	0.9948	0.0021	95/95/95	0.99602	0.00230	0.99097-1.00107	0.98889-1.00315
118	12	59792	0.9968	0.0031	0.9970	0.0029	0.9937	0.0022	95/95/95	0.99489	0.00253	0.98916-1.00061	0.98667-1.00311
120	10	49906	0.9984	0.0033	0.9984	0.0032	0.9939	0.0027	95/95/95	0.99535	0.00317	0.98785-1.00285	0.98425-1.00645
122	8	40048	0.9995	0.0039	0.9996	0.0038	0.9961	0.0025	95/95/95	0.99611	0.00293	0.98858-1.00364	0.98430-1.00793
124	6	29888	0.9983	0.0050	0.9987	0.0050	0.9940	0.0028	95/95/95	0.99372	0.00403	0.98089-1.00655	0.97017-1.01727
126	4	20008	1.0028	0.0059	1.0031	0.0061	0.9973	0.0029	95/95/95	0.99704	0.00581	0.92325-1.07083	0.62746-1.36662
127	3	15146	0.9972	0.0025	0.9974	0.0029	0.9950	0.0025					
128	2	9981	0.9984	0.0038	0.9992	0.0040	0.9938	0.0039					

N31

the minimum estimated standard deviation for the col/abs/tl keff estimator occurs with 6 inactive cycles and 124 active cycles.

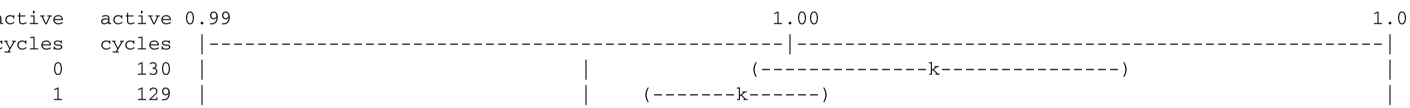
N32

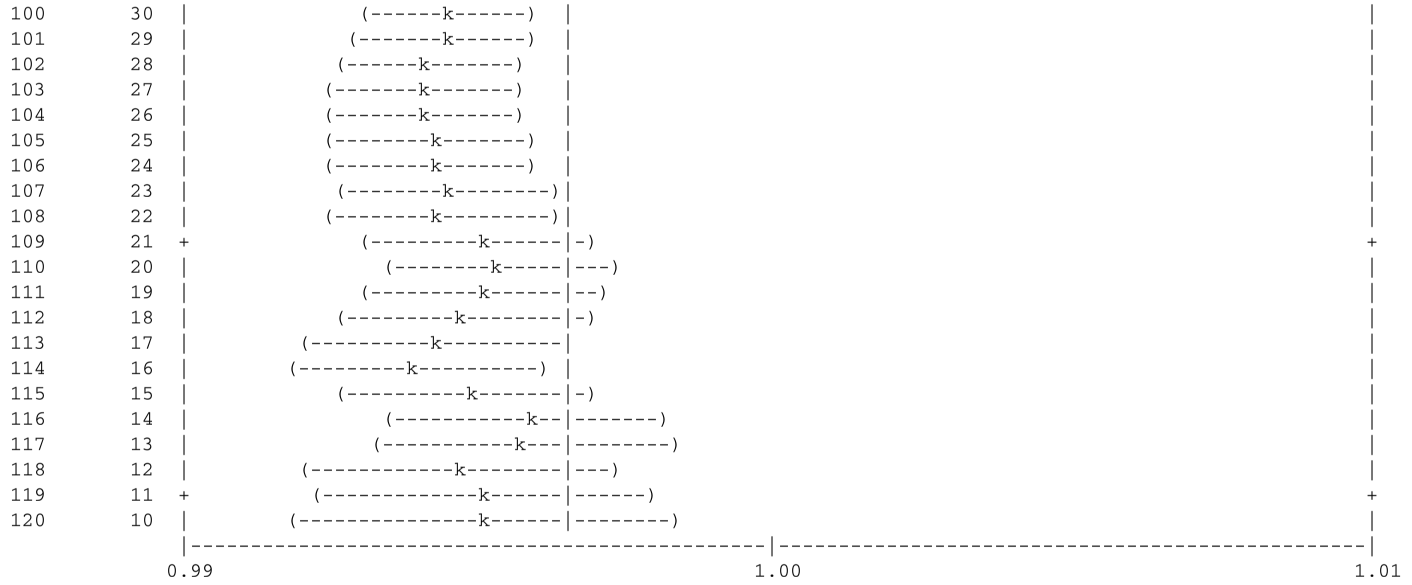
the first active half of the problem skips 30 cycles and uses 50 active cycles; the second half skips 80 and uses 50 cycles.
the col/abs/trk-len keff, one standard deviation, and 68, 95, and 99 percent intervals for each active half of the problem are:

problem	keff	standard deviation	68% confidence	95% confidence	99% confidence
first half	0.99764	0.00123	0.99641 to 0.99888	0.99517 to 1.00012	0.99434 to 1.00095
second half	0.99566	0.00105	0.99461 to 0.99672	0.99356 to 0.99777	0.99285 to 0.99848
final result	0.99667	0.00079	0.99588 to 0.99747	0.99509 to 0.99825	0.99458 to 0.99877

the first and second half values of k(collision/absorption/track length) appear to be the same at the 95 percent confidence level.
1plot of the estimated col/abs/track-length keff one standard deviation interval by active cycle number (| = final keff = 0.99667)

N33





N34 1tally 1 nps = 649608

tally type 1 number of particles crossing a surface.

tally for neutrons

number of histories used for normalizing tallies = 500000.00

surface 1

energy		
1.0000E-07	0.00000E+00	0.0000
4.0000E-07	0.00000E+00	0.0000
1.0000E-06	0.00000E+00	0.0000
3.0000E-06	0.00000E+00	0.0000
1.0000E-05	0.00000E+00	0.0000
3.0000E-05	0.00000E+00	0.0000
1.0000E-04	0.00000E+00	0.0000
5.5000E-04	0.00000E+00	0.0000
3.0000E-03	2.48647E-05	0.2106
1.7000E-02	5.53524E-04	0.0438
1.0000E-01	1.38510E-02	0.0087
4.0000E-01	9.59898E-02	0.0033
9.0000E-01	1.39485E-01	0.0029
1.4000E+00	8.81174E-02	0.0040
3.0000E+00	1.45233E-01	0.0031
2.0000E+01	9.10111E-02	0.0041
total	5.74266E-01	0.0008

```
================================================================================================================================

          results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally   1

tfc bin     --mean--      ---------relative error---------      ----variance of the variance----      --figure of merit--     -pdf-
behavior    behavior      value   decrease   decrease rate      value   decrease   decrease rate       value     behavior     slope

desired      random       <0.10      yes      1/sqrt(nps)       <0.10      yes        1/nps           constant    random      >3.00
observed     random        0.00      yes          yes            0.00      yes         yes            constant    random      10.00
passed?        yes          yes      yes          yes              yes      yes         yes              yes         yes         yes

================================================================================================================================


this tally meets the statistical criteria used to form confidence intervals: check the tally fluctuation chart to verify.
the results in other bins associated with this tally may not meet these statistical criteria.

----- estimated confidence intervals:  -----

estimated asymmetric confidence interval(1,2,3 sigma): 5.7381E-01 to 5.7472E-01; 5.7335E-01 to 5.7518E-01; 5.7289E-01 to 5.7564E-01
estimated  symmetric confidence interval(1,2,3 sigma): 5.7381E-01 to 5.7472E-01; 5.7335E-01 to 5.7518E-01; 5.7289E-01 to 5.7564E-01

1analysis of the results in the tally fluctuation chart bin (tfc) for tally   1 with nps =    649608    print table 160


normed average tally per history  = 5.74266E-01          unnormed average tally per history  = 5.74266E-01
estimated tally relative error    = 0.0008               estimated variance of the variance  = 0.0000
relative error from zero tallies  = 0.0006               relative error from nonzero scores  = 0.0005

number of nonzero history tallies =      427581          efficiency for the nonzero tallies  = 0.8552
history number of largest  tally  =      312325          largest  unnormalized history tally = 1.74173E+00
(largest  tally)/(average tally)  = 3.03297E+00          (largest  tally)/(avg nonzero tally)= 2.59368E+00

(confidence interval shift)/mean  = 0.0000               shifted confidence interval center  = 5.74266E-01


if the largest  history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:
nps =    499004 for this table because  30 keff cycles and    150604 histories were skipped before tally accumulation.

     estimated quantities          value at nps          value at nps+1          value(nps+1)/value(nps)-1.

     mean                           5.74266E-01           5.74268E-01                  0.000004
     relative error                 7.96385E-04           7.93880E-04                 -0.003145
     variance of the variance       2.28492E-06           2.30641E-06                  0.009406
     shifted center                 5.74266E-01           5.74266E-01                  0.000000
     figure of merit                1.93076E+05           1.94296E+05                  0.006320

the estimated slope of the 198 largest  tallies starting at  1.20362E+00 appears to be decreasing at least exponentially.
```

```
 the empirical history score probability density function appears to be increasing at the largest  history scores:
 please examine. see print table 161.
 the large score tail of the empirical history score probability density function appears to have no unsampled regions.

 fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (6.123E+04)*( 1.776E+00)**2 = (6.123E+04)*(3.153E+00) = 1.931E+05
SKIP 52 LINES OF OUTPUT
N35 1tally   6        nps =   649608
          tally type 6    track length estimate of heating.           units   mev/gram
          tally for  neutrons
 number of histories used for normalizing tallies =   500000.00

          masses
                  cell:       1
                       5.24200E+04

 cell  1
      energy
    1.0000E-07   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000
    3.0000E-05   3.59909E-09 1.0000
    1.0000E-04   1.95884E-08 0.4192
    5.5000E-04   4.66725E-08 0.3175
    3.0000E-03   3.15463E-07 0.1131
    1.7000E-02   4.81914E-06 0.0285
    1.0000E-01   6.08661E-05 0.0071
    4.0000E-01   2.55291E-04 0.0030
    9.0000E-01   2.73566E-04 0.0026
    1.4000E+00   1.71918E-04 0.0033
    3.0000E+00   3.00000E-04 0.0025
    2.0000E+01   1.66525E-04 0.0034
      total      1.23337E-03 0.0008

 ============================================================================================================================================

          results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally   6

 tfc bin     --mean--      ---------relative error---------      ----variance of the variance----      --figure of merit--      -pdf-
 behavior    behavior      value    decrease    decrease rate      value    decrease    decrease rate       value     behavior     slope

 desired      random       <0.10      yes       1/sqrt(nps)       <0.10      yes         1/nps           constant    random      >3.00
 observed    decrease       0.00      yes           yes            0.00      yes          yes            constant    random      10.00
 passed?        no           yes      yes           yes             yes      yes          yes               yes        yes         yes

 ============================================================================================================================================
```

```
 warning.  the tally in the tally fluctuation chart bin did not pass  1 of the 10 statistical checks.

1analysis of the results in the tally fluctuation chart bin (tfc) for tally   6 with nps =    649608    print table 160


 normed average tally per history  = 1.23337E-03          unnormed average tally per history  = 6.46533E+01
 estimated tally relative error    = 0.0008              estimated variance of the variance  = 0.0000
 relative error from zero tallies  = 0.0001              relative error from nonzero scores  = 0.0008

 number of nonzero history tallies =      499004         efficiency for the nonzero tallies  = 0.9980
 history number of largest  tally  =      615693         largest  unnormalized history tally = 4.46954E+02
 (largest  tally)/(average tally)  = 6.91309E+00         (largest  tally)/(avg nonzero tally)= 6.89932E+00

 (confidence interval shift)/mean  = 0.0000              shifted confidence interval center  = 1.23337E-03


 if the largest  history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:
 nps =    499004 for this table because  30 keff cycles and    150604 histories were skipped before tally accumulation.

      estimated quantities           value at nps           value at nps+1          value(nps+1)/value(nps)-1.

      mean                            1.23337E-03             1.23339E-03                  0.000012
      relative error                  8.39358E-04             8.37048E-04                 -0.002751
      variance of the variance        6.73113E-06             6.80743E-06                  0.011335
      shifted center                  1.23337E-03             1.23337E-03                  0.000000
      figure of merit                 1.73812E+05             1.74772E+05                  0.005526

 the estimated slope of the 200 largest  tallies starting at  2.66524E+02 appears to be decreasing at least exponentially.
 the large score tail of the empirical history score probability density function appears to have no unsampled regions.

 fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (6.123E+04)*( 1.685E+00)**2 = (6.123E+04)*(2.839E+00) = 1.738E+05
SKIP TABLES 161 AND 162 OF OUTPUT
N36 1tally   7        nps =   649608
           tally type 7    track length estimate of fission heating.    units   mev/gram
           tally for  neutrons
 number of histories used for normalizing tallies =   500000.00

           masses
                   cell:       1
                        5.24200E+04

 cell  1
      energy
    1.0000E-07   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000
    3.0000E-05   3.84638E-09 1.0000
```

```
   1.0000E-04   2.09336E-08 0.4192
   5.5000E-04   4.98747E-08 0.3175
   3.0000E-03   3.37077E-07 0.1131
   1.7000E-02   5.15097E-06 0.0285
   1.0000E-01   6.49910E-05 0.0071
   4.0000E-01   2.72755E-04 0.0030
   9.0000E-01   2.92399E-04 0.0026
   1.4000E+00   1.84497E-04 0.0033
   3.0000E+00   3.22804E-04 0.0025
   2.0000E+01   1.80871E-04 0.0034
     total      1.32388E-03 0.0008
```

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==========================================================================================================================================

          results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally   7

tfc bin     --mean--      ---------relative error---------      ----variance of the variance----      --figure of merit--     -pdf-
behavior    behavior      value   decrease   decrease rate      value   decrease   decrease rate       value     behavior     slope

desired      random       <0.10      yes      1/sqrt(nps)       <0.10      yes        1/nps          constant    random      >3.00
observed    decrease       0.00      yes          yes            0.00      yes         yes           constant    random      10.00
passed?        no           yes      yes          yes             yes      yes         yes              yes        yes         yes

==========================================================================================================================================
```

```
 warning.  the tally in the tally fluctuation chart bin did not pass  1 of the 10 statistical checks.

1analysis of the results in the tally fluctuation chart bin (tfc) for tally   7 with nps =    649608    print table 160


 normed average tally per history  = 1.32388E-03          unnormed average tally per history  = 6.93978E+01
 estimated tally relative error    = 0.0008              estimated variance of the variance  = 0.0000
 relative error from zero tallies  = 0.0001              relative error from nonzero scores  = 0.0008

 number of nonzero history tallies =      499004         efficiency for the nonzero tallies  = 0.9980
 history number of largest  tally  =      615693         largest  unnormalized history tally = 4.77488E+02
 (largest  tally)/(average tally)  = 6.88045E+00         (largest  tally)/(avg nonzero tally)= 6.86674E+00

 (confidence interval shift)/mean  = 0.0000              shifted confidence interval center  = 1.32388E-03


 if the largest  history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:
 nps =    499004 for this table because  30 keff cycles and    150604 histories were skipped before tally accumulation.

      estimated quantities           value at nps           value at nps+1           value(nps+1)/value(nps)-1.

      mean                            1.32388E-03             1.32390E-03                    0.000012
```

```
      relative error                 8.38106E-04             8.35792E-04                   -0.002761
      variance of the variance       6.69396E-06             6.76945E-06                    0.011277
      shifted center                 1.32388E-03             1.32388E-03                    0.000000
      figure of merit                1.74331E+05             1.75298E+05                    0.005544

 the estimated slope of the 200 largest  tallies starting at  2.84998E+02 appears to be decreasing at least exponentially.
 the large score tail of the empirical history score probability density function appears to have no unsampled regions.

 fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (6.123E+04)*( 1.687E+00)**2 = (6.123E+04)*(2.847E+00) = 1.743E+05
SKIP TABLES 161 AND 162 OF OUTPUT
N37 1tally  14        nps =   649608
+                                 total fission neutrons (track length keff), total loss to (n,xn)
                                  total neutron captures, total fission and neutron heating (mev/gram)
           tally type 4    track length estimate of particle flux.
           tally for  neutrons
 number of histories used for normalizing tallies =   500000.00
           multiplier bin  1:   1.34221E+02   10         -6     -7
           multiplier bin  2:   1.34221E+02   10         16    :       17
           multiplier bin  3:   1.34221E+02   10         -2
           multiplier bin  4:   1.34221E+02   10         -6
           multiplier bin  5:   2.56050E-03   10          1     -4

           volumes
                   cell:       1
                        2.79722E+03

 cell  1
     mult bin:            1                   2                   3                   4                   5
      energy
    1.0000E-07   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    3.0000E-05   2.71295E-06 1.0000   0.00000E+00 0.0000   1.80413E-06 1.0000   1.11470E-06 1.0000   3.59909E-09 1.0000
    1.0000E-04   1.47650E-05 0.4192   0.00000E+00 0.0000   3.84483E-06 0.4508   6.06666E-06 0.4192   1.95884E-08 0.4192
    5.5000E-04   3.51777E-05 0.3175   0.00000E+00 0.0000   5.23148E-06 0.3224   1.44540E-05 0.3175   4.66726E-08 0.3175
    3.0000E-03   2.37749E-04 0.1131   0.00000E+00 0.0000   4.73799E-05 0.1200   9.76867E-05 0.1131   3.15464E-07 0.1131
    1.7000E-02   3.63095E-03 0.0285   0.00000E+00 0.0000   5.49389E-04 0.0286   1.49278E-03 0.0285   4.81915E-06 0.0285
    1.0000E-01   4.56973E-02 0.0071   0.00000E+00 0.0000   5.91256E-03 0.0072   1.88347E-02 0.0071   6.08661E-05 0.0071
    4.0000E-01   1.94026E-01 0.0030   0.00000E+00 0.0000   1.68214E-02 0.0031   7.90463E-02 0.0030   2.55292E-04 0.0030
    9.0000E-01   2.11210E-01 0.0026   0.00000E+00 0.0000   1.14611E-02 0.0026   8.47444E-02 0.0026   2.73567E-04 0.0026
    1.4000E+00   1.36136E-01 0.0033   0.00000E+00 0.0000   4.88532E-03 0.0034   5.34726E-02 0.0033   1.71918E-04 0.0033
    3.0000E+00   2.48420E-01 0.0025   0.00000E+00 0.0000   4.50441E-03 0.0026   9.35550E-02 0.0025   3.00000E-04 0.0025
    2.0000E+01   1.57333E-01 0.0035   2.65404E-03 0.0102   5.58351E-04 0.0040   5.24197E-02 0.0034   1.66525E-04 0.0034
      total      9.96743E-01 0.0008   2.65404E-03 0.0102   4.47508E-02 0.0015   3.83685E-01 0.0008   1.23337E-03 0.0008


 ================================================================================================================================
```

results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally 14

tfc bin behavior	--mean-- behavior	---------relative error--------- value	decrease	decrease rate	----variance of the variance---- value	decrease	decrease rate	--figure of merit-- value	behavior	-pdf- slope
desired	random	<0.10	yes	1/sqrt(nps)	<0.10	yes	1/nps	constant	random	>3.00
observed	decrease	0.00	yes	yes	0.00	yes	yes	constant	random	10.00
passed?	no	yes	yes	yes	yes	yes	yes	yes	yes	yes

warning. the tally in the tally fluctuation chart bin did not pass 1 of the 10 statistical checks.

1analysis of the results in the tally fluctuation chart bin (tfc) for tally 14 with nps = 649608 print table 160

normed average tally per history	= 9.96743E-01	unnormed average tally per history	= 2.78811E+03
estimated tally relative error	= 0.0008	estimated variance of the variance	= 0.0000
relative error from zero tallies	= 0.0001	relative error from nonzero scores	= 0.0008
number of nonzero history tallies	= 499004	efficiency for the nonzero tallies	= 0.9980
history number of largest tally	= 615693	largest unnormalized history tally	= 1.80481E+04
(largest tally)/(average tally)	= 6.47324E+00	(largest tally)/(avg nonzero tally)	= 6.46034E+00
(confidence interval shift)/mean	= 0.0000	shifted confidence interval center	= 9.96743E-01

if the largest history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:
nps = 499004 for this table because 30 keff cycles and 150604 histories were skipped before tally accumulation.

estimated quantities	value at nps	value at nps+1	value(nps+1)/value(nps)-1.
mean	9.96743E-01	9.96754E-01	0.000011
relative error	8.31334E-04	8.28991E-04	-0.002818
variance of the variance	6.62725E-06	6.69435E-06	0.010125
shifted center	9.96743E-01	9.96744E-01	0.000000
figure of merit	1.77183E+05	1.78186E+05	0.005660

the estimated slope of the 200 largest tallies starting at 1.13378E+04 appears to be decreasing at least exponentially.
the large score tail of the empirical history score probability density function appears to have no unsampled regions.

fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (6.123E+04)*(1.701E+00)**2 = (6.123E+04)*(2.894E+00) = 1.772E+05
SKIP TABLES 161 AND 162 OF OUTPUT
N38 1tally 34 nps = 649608
tally type 4 track length estimate of particle flux.
tally for neutrons
number of histories used for normalizing tallies = 500000.00

```
          multiplier bin  1:  -1.00000E+00   10         -6     -7
          multiplier bin  2:  -1.00000E+00   10         16     :       17
          multiplier bin  3:  -1.00000E+00   10         -2
          multiplier bin  4:  -1.00000E+00   10         -6
          multiplier bin  5:  -1.90767E-05   10          1     -4

          volumes
                 cell:       1
                       1.00000E+00

 energy bin:   0.          to  2.00000E+01
         cell:           1
    mult bin
         1       9.96744E-01 0.0008
         2       2.65404E-03 0.0102
         3       4.47508E-02 0.0015
         4       3.83685E-01 0.0008
         5       1.23337E-03 0.0008

 ============================================================================================================================

          results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally  34

 tfc bin     --mean--      ---------relative error---------      ----variance of the variance----      --figure of merit--     -pdf-
 behavior    behavior      value   decrease   decrease rate      value   decrease   decrease rate       value     behavior     slope

 desired      random       <0.10      yes      1/sqrt(nps)       <0.10      yes        1/nps           constant    random      >3.00
 observed    decrease       0.00      yes          yes             0.00      yes         yes            constant    random      10.00
 passed?        no           yes      yes          yes              yes      yes         yes               yes        yes         yes

 ============================================================================================================================


 warning.  the tally in the tally fluctuation chart bin did not pass  1 of the 10 statistical checks.

1analysis of the results in the tally fluctuation chart bin (tfc) for tally  34 with nps =    649608    print table 160


 normed average tally per history  = 9.96744E-01          unnormed average tally per history  = 9.96744E-01
 estimated tally relative error    = 0.0008              estimated variance of the variance  = 0.0000
 relative error from zero tallies  = 0.0001              relative error from nonzero scores  = 0.0008

 number of nonzero history tallies =      499004         efficiency for the nonzero tallies  = 0.9980
 history number of largest  tally  =      615693         largest  unnormalized history tally = 6.45216E+00
 (largest  tally)/(average tally)  = 6.47324E+00         (largest  tally)/(avg nonzero tally)= 6.46034E+00

 (confidence interval shift)/mean  = 0.0000              shifted confidence interval center  = 9.96744E-01
```

```
 if the largest  history score sampled so far were to occur on the next history, the tfc bin quantities would change as follows:
 nps =    499004 for this table because  30 keff cycles and    150604 histories were skipped before tally accumulation.

      estimated quantities           value at nps           value at nps+1          value(nps+1)/value(nps)-1.

      mean                            9.96744E-01            9.96755E-01                  0.000011
      relative error                  8.31334E-04            8.28991E-04                 -0.002818
      variance of the variance        6.62725E-06            6.69435E-06                  0.010125
      shifted center                  9.96744E-01            9.96744E-01                  0.000000
      figure of merit                 1.77183E+05            1.78186E+05                  0.005660

 the estimated slope of the 200 largest  tallies starting at  4.05323E+00 appears to be decreasing at least exponentially.
 the large score tail of the empirical history score probability density function appears to have no unsampled regions.

 fom = (histories/minute)*(f(x) signal-to-noise ratio)**2 = (6.123E+04)*( 1.701E+00)**2 = (6.123E+04)*(2.894E+00) = 1.772E+05
SKIP TABLES 161 AND 162 OF OUTPUT
 ================================================================================================================================
 =     N39                                                                                                                      =
 =     the following output gives the predicted change in a tally for perturbation     1.                                      =
 =     the differential operator method was used to obtain these results (1st and/or 2nd order).                                =
 =                                                                                                                              =
 ================================================================================================================================
```

N40

```
1tally   1        nps =   649608
           tally type 1    number of particles crossing a surface.
           tally for  neutrons
 number of histories used for normalizing tallies =   500000.00

 surface  1
      energy
    1.0000E-07   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000
    3.0000E-05   0.00000E+00 0.0000
    1.0000E-04   0.00000E+00 0.0000
    5.5000E-04   0.00000E+00 0.0000
    3.0000E-03   2.42629E-05 0.2131
    1.7000E-02   5.31073E-04 0.0440
    1.0000E-01   1.35404E-02 0.0087
    4.0000E-01   9.36279E-02 0.0032
    9.0000E-01   1.34865E-01 0.0028
    1.4000E+00   8.42582E-02 0.0040
    3.0000E+00   1.37559E-01 0.0031
    2.0000E+01   8.63042E-02 0.0041
      total      5.50709E-01 0.0008
```

```
SKIP 116 LINES OF OUTPUT
1tally   6        nps =   649608
           tally type 6    track length estimate of heating.           units   mev/gram
           tally for  neutrons
 number of histories used for normalizing tallies =   500000.00

           masses
                   cell:       1
                        5.24200E+04

 cell  1
      energy
    1.0000E-07   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000
    3.0000E-05   3.50457E-09 1.0000
    1.0000E-04   2.02661E-08 0.4126
    5.5000E-04   4.67126E-08 0.3116
    3.0000E-03   3.13515E-07 0.1102
    1.7000E-02   4.81153E-06 0.0279
    1.0000E-01   6.15670E-05 0.0070
    4.0000E-01   2.57605E-04 0.0029
    9.0000E-01   2.71966E-04 0.0025
    1.4000E+00   1.68439E-04 0.0033
    3.0000E+00   2.91198E-04 0.0024
    2.0000E+01   1.61421E-04 0.0033
      total      1.21739E-03 0.0008
SKIP 155 LINES OF OUTPUT
1tally   7        nps =   649608
           tally type 7    track length estimate of fission heating.    units   mev/gram
           tally for  neutrons
 number of histories used for normalizing tallies =   500000.00

           masses
                   cell:       1
                        5.24200E+04

 cell  1
      energy
    1.0000E-07   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000
    3.0000E-05   3.74536E-09 1.0000
    1.0000E-04   2.16578E-08 0.4126
    5.5000E-04   4.99175E-08 0.3116
```

```
    3.0000E-03   3.34987E-07 0.1102
    1.7000E-02   5.14276E-06 0.0279
    1.0000E-01   6.57394E-05 0.0070
    4.0000E-01   2.75227E-04 0.0029
    9.0000E-01   2.90689E-04 0.0025
    1.4000E+00   1.80762E-04 0.0033
    3.0000E+00   3.13332E-04 0.0024
    2.0000E+01   1.75328E-04 0.0033
      total      1.30663E-03 0.0008
SKIP 158 LINES OF OUTPUT
N41 1tally  14        nps =   649608
+                               total fission neutrons (track length keff), total loss to (n,xn)
                                total neutron captures, total fission and neutron heating (mev/gram)
          tally type 4    track length estimate of particle flux.
          tally for  neutrons
 number of histories used for normalizing tallies =   500000.00
          multiplier bin  1:   1.34221E+02   10          -6     -7
          multiplier bin  2:   1.34221E+02   10          16     :       17
          multiplier bin  3:   1.34221E+02   10          -2
          multiplier bin  4:   1.34221E+02   10          -6
          multiplier bin  5:   2.56050E-03   10           1     -4

          volumes
                  cell:       1
                       2.79722E+03

 cell  1
     mult bin:            1                   2                   3                   4                   5
      energy
    1.0000E-07   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    4.0000E-07   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    1.0000E-06   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    3.0000E-06   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    1.0000E-05   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000   0.00000E+00 0.0000
    3.0000E-05   2.64171E-06 1.0000   0.00000E+00 0.0000   1.75675E-06 1.0000   1.08543E-06 1.0000   3.50458E-09 1.0000
    1.0000E-04   1.52758E-05 0.4126   0.00000E+00 0.0000   3.97466E-06 0.4460   6.27654E-06 0.4126   2.02661E-08 0.4126
    5.5000E-04   3.52078E-05 0.3116   0.00000E+00 0.0000   5.24051E-06 0.3158   1.44664E-05 0.3116   4.67126E-08 0.3116
    3.0000E-03   2.36275E-04 0.1102   0.00000E+00 0.0000   4.67114E-05 0.1152   9.70811E-05 0.1102   3.13516E-07 0.1102
    1.7000E-02   3.62515E-03 0.0279   0.00000E+00 0.0000   5.48441E-04 0.0280   1.49040E-03 0.0279   4.81154E-06 0.0279
    1.0000E-01   4.62236E-02 0.0070   0.00000E+00 0.0000   5.97929E-03 0.0070   1.90516E-02 0.0070   6.15670E-05 0.0070
    4.0000E-01   1.95781E-01 0.0029   0.00000E+00 0.0000   1.69839E-02 0.0030   7.97627E-02 0.0029   2.57605E-04 0.0029
    9.0000E-01   2.09969E-01 0.0025   0.00000E+00 0.0000   1.14010E-02 0.0025   8.42488E-02 0.0025   2.71967E-04 0.0025
    1.4000E+00   1.33378E-01 0.0033   0.00000E+00 0.0000   4.78765E-03 0.0033   5.23902E-02 0.0033   1.68439E-04 0.0033
    3.0000E+00   2.41121E-01 0.0024   0.00000E+00 0.0000   4.37526E-03 0.0025   9.08100E-02 0.0024   2.91198E-04 0.0024
    2.0000E+01   1.52513E-01 0.0034   2.57364E-03 0.0100   5.41141E-04 0.0039   5.08131E-02 0.0033   1.61421E-04 0.0033
      total      9.82900E-01 0.0008   2.57364E-03 0.0100   4.46744E-02 0.0015   3.78686E-01 0.0008   1.21739E-03 0.0008
SKIP 158 LINES OF OUTPUT
N42 1tally  34        nps =   649608
```

```
          tally type 4    track length estimate of particle flux.
          tally for  neutrons
 number of histories used for normalizing tallies =   500000.00
          multiplier bin  1:  -1.00000E+00   10         -6     -7
          multiplier bin  2:  -1.00000E+00   10         16    :       17
          multiplier bin  3:  -1.00000E+00   10         -2
          multiplier bin  4:  -1.00000E+00   10         -6
          multiplier bin  5:  -1.90767E-05   10          1     -4

          volumes
                  cell:       1
                       1.00000E+00

 energy bin:   0.          to  2.00000E+01
         cell:           1
    mult bin
         1       1.04902E+00 0.0008
         2       2.74725E-03 0.0100
         3       4.76767E-02 0.0015
         4       4.04156E-01 0.0008
         5       1.29927E-03 0.0008
SKIP 155 LINES OF OUTPUT
1status of the statistical checks used to form confidence intervals for the mean for each tally bin
```

N43

```
 tally   result of statistical checks for the tfc bin (the first check not passed is listed) and error magnitude check for all bins

     1   passed the 10 statistical checks for the tally fluctuation chart bin result
         missed all bin error check:    17 tally bins had     8 bins with zeros and     1 bins with relative errors exceeding 0.10

     6   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         missed all bin error check:    17 tally bins had     5 bins with zeros and     4 bins with relative errors exceeding 0.10

     7   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         missed all bin error check:    17 tally bins had     5 bins with zeros and     4 bins with relative errors exceeding 0.10

    14   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         missed all bin error check:    85 tally bins had    35 bins with zeros and    16 bins with relative errors exceeding 0.10

    34   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         passed all bin error check:     5 tally bins all have relative errors less than 0.10 with no zero bins

 for perturbation     1

     1   passed the 10 statistical checks for the tally fluctuation chart bin result
         missed all bin error check:    17 tally bins had     8 bins with zeros and     1 bins with relative errors exceeding 0.10

     6   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         missed all bin error check:    17 tally bins had     5 bins with zeros and     4 bins with relative errors exceeding 0.10
```

```
     7   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         missed all bin error check:    17 tally bins had     5 bins with zeros and     4 bins with relative errors exceeding 0.10

    14   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         missed all bin error check:    85 tally bins had    35 bins with zeros and    16 bins with relative errors exceeding 0.10

    34   missed  1 of 10 tfc bin checks: the estimated mean has a trend during the last half of the problem
         passed all bin error check:     5 tally bins all have relative errors less than 0.10 with no zero bins


 the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

 the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

 warning.     8 of the  10 tally fluctuation chart bins did not pass all 10 statistical checks.
 warning.     8 of the  10 tallies had bins with relative errors greater than recommended.
1tally fluctuation charts

                    tally    1                                  tally    6                                  tally    7
      nps      mean      error   vov  slope    fom      mean      error   vov  slope    fom      mean      error   vov  slope    fom
    64000   0.0000E+00 0.0000 0.0000   0.0 0.0E+00   0.0000E+00 0.0000 0.0000   0.0 0.0E+00   0.0000E+00 0.0000 0.0000   0.0 0.0E+00
   128000   0.0000E+00 0.0000 0.0000   0.0 0.0E+00   0.0000E+00 0.0000 0.0000   0.0 0.0E+00   0.0000E+00 0.0000 0.0000   0.0 0.0E+00
   192000   5.7433E-01 0.0027 0.0000  10.0  195508   1.2361E-03 0.0029 0.0001  10.0  175340   1.3268E-03 0.0029 0.0001  10.0  175868
   256000   5.7424E-01 0.0017 0.0000  10.0  192540   1.2331E-03 0.0018 0.0000  10.0  173935   1.3236E-03 0.0018 0.0000  10.0  174454
   320000   5.7408E-01 0.0014 0.0000  10.0  193045   1.2344E-03 0.0014 0.0000  10.0  174629   1.3250E-03 0.0014 0.0000  10.0  175148
   384000   5.7441E-01 0.0012 0.0000  10.0  193385   1.2346E-03 0.0012 0.0000  10.0  174011   1.3252E-03 0.0012 0.0000  10.0  174521
   448000   5.7421E-01 0.0010 0.0000  10.0  192774   1.2349E-03 0.0011 0.0000  10.0  173839   1.3255E-03 0.0011 0.0000  10.0  174351
   512000   5.7414E-01 0.0009 0.0000  10.0  193168   1.2347E-03 0.0010 0.0000  10.0  174212   1.3253E-03 0.0010 0.0000  10.0  174731
   576000   5.7446E-01 0.0009 0.0000  10.0  193686   1.2338E-03 0.0009 0.0000  10.0  174042   1.3244E-03 0.0009 0.0000  10.0  174561
   640000   5.7432E-01 0.0008 0.0000  10.0  193139   1.2335E-03 0.0008 0.0000  10.0  173792   1.3240E-03 0.0008 0.0000  10.0  174312
   649608   5.7427E-01 0.0008 0.0000  10.0  193076   1.2334E-03 0.0008 0.0000  10.0  173812   1.3239E-03 0.0008 0.0000  10.0  174331


                    tally   14                                 tally   34
      nps      mean      error   vov  slope    fom      mean      error   vov  slope    fom
    64000   0.0000E+00 0.0000 0.0000   0.0 0.0E+00   0.0000E+00 0.0000 0.0000   0.0 0.0E+00
   128000   0.0000E+00 0.0000 0.0000   0.0 0.0E+00   0.0000E+00 0.0000 0.0000   0.0 0.0E+00
   192000   9.9901E-01 0.0029 0.0001  10.0  178833   9.9902E-01 0.0029 0.0001  10.0  178833
   256000   9.9652E-01 0.0018 0.0000  10.0  177393   9.9652E-01 0.0018 0.0000  10.0  177393
   320000   9.9759E-01 0.0014 0.0000  10.0  177998   9.9759E-01 0.0014 0.0000  10.0  177998
   384000   9.9771E-01 0.0012 0.0000  10.0  177267   9.9771E-01 0.0012 0.0000  10.0  177267
   448000   9.9795E-01 0.0011 0.0000  10.0  177119   9.9795E-01 0.0011 0.0000  10.0  177119
   512000   9.9769E-01 0.0010 0.0000  10.0  177582   9.9769E-01 0.0010 0.0000  10.0  177582
   576000   9.9706E-01 0.0009 0.0000  10.0  177407   9.9706E-01 0.0009 0.0000  10.0  177407
   640000   9.9682E-01 0.0008 0.0000  10.0  177182   9.9682E-01 0.0008 0.0000  10.0  177182
   649608   9.9674E-01 0.0008 0.0000  10.0  177183   9.9674E-01 0.0008 0.0000  10.0  177183
1tally fluctuation charts - for perturbation     1
```

	tally 1					tally 6					tally 7				
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom	mean	error	vov	slope	fom
64000	0.0000E+00	0.0000	0.0000	0.0	0.0E+00	0.0000E+00	0.0000	0.0000	0.0	0.0E+00	0.0000E+00	0.0000	0.0000	0.0	0.0E+00
128000	0.0000E+00	0.0000	0.0000	0.0	0.0E+00	0.0000E+00	0.0000	0.0000	0.0	0.0E+00	0.0000E+00	0.0000	0.0000	0.0	0.0E+00
192000	5.5076E-01	0.0027	0.0000	1.9	207341	1.2199E-03	0.0028	0.0001	10.0	184698	1.3093E-03	0.0028	0.0001	10.0	185370
256000	5.5070E-01	0.0017	0.0000	1.8	204072	1.2173E-03	0.0018	0.0000	10.0	182658	1.3066E-03	0.0018	0.0000	10.0	183321
320000	5.5049E-01	0.0013	0.0000	1.8	204527	1.2184E-03	0.0014	0.0000	10.0	183658	1.3078E-03	0.0014	0.0000	10.0	184323
384000	5.5085E-01	0.0011	0.0000	10.0	204839	1.2184E-03	0.0012	0.0000	10.0	183083	1.3077E-03	0.0012	0.0000	10.0	183741
448000	5.5063E-01	0.0010	0.0000	10.0	204202	1.2188E-03	0.0011	0.0000	10.0	182890	1.3081E-03	0.0011	0.0000	10.0	183547
512000	5.5054E-01	0.0009	0.0000	10.0	204621	1.2186E-03	0.0010	0.0000	10.0	183337	1.3079E-03	0.0010	0.0000	10.0	184003
576000	5.5086E-01	0.0008	0.0000	10.0	205127	1.2177E-03	0.0009	0.0000	10.0	183164	1.3070E-03	0.0009	0.0000	10.0	183828
640000	5.5075E-01	0.0008	0.0000	10.0	204549	1.2175E-03	0.0008	0.0000	10.0	182817	1.3067E-03	0.0008	0.0000	10.0	183483
649608	5.5071E-01	0.0008	0.0000	10.0	204486	1.2174E-03	0.0008	0.0000	10.0	182830	1.3066E-03	0.0008	0.0000	10.0	183495

	tally 14					tally 34				
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom
64000	0.0000E+00	0.0000	0.0000	0.0	0.0E+00	0.0000E+00	0.0000	0.0000	0.0	0.0E+00
128000	0.0000E+00	0.0000	0.0000	0.0	0.0E+00	0.0000E+00	0.0000	0.0000	0.0	0.0E+00
192000	9.8499E-01	0.0028	0.0001	10.0	189928	1.0512E+00	0.0028	0.0001	10.0	189979
256000	9.8280E-01	0.0018	0.0000	10.0	187885	1.0489E+00	0.0018	0.0000	10.0	187938
320000	9.8374E-01	0.0014	0.0000	10.0	188811	1.0499E+00	0.0014	0.0000	10.0	188859
384000	9.8367E-01	0.0012	0.0000	10.0	188133	1.0498E+00	0.0012	0.0000	10.0	188184
448000	9.8395E-01	0.0010	0.0000	10.0	187939	1.0501E+00	0.0010	0.0000	10.0	187990
512000	9.8374E-01	0.0009	0.0000	10.0	188480	1.0499E+00	0.0009	0.0000	10.0	188532
576000	9.8311E-01	0.0009	0.0000	10.0	188300	1.0492E+00	0.0009	0.0000	10.0	188352
640000	9.8294E-01	0.0008	0.0000	10.0	187983	1.0491E+00	0.0008	0.0000	10.0	188034
649608	9.8290E-01	0.0008	0.0000	10.0	187978	1.0490E+00	0.0008	0.0000	10.0	188029

```
************************************************************************************************************************
dump no.    2 on file kcode.r      nps =    649608     coll =        2031596     ctm =    8.72     nrn =       33602569


       18 warning messages so far.


run terminated when   130 kcode cycles were done.

computer time =    8.96 minutes

mcnp     version 5     12212002                    01/16/03 14:23:42                   probid =  01/16/03 14:14:32
```

Notes:

N1: This one-dimensional model of Godiva is from Reference 1.

N2: Default cross sections are used to include the proper delayed neutron and unresolved resonance data from ENDF6.

N3: The KCODE card indicates this is a criticality calculation with a nominal source size of 5,000 particles per cycle, an estimate of k_{eff} of 1.0, skips 30 cycles before averaging k_{eff} and tallies, and runs a total of 130 cycles (if computer time permits). A total of 5,000 particles was selected to run the problem in less than 10 minutes. Tally normalization will be by the starting source weight by default. In general, it is recommended that at least 30 cycles be skipped and 100 active cycles be run for this problem. More complex problems will usually require more inactive and active cycles.

To normalize a criticality calculation by the steady−state power level of a reactor, use the following conversion:

$$\left(\frac{1\ joule/\sec}{watt}\right)\left(\frac{1\ MeV}{1.602 \times 10^{-13}\ joules}\right)\left(\frac{fission}{180\ MeV}\right) = 3.467 \times 10^{10}\ \ fissions/watt - \sec$$

Therefore, to produce P watts of power, one needs 3.467×10^{10} P fissions per second. This power level produces 3.467×10^{10} x P x ν neutrons/sec, which is the neutron source strength per second for power level P in watts. For an average ν of 2.6 neutrons/fission, the neutron source strength is 9.0×10^{10} P neutrons/sec. The power level normalization should be in the tally on the FM card and NOT in the source on an SDEF card for the initial distribution.

The tallies in a KCODE calculation must be scaled to the steady state power level of the critical system in units of fission neutrons per unit time. For example, if Godiva is operating at a power level of 100 watts, the tally scaling factor would be (100 x 3.467 x 10^{10} fission/sec) (2.597 neutrons/fission) = 9.0×10^{12} neutrons/sec. (The value ν is listed in the box containing the final k_{eff} result). All tallies are steady state and will have units of per second. KCODE tallies for subcritical systems do not include any multiplication effects because fission is treated as an absorption. KCODE tallies for subcritical systems can be estimated by multiplying the results by the system multiplication $1/(1-k_{eff})$. See Chapter 2 beginning on page 2-166 for further discussion.

N4: One fission source point at the center of the 93.7% enriched uranium sphere is used to begin the first cycle. When an SRCTP fission site source file is used, the KSRC card must be removed. An SDEF card could be used in place of the KSRC card to define the initial fission source distribution.

The fission neutron sources for each generation are the fission locations and neutron energies from fissions found in the previous generation. Therefore, in a k_{eff} calculation the fission distribution converges to a stable, but statistically varying, distribution as a function of space. The fission distribution must converge in the inactive cycles before the

active cycles begin. Usually the first generation source is not too important because subsequent generations will have converged. If the user source selects good source points on the KSRC or SDEF card or from an SRCTP file, the problem will converge to a stable k_{eff} in fewer generations. It is critical that the fission source points converge before k_{eff}s and tallies are calculated to ensure proper mean k_{eff}s and confidence intervals. MCNP has statistical checks to assist in assessing k_{eff} convergence.

The correct fission source distribution is proportional to the product of the macroscopic fission cross-section and the neutron flux that, in turn, is proportional to the power distribution. The approximate power distribution is often known and can provide guidance for the initial spatial fission source definition. The closer the initial spatial source definition is to the correct spatial distribution the faster the convergence of the fission source distribution will be, and fewer inactive cycles will be required. If an SRCTP file is available for a similar problem, it should be used as the initial source distribution.

N5: The PERT card perturbs the density of cell 1. The effect of increasing the density from 18.74 g/cc to 20.0 g/cc will be estimated for each of the tallies in the problem using the differential operator technique, including the k_{eff} eigenvalue. The METHOD = –1 causes the estimated change to be combined with the unperturbed value to give the perturbed value directly. Because large perturbations can cause the differential operator technique to break down, it is suggested that the perturbation not exceed 25%. The perturbation capability also assumes that the underlying fundamental mode (fission neutron source shape) is not significantly affected.

N6: This note shows the use of the FM card to calculate the quantities described by the FC14 comment card. The atom density times the volume of the sphere is 134.2212 atoms-cm^3/barn-cm and is used as a tally multiplier to obtain volume reaction rates. Tallies 14 and 34 (no division by the volume since the SD card contains unity) achieve the same tallies in two different ways. The first multiplier bin is the total number of fission neutrons created by fission. This tally is equal to the track length estimate of k_{eff}. The second multiplier bin is the total number of neutrons lost to (n,xn) reactions. The third multiplier bin is the total number of captures. This value is slightly different from the total capture in the problem summary because the tally is a track length estimator and the summary table uses an absorption estimator. The fourth multiplier bin is an estimate of the total number of fissions. The average ν is obtained by the ratio of bin 1 to bin 4, which should agree with the ν in the boxed final k_{eff} results. The fifth multiplier bin is the total neutron heating tally. The multiplier for the fifth bin is the atom density divided by the gram density of cell 1 to calculate heating in units of MeV/gram.

N7: The E0 card uses the Hansen-Roach energy structure as the energy bins for all tallies except Tally 34 because an E34 card exists.

N8: Tally 34 demonstrates an alternate way to specify the tallies listed in Tally 14. The SD34 card divides the tally by a volume of one instead of by the real volume, which is equivalent to multiplying the tally by the volume. The constant on multiplier bin 5 (heating tally) is 1/cell mass. Remember that the SD34 card replaced the real volume by a

value of one, effectively multiplying by the volume. In the unperturbed case, the bin 5 tally gives the same results as Tally 14. See other notes (such as **N10**, **N12**, **N41**, and **N42**) discussing the perturbed tallies.

–Print Table 90–

N9: Print Table 90 gives detailed information about the criticality source from the KSRC card, including points accepted and rejected. Entries from the KCODE card are echoed. Table 90 shows that total (as opposed to prompt) fission ν data are being used by default to account for the effect of delayed neutrons. Delayed neutrons are generated according to the proper delayed neutron fraction for a fissile material, and their energy is sampled from the appropriate delayed neutron spectrum. The delayed neutron libraries are contained in the ZAID.66c cross sections. Delayed neutrons typically have a softer spectrum than prompt neutrons; neglecting this difference in energy can have a small effect. Delayed neutron production can be turned off using the TOTNU card.

–Print Table 30–

N10: These warnings alert the user to the fact that tallies with positive multipliers (Tally 14) may not be properly perturbed, and the results reported may be erroneous. Generally, negative multipliers are needed if tallies involve perturbed materials. Tallies not involving materials, or only involving unperturbed nuclides, are generally safe.

–Print Table 40–

N11: A warning of unnormalized fractions was issued because the sum of the material fractions from the M10 card is not the same as the density in cell 1 and was also not unity.

N12: These warnings indicate that the density perturbation may not be properly corrected for the neutron energy deposition tally (Tally 6) or the fission energy deposition tally (Tally 7). Generally the F6 and F7 tallies are correctly perturbed.

–Print Table 50–

N13: These densities and volumes were used in determining the multipliers for the FM card.

–Print Table 100–

N14: The cross-section tables show that all three isotopes use the total ν. These particular evaluations also have the full delayed neutron energy-time distributions and unresolved resonance data. (See Table G .3 in Appendix G)

N15: At the end of the cross-section processing, and before histories are started, the first dump is made to the RUNTPE file kcode.r. This dump contains all the fixed information about the problem. Subsequent dumps will contain only information that accumulates as histories are run, such as k_{eff} and tally information.

N16: An SRCTP file has been generated (kcode.s because of the name option) for possible use as a source in future versions of the problem. Note the number of warning messages so far–they should all be understood.

–Print Table 110–

N17: Print Table 110 shows starting information about the first 50 histories and indicates that all source points are at the origin as specified on the KSRC card. The directions are isotropic and the energy is sampled from a Watt fission spectrum for uranium for the first cycle.

–Print Table 175–

N18: Thirty cycles are skipped before averaging of k_{eff} and prompt removal lifetimes. Tallies, photon production, DXTRAN summary and activity tables, and other options are also turned off during the first 30 cycles. Cycle 31 is the first active cycle. Cycle 32 begins simple averages over active cycles. Cycle 33 begins 2–combined estimators that require a minimum of three active cycles. Cycle 34 begins 3–combined estimators of k_{eff} and prompt removal lifetimes.

N19: There are three k_{eff} and prompt removal lifetime estimators, and they use the collision, absorption, and track length methods discussed in Chapter 2 beginning on page 2-170. All combinations of these estimators are included. The positive correlations of the various k_{eff} and prompt removal lifetime estimators result in almost no reduction in the relative errors for the combined estimators. The k(col/abs/tk ln) estimator is generally selected (see **N21**). After 130 total cycles and 100 averaging cycles, all of the k_{eff} values agree well at ~0.996 and have an estimated relative error at the 1σ level of ~0.0010. File kcode.s contains the 4,931 fission source points that were generated during k_{eff} cycle 130.

N20: The problem summary provides information for the 100 active cycles. The source particle weight for summary table normalization is the requested 100 cycles x 5000 histories/cycle = 500,000 histories. Whenever the default tally normalization by source particle weight is used, the source weight in the summary table is always exactly 1.000. The neutrons created from both prompt and delayed fission are zero because the actual fission neutrons produced are written to the source for the next cycle. In a noncriticality problem with a point source, both these values would be nonzero provided that the proper cross sections were used. The loss side of the table gives general guidelines about what happened in the problem. The values will not agree exactly with separate tallies in the problem because collision estimators are used for the summary table and track length estimators are used for the tallies. The loss to fission category is for the weight lost to fission, which is treated as a terminal event for the criticality calculation. Parasitic capture is listed separately. No tracks were lost to either the capture or fission categories because implicit capture is being used (the default for EMCNF with no PHYS:N card present is 0). Capture and absorption (capture + fission) both mean (n,0n). The (n,xn) reactions are allowed to occur during a k_{eff} cycle because they are considered to be internal to the cycle.

N21: Hundreds, often thousands, of values of k_{eff} are printed in a single KCODE problem. This page is the summary page which features the single best estimate of k_{eff} clearly outlined inside the box: "the final estimated combined collision/absorption/track-length k_{eff} = 0.99667 with an estimated standard deviation of 0.00079." Other final quantities that appear in the box are the k_{eff} confidence intervals; prompt removal lifetime; average neutron energy causing fission; energy of the average neutron lethargy causing fission; fission percentages of the thermal, intermediate, and fast ranges; average fission neutrons produced per neutron absorbed in fissionable cells and all cells; and the average number of neutrons produced per fission. The Energy of the Average neutron Lethargy causing Fission (EALF) = $\exp\{\int(\ln E)\Phi(E)\Sigma_f(E)dE / \int\Phi(E)\Sigma_f(E)dE\}$.

This summary page also includes a check to determine if each cell with fissionable material had tracks entering, collisions, and fission source points to assess problem sampling. Fissionable cells that have no entering tracks may indicate geometry errors on the part of the user, excessive detail in the user's problem setup, or undersampling that can lead to an underestimate of k_{eff}. Normality tests are made of the active k_{eff} values for each of the three estimators at the 95% and 99% confidence levels. If the k_{eff} estimators are all not normally distributed at the 99% confidence level, then all the Monte Carlo assumptions based upon the Central Limit Theorem may be suspect and the boxed results are not printed. In particular, the estimated relative errors and confidence intervals may be underestimated. See the discussion in Chapter 2 beginning on page 2-180. Note that all error estimators for k_{eff} are standard deviations, not relative errors.

N22: The summary page also gives a table of k_{eff} and confidence intervals if the largest value of k_{eff} for each estimator were to occur on the next cycle. This information provides an indication of the "upper bound" of k_{eff} in a worst-case sampling scenario. This is one of the more useful indicators of how well converged the estimation of k_{eff} appears to be.

N23: Three estimates (col/abs/trk len) and all combinations are made of the prompt removal lifetimes, including standard deviations, just as is done for k_{eff}. Lifetimes are quoted in seconds rather than shakes. Four lifetimes are then summarized. The "fraction" f_i, where i = escape, capture (n,0n), and fission, is the weight lost per source particle from the summary table normalized so that $f_e + f_c + f_f = 1.0$. In the present example, ~57% of the source neutrons escape. This large escape fraction is to be expected for such a small assembly where the neutron mean free path is within a few factors of the radius of the sphere. The lifetimes are defined as $\tau_x = \tau_r/f_x$ where x = e,c,f. That is, the escape, capture, and fission lifetimes are defined in terms of their loss fractions f_x and the removal lifetime τ_r. The lifetimes are the average time between fissions or the mean time between captures (n,0n). The lifetimes (c/a/t) are slightly different from the absorption lifetimes because the collision and track length estimators are included. The best lifetime estimator is the 3–combined covariance–weighted lifetime (c/a/t).

N24: This section gives the value of k_{eff} that was estimated for a density of 20.0 g/cc using the differential operator perturbation technique on the track length estimator of k_{eff}. This technique estimates that a Godiva with a density of 20.0 g/cc would have an eigenvalue of 1.04902 with a standard deviation of 0.00081. This value compares very well with the

result obtained from running a separate problem with the increased density (k_{eff}=1.05243 with a standard deviation of 0.00084).

N25: The batch table approximates alternate k_{eff} batch size values. It shows k_{eff} and its variance as it would have been calculated with a different number of k_{eff} cycles per batch to assess k_{eff} correlation effects. This table saves making dozens of independent MCNP calculations to get the same information. For this problem there are seven different batch combinations: 100 batches of 1 cycle, 50 batches of 2 cycles, 25 batches of 4 cycles, 20 batches of 5 cycles, 10 batches of 10 cycles, 5 batches of 20 cycles, and 4 batches of 25 cycles. The batch size table is not the same as running 50 active cycles with 10,000 histories each or 20 active cycles with 25000 histories each. The batching is approximate because each cycle is still generated from the previous cycle rather than each batch being generated from the previous batch. The batch table is intended to see if the standard deviation (and confidence interval) increases substantially by averaging over k_{eff} cycles to reduce the cycle-to-cycle correlation. If there is a significant increase in the standard deviation (over 30%) then there may be too much correlation between cycles. In that case, the more correct standard deviation and confidence intervals may be the larger value of the standard deviation and confidence intervals from the batch size table summary (see note **N26**).

N26: The above alternate batch size results are summarized with confidence intervals and a normality check. The individual k_{eff} estimator averages are the same by batch size, but the estimated standard deviations change. Both the three-combined average k_{eff} and its standard deviation change by batching. The confidence intervals can be compared to assess if there appears to be a substantial cycle–to–cycle correlation effect. Because the estimated standard deviation itself has a statistical uncertainty, it is recommended to use collapses that produce at least 30 k_{eff} batches.

N27: This is the k_{eff}–by–cycle table. The individual and average k_{eff} estimator results by cycle repeat the information printed while the run was in progress (see notes **N18** and **N19**) in a more readable format. The first 30 cycles are inactive to allow the fission source spatial distribution to equilibrate. A k_{eff} FOM is also included to assess its stability.

N28: The largest and smallest values for each of the three k_{eff} estimators and the cycle at which they occurred are provided.

N29: The average k_{eff}–by–cycle table results for the combined col/abs/track–length estimator are plotted. The final three-combined k_{eff} value (0.99667) is marked with the vertical line. This plot should be examined for any trends in the average k_{eff}.

N30: This is the k_{eff}–by–number–of–active–cycles table. It provides a summary of what the results for each estimator and the combined col/abs/track-length would be had there been a different number of settle or skip cycles and active cycles. The combination actually used in this problem, 30 settle cycles and 100 active cycles, is marked with an asterisk (*). Unlike the approximate batch table, the skip/active cycle table provides exactly the results you would have had by changing the number of skip cycles on the KCODE card.

Note that skipping up to two cycles produces k_{eff} values that do not appear normally distributed at the 99% confidence level.

N31: The skip/active cycle resulting in the minimum k_{eff} error is identified. In this problem, the minimum statistical error occurs at 6 settle cycles and 124 active cycles rather than 30 and 100. If the number of skipped cycles to produce the minimum statistical error is significantly greater than the number of cycles actually skipped, the normal spatial mode may not have been achieved in the skipped cycles. The problem can be rerun with more settle cycles or the entry from the table for the number of skipped cycles producing the minimum standard deviation can be used.

N32: The k_{eff} and its estimated standard deviation for the first and second active halves of the problem are checked to see if they appear to be statistically the same value. They do for this problem at the 95% confidence level.

N33: The average k_{eff}-by-inactive-cycle table results for the combined col/abs/track-length estimator (**N30**) are plotted. The final k_{eff} value (0.99667) is marked with the vertical line. k_{eff} clearly decreases with an increasing number of inactive cycles because the KSRC source point is at the center of the assembly. A neutron born in the center of the sphere has a much larger probability of causing fission and therefore over estimates k_{eff}. The initial cycles have a spatial fission source that is biased toward the center and, as the source updates from cycle to cycle, the spatial fission source spreads outward toward the correct distribution, lowering k_{eff}.

N34: The F1 total leakage tally for the active cycles agrees exactly with the total weight lost to escape in the problem summary table (see note **N20**).

N35: The F6 heating tally in the uranium sphere of 1.233×10^{-3}(0.0008) MeV/g does not include any heating estimate from photons. To account for prompt photons, a coupled neutron/photon criticality problem must be run using a MODE N P card. An F7 fission heating tally may give a good approximation for this problem (see note **N36**).

N36: The F7 prompt fission heating tally is larger than the F6 total heating tally because the F7 tally includes photons and the F6 tally does not. The F7 fission heating estimate assumes that all photons are deposited locally. The difference between the F6 and F7 tallies is discussed in Chapter 2 beginning on page 2-89. Because Godiva is an optically thick system to photons, the F7 tally should be a good approximation to the total heating. A MODE N P calculation of this problem produced a neutron heating (F6) of 1.232×10^{-3} (0.0008) MeV/g and a photon heating of 6.457×10^{-5} (0.0016), which adds to about the estimate of the F7 tally, 1.324×10^{-3} (0.0008) (the estimated relative errors are listed in parentheses). If the 100-watt neutron/sec scaling in note N3 is used to scale the one neutron (see **N20**) Tally 7, (1.324×10^{-3} MeV/g) (52,420 g) (9.0×10^{12} neutrons/sec) (1.602×10^{-13} watt-sec/MeV) = 100.07 watts. Thus, the source scaling and tally heating are consistent with the assumed 100-watt power level.

N37: The F14 flux tally has five multiplier bins. The tallies below 0.1 MeV are small because there is no moderator. Multiplier bin 1 is the total number of fission neutrons produced

per source neutron and agrees exactly with the track length k_{eff} estimator described in note **N21**. The estimated errors may differ because k_{eff} (track length) is a batch-averaged standard deviation while Tally F14 is a history-averaged relative error. The percentages of fission neutrons above and below 0.1 MeV agree with the percentage of fissions shown in the final k_{eff} results box (see **N21**). Bin 2 estimates the number of neutrons lost to (n,xn) reactions. The difference between this track length tally and the collision estimate in the problem summary (**N20**) is purely statistical (the summary table is collision-estimator based and F14 is based on the track length). Multiplier bin 3 estimates captures (n,0n), which agrees with the problem summary weight lost to capture (n,0n) with a slight difference between the tally track length estimator and the problem summary collision capture estimator. Multiplier bin 4 gives the total number of fissions, as opposed to the total number of fission neutrons in bin 1. Dividing multiplier bin 1 by multiplier bin 4 gives the estimated average value of ν of 2.5978 neutrons produced per fission, which agrees with the final boxed result (see **N21**). Multiplier bin 5 is the total neutron heating tally that agrees exactly with the F6 tally (see **N35**). The statistical checks for the total of the first FM card bin (track length k_{eff}) are all passed.

N38: Tally 34 illustrates a different way of doing Tally 14 using the SD card. The SD card sets the tally divisor to one, not the volume, which has the same effect as multiplying by the volume. Note how the first multiplier bin, the track length estimate of k_{eff}, is identical to the first multiplier bin in Tally 14, which is multiplied by the atom density times the volume. The second multiplier bin is the (n,2n) + (n,3n) reaction rate; that is, the track length estimate of the total loss to (n,xn), and agrees with the collision (n,xn) estimate in the problem summary table. Multiplier bins 3 and 4 are the capture (n,0n) and fission rates, which agree exactly with multiplier bins 3 and 4 in Tally 14 and differ from the weight lost to capture (n,0n) and fission in the problem summary table only by the difference between track length estimators and collision estimators. Multiplier bin 5 is the heating tally and it agrees exactly with bin 5 of Tally 14 and also Tally 6. Tally 14 and Tally 34 agree to within the precision of the constants specified on the FM card. There is a slight monotonic decrease in the first FM card bin caused by the slightly decreasing k_{eff} in the last half of the problem.

N39: The tallies that follow have been corrected for the perturbation. The perturbation capability assumes that the underlying fundamental mode (neutron flux shape) is not affected significantly.

N40: This table lists the perturbed result of Tally 1, the total leakage (escape) from the assembly when the density was increased to 20 g/cc. As expected, increasing the material density decreases the mean free path of a neutron and decreases the leakage from the assembly.

N41: The perturbed results of Tally 14 should be immediately questioned because the track length estimate of k_{eff} (multiplier bin 1) is not equal to the perturbed k_{eff} track length estimate in **N24**. The positive bin multiplier caused this error. Perturbation of a cross-section-dependent tally requires a negative multiplier so that a needed correction is made (see page 2-195). Bins 1–4 are wrong. Bin 5 is correct because it is a cross-section-

independent tally that does NOT need the correction, so a positive multiplier is correctly used. See note **N10**.

N42: Since Tally 34 used negative bin multipliers the perturbed values for this tally are correct. Note that bin 1 is equal to the perturbed track length estimate in **N24** (k_{eff} = 1.04902).

N43: The tally fluctuation charts confirm stable, efficient tallies in the total bins monitored. The slight k_{eff} decrease in the last half of the problem causes the mean random behavior check not to pass. The charts confirm that the first 30 cycles (150,604 histories) were skipped because of the zero tally results after 128,000 particles were run. These charts include both the perturbed and unperturbed results for the selected bins.

A few final points should be made about KCODE calculations. To make a KCODE calculation using the SRCTP source points file produced by a previous run, remove the KSRC card from the input file. To do a continue–run, the standard MCNP rules apply. Having an input file beginning with CONTINUE may be needed. If the previous run terminated because all the cycles requested by the KCODE card were completed, another KCODE card in a continue–run input file with a new total (not how many more) number of cycles to run is needed. Otherwise, only one more cycle will be run and the code will stop again. If the previous run was interrupted and stopped before all KCODE card cycles were completed, a continue-run input file is not needed. The code will start where it was stopped and continue until it is finished. The SRCTP file is not required for a KCODE continue–run because the source points information is contained on the RUNTPE file.

V. EVENT LOG AND GEOMETRY ERRORS

MCNP cannot detect a geometry error while processing data from the INP file. Particles must actually be run. When a particle gets to a place in the geometry that is not correctly specified, it gets lost—it simply does not know where to go next. If this happens, you will get in the output file a debug print and event-log print for each lost particle. When ten particles get lost, MCNP stops. The default of ten lost particles for printing and termination can be changed with the LOST card, but doing this is generally unwise. See Chapter 3 beginning on page 3-8 for a more complete discussion of how to use the plotter and set up a problem to flood the voided (VOID card) geometry with particles to check for geometry errors.

A. Event Log

An event–log print of all particle events (source, surface crossing, collisions, etc.) is produced by a lost particle and also by the third and fourth entries on the DBCN card. When a particle gets lost, the history is rerun and event–log printing is turned on during the rerun, making some of the summary information slightly incorrect. The following example is from the file CONC2, which is the same as the CONC problem with all of the tallies taken out. The importance of the concrete shell is set to two to provide splitting in the event log. CONC2 runs only two histories (nps 2) and an event log is forced by a DBCN card (dbcn 2j 1 2). The shell is given an importance of two to cause particles to split when they leave the source cell and enter the shell.

The event log is reproduced on the next page. See Table F.8 in Appendix F for a full description of the TYR Block, which explains the value for R.

An event log for a history producing a large score can uncover what aspects about the random walk were responsible for this large score. MCNP variance reduction methods can then be applied to sample this region of phase space more often, thereby increasing problem efficiency.

```
1     event log for particle history no.         1          ijk =        6647299061401

     cell     x         y         z         u         v         w       erg      wgt                       nch     nrn

 src    1  0.000+00  0.000+00  0.000+00  5.085-01  4.733-01  7.193-01 1.400+01 1.000+00   particle=neutron        2
   s    2  1.831+02  1.704+02  2.590+02  5.085-01  4.733-01  7.193-01 1.400+01 5.000-01   surf=     1   npa= 1    2
   c    2  1.841+02  1.714+02  2.605+02 -2.302-01  9.676-01  1.039-01 5.760+00 3.832-01 14000.60c r=  71     1    10
   t    2  1.841+02  1.714+02  2.605+02 -2.302-01  9.676-01  1.039-01 5.760+00 3.832-01   energy cutoff           10

 bnk    2  1.831+02  1.704+02  2.590+02  5.085-01  4.733-01  7.193-01 1.400+01 5.000-01 n imp split                  2 10
   c    2  1.837+02  1.709+02  2.598+02 -6.623-02  5.268-01  8.474-01 1.369+01 4.370-01  8016.62c r=   2     2    17
   c    2  1.827+02  1.786+02  2.722+02 -7.627-01  6.079-01  2.207-01 6.949+00 3.796-01  8016.62c r=  52     3    25
   t    2  1.827+02  1.786+02  2.722+02 -7.627-01  6.079-01  2.207-01 6.949+00 3.796-01   energy cutoff           25
1     event log for particle history no.         2          ijk =      130407176137285

     cell     x         y         z         u         v         w       erg      wgt                       nch     nrn

 src    1  0.000+00  0.000+00  0.000+00  8.952-01 -4.447-01 -2.944-02 1.400+01 1.000+00   particle=neutron        2
   s    2  3.223+02 -1.601+02 -1.060+01  8.952-01 -4.447-01 -2.944-02 1.400+01 5.000-01   surf=     1   npa= 1    2
   c    2  3.239+02 -1.609+02 -1.065+01  5.069-01 -4.979-01  7.037-01 1.340+01 4.370-01  8016.62c r=   2     1     9
   c    2  3.269+02 -1.639+02 -6.470+00  5.672-02 -5.358-01  8.424-01 1.322+01 3.780-01  8016.62c r=   2     2    16
   c    2  3.277+02 -1.708+02  4.388+00 -8.928-01  4.460-01  6.349-02 1.209+01 2.876-01 14000.60c r=   2     3    23
   s    1  3.191+02 -1.665+02  4.994+00 -8.928-01  4.460-01  6.349-02 1.209+01 2.876-01   surf=     1   npa= 0    24
   s    2 -3.216+02  1.536+02  5.056+01 -8.928-01  4.460-01  6.349-02 1.209+01 2.876-01   surf=     1   npa= 0    24
   c    2 -3.244+02  1.550+02  5.076+01 -8.617-01  3.750-01 -3.419-01 1.202+01 2.528-01 13027.62c r=   2     4    31
   c    2 -3.249+02  1.552+02  5.057+01 -6.556-01  6.236-01 -4.258-01 1.193+01 2.111-01  8016.62c r=   2     5    38
   t    2 -3.249+02  1.552+02  5.057+01 -6.556-01  6.236-01 -4.258-01 1.193+01 2.111-01   energy cutoff           38

 bnk    2  3.223+02 -1.601+02 -1.060+01  8.952-01 -4.447-01 -2.944-02 1.400+01 5.000-01 n imp split                  2 38
   c    2  3.337+02 -1.657+02 -1.097+01  2.572-01  6.412-01 -7.230-01 1.575+00 3.995-01 20000.62c r=  22     6    46
   t    2  3.337+02 -1.657+02 -1.097+01  2.572-01  6.412-01 -7.230-01 1.575+00 3.995-01   energy cutoff           46
```

HISTORY NUMBER 1

The first neutron starts with the correct parameters and immediately crosses surface 1 into cell 2 as we would expect because cell 1 is a void. The cell importance increases to 2 in cell 2 and the original particle is split into two tracks, one of which is put in the bank (NPA=1) and the other followed. If there had been a four-for-one split instead of two–for–one as we have here, NPA would be 3, indicating one entry into the bank representing three tracks.

The next event is a collision for the track that is being followed. It has an inelastic collision with silicon (14000.60c) in cell 2. Its energy after the collision is 5.760 MeV, which results in a termination because the energy cutoff in the problem is 12 MeV. The neutron weight was reduced by the implicit capture survival probability.

At this point the bank is checked for any tracks and one is found that got there as a result of importance splitting. “n imp split 2 10” means the particle was put in the bank with random number nrn = 2 from a split occurring at the surface. The nrn at the time of bank retrieved is 10. That track is started at the point where it was created at the surface crossing. It has an elastic collision with oxygen (8016.62c). Its energy after the collision is 13.69 MeV. A second collision with oxygen occurs, but this time it is inelastic with one neutron out. The energy after collision is 6.949 MeV, resulting in its termination due to energy cutoff. The total number of collisions per history (NCH) is three for this history.

HISTORY NUMBER 2

The second source particle is started. It is split, has two collisions with oxygen, one collision with silicon, and crosses surface 1 back into cell 1. The particle then crosses back into cell 2, has a collision with aluminum and then with oxygen and is terminated because of energy cutoff. The second track of this second source neutron is returned from the bank. It has one collision, falls below the energy cutoff, and is terminated.

By default only 600 lines of the event log are printed for each history. This value can be changed by the fifth entry on the DBCN card.

B. Debug Print for a Lost Particle

For a lost particle, an event log is automatically printed, but by default without the banking and collision events. (These events will print if the 11th entry of the DBCN card is set to 1.)

In addition to getting the event-log print for a lost particle, you will also get a debug print that gives you additional information. It tells you what the geometry description is in terms of cell/surface relations at the point the particle got lost. Sometimes the problem is an incorrectly specified surface sense.

If the geometry of Figure 4-11. in Chapter 4 is specified incorrectly such that the undefined tunnel going off to the right of surface 5 remains, you will get the following debug print:

```
 1     lost particle no.  1    no cell found in subroutine newcel    history no. 21
   the neutron  currently being tracked has reached surface     5.  there
   appears to be no cell on the other side of the surface from cell     2
   at that point.
   the neutron  is in cell     2.
   x,y,z coordinates:         -9.88564E-01    5.00000E+00    1.68033E-01
   u,v,w direction cosines:   -1.97652E-01    9.79696E-01    3.35962E-02
   energy = 1.40000E+01    weight = 1.00000E+00    time = 9.77199E-02
   sqrt(z**2+x**2) = 1.00274E+00
   the distance to surface      5 from the last event is 2.04145E+00
   the distance to collision from the last event is 1.00000E+37
   the number of neutron  collisions so far in this history is     0.
   the cells so far found on the other side of surface      5 of cell    2
   (and the surface with respect to which the point x,y,z had the wrong sense) are:
   (see chapter 5 of the mcnp manual.)
       3
```

The *x,y,z* coordinates give the location of the particle when it got lost. If the geometry is plotted with *x,y,z* as the origin, the geometry in the vicinity of the lost particle can be examined. Dashed lines in the plot indicate the improperly specified portion of the geometry (see Chapter 3 page 3-8).

The last portion of the debug print pinpoints the geometry error. The particle has just exited cell 2 by crossing surface 5. The only known cell on the other side of surface 5 from cell 2 is cell 3. However, cell 3 has been defined as (2:–1) (4:5:–3). The particle is in the undefined tunnel region (–2 5), not in cell 3. If cell 3 were only the area to the right of surface 5 and defined without the union operator, the debug print would be even more specific, listing 3 (2) to indicate that the particle has the wrong sense with respect to surface 2 of cell 3.

VI. REFERENCES

1. Raphael J. LaBauve, “Highly Enriched Uranium Systems,” in *International Handbook of Evaluated Criticality,* HEU-MET-FAST-001 (NEA/NSC/DOC(95)03/II, Volume II, Revision 2, September 30, 2002.

APPENDIX A - SUMMARY OF MCNP COMMANDS

CONTENTS

Appendix A is a summary of general information, input cards, and plot commands. It is intended to be used by intermediate to advanced users as a quick reference. A less experienced user should not expect to find Appendix A sufficient. Right justified page numbers are cross-references to pages in the MCNP5 manual where detailed information can be found (for example, 3-32 refers to Chapter 3 page 32). The terms card and command are used interchangeably to mean one or more lines of input. File and card names are shown in this appendix in UPPER case; however, upper, lower, or mixed case is also allowed.

Sections II, III and IV each have the following subsections:

1) alphabetical command list with a one-line description,
2) alphabetical one-line list by command function category, and
3) alphabetical command list with a very concise description of each command.

Report Appendix A errors to a Group X-5 MCNP team member or e-mail: mcnp@lanl.gov.

I. GENERAL INFO, FILE NAMES, EXECUTION LINE, UNITS

A. Form of Input (INP) File: Required to Initiate and Run a Problem

			1–3,3–1
MESSAGE block	*optional*	MESSAGE: begins in column 1 followed by execution line options and files. Omit INP=. A blank line must follow.	3–1
title card	*required*	one line up to 80 character; first INP line if no MESSAGE block.	
cell cards	*required*		3–9
blank line	*required*	delimiter between cell cards and surface cards	
surface cards	*required*		3–11
blank line	*required*	delimiter between surface cards and data cards	
data cards	*required*	all other cards. Most INP file commands in Section II are this type and are placed here.	
blank line	*recommended*	terminates INP file Anything written after last blank line will not be read as a part of the problem.	

B. Form of CONTINUE Input File: Requires a RUNTPE file

3–2

CONTINUE and RUNTPE files are needed for continuation if the prior run finished all NPS histories or KCODE cycles. An unfinished problem requires only RUNTPE for continuation.

In a CONTINUE input file the number of histories or cycles can be increased as follows:

1. Change NPS to new TOTAL (not increment) number of histories.
2. Change the fourth KCODE card entry to new TOTAL number of cycles.
3. Change CTME to the number of additional minutes for the continue run.
4. Use NPS = –1 to reprint the results portion of the OUTP file.

The word ***continue*** begins in column 1 of line one followed by data cards on subsequent lines. The following data cards are allowed in a continue run after the CONTINUE line:

CTME, DBCN, DD, FQ, IDUM, KCODE, LOST, MESH, MPLOT, NPS, PRDMP, PRINT, RDUM, TALNP, ZA,ZB,ZC

A blank line terminator is recommended. Anything else can be put after the blank line terminator.

C. MCNP File Names and Contents

1–12,B–2

File names must be ≤ 256 characters or ≤ 255 characters with the NAME option.
All files can be renamed on the execute line or in the MESSAGE block except WXXA.
Only enough of the default file name needs to be typed so that it is unique:

i=infile, o=outfile, mc=mcfile, wwi=wwifile

COM	read by MCNP as a source of geometry, tally, or cross-section plot commands
COMOUT	all geometry, tally, or cross-section plotting commands are written to this file
DUMN1,DUMN2	dummy file names 1 and 2
INP	original problem input file (cannot be renamed in the MESSAGE block)
MCTAL	ASCII tally results file (Appendix B, Section D)
MESHTAL	ASCII mesh tally results file
OUTP	output file of problem results
PLOTM.PS	graphics postscript file plotm.ps
PTRAC	particle tracks file
RSSA	binary surface source read file
RUNTPE	binary problem start-restart data
SRCTP	binary KCODE source distribution
WSSA	binary surface source write file
WWINP	weight window input file
WWONE	single energy- or time-independent weight window output
WWOUT	output file from the weight window generator
WXXA	binary surface source scratch file (cannot be renamed)
XSDIR	cross-section tables directory

The NAME option names all generated files in a predictable way and replaces setting all file names individually.

NAME=***input*** (≤ 255 characters) appends a letter to the end of file ***input***:
OUTP=inputo, RUNTPE=inputr, SRCTP=inputs, MCTAL=inputm, PTRAC=inputp

Unique abbreviations are accepted for setting file names:

i=input, o=outtest, r=runtest,... or n=input, i=test, n=test
Reads from file test and creates OUTP=test.o, RUNTPE=test.r....

D. MCNP Execution Line Options and Useful Combinations

1–13

To run an executable named **mcnp**, type: **mcnp** options files
The execution line options follow. File names are listed in Section C above.

I	set up the problem specified in the INP file and check for input errors
X	get the cross-section tables required by the problem
R	run the problem
P	plot the problem geometry from an INP or a RUNTPE file
Z	plot tally results from RUNTPE or MCTAL files plot cross sections from INP (IXZ)
IXR	read INP, get cross sections, and transport particles {***default***}
IP	read INP and plot the geometry from INP file
IX	read INP and cross sections and check for input and material cross-section errors
IXZ	read INP, read cross sections, and plot cross sections
IPXRZ	run all options (usually not practical)
C m	perform a continue run starting with dump **m** (omitting **m** uses last dump)
CN	continue run but write each dump immediately after fixed data on RUNTPE
DBUG n	write one-line DBCN debug information to output file every **n** histories (see DBCN(2)). 8 byte integer values are allowed for n.
FATAL	run the problem even if fatal input errors are found (this option is NOT recommended)
NOTEK	suppress terminal plotting and send plots to graphics metafile PLOTM
PRINT	create the full output file (same as a blank PRINT card)
TASKS	use MPI or PVM multiprocessing with threads for each process MPI: **mpirun -np *n* mcnp tasks *m* ... eol** ***n*** = number of MPI processes, ***m*** = number of threads Only ***n*** or ***m*** is allowed for multiprocessing or threads respectively. eol instructs MCNP to ignore all commands that follow; some commands may be added by MPI. Use **eol** with MPICH implementation of MPI, as needed with others. PVM: **mcnp tasks *n* x *m* ...**(***n*** PVM processes, ***m*** threads each: ***tasks 5x4***) Use -n to disable distributed memory load balancing, fault tolerance tasks m for threads only (do not include “x”) tasks n for PVM only (do not include “x”) DBCN(2,3,4), SSW, and PTRAC are incompatible with tasks > 1 (FATAL error).
BALANCE	provides load balancing when used with MPI

EOL Add after all other MCNP keywords to distinguish MCNP keywords from directives added by MPICH. Only needed if the MPICH implementation of MPI is used.

E. MCNP Execution Lines for Various Types of Problems

1–13

To run an executable named **mcnp**, type: **mcnp** options files

Examples of three different MCNP execution lines for an initial run of a problem:

mcnp (INP exists, OUTP, RUNTPE, and other default file names will be created)

mcnp inp=test1 outp=testout1 runtpe=testrun1 (= tells what file names are set to)

mcnp n=test1
(n is NAME option: INP=test1, OUTP=test1o, RUNTPE=test1r, MCTAL=test1m, SRCTP=test1s, PTRAC=test1p, WWOUT=test1e, WWONE=test11)

To continue an MCNP run, type: **mcnp c** (or **cn**) **run=file** (runtpe to be continued) **inp=file ...**.

If the initial problem did not complete, a CONTINUE inp file is not needed. A problem can be continued as many times as desired (see PRDMP card to control dumps).

To plot problem geometry, type: **mcnp ip inp=file ...** or **mcnp p runtpe=file**
To plot problem cross-sections, type: **mcnp ixr inp=file ...**
To plot problem tally results, type: **mcnp z runtpe=file** or
mcnp z mctal=MCTAL filename

F. MCNP Physical Units and Tally Units

1–1,3–81

Length = centimeters
Area = cm^2
Volume = cm^3
Mass = grams
Energies = MeV
Time = shakes (10^{-8} sec)

Temperatures = MeV (kT: see TMP card)
Atom Densities = atoms/barn-cm
Heating Numbers = MeV/collision
Mass Densities = gm/cm^3
Cross sections = barns (10^{-24} cm^2)

Source weight (see SDEF card,WGT entry) in particles (pulse) or particles/unit time(steady state).
Tally units: All tallies below have additional units of "per unit source time" for steady state.

F1 current tally = particle weight (WGT)	units = particles
F2 surface flux tally = WGT/(cosine of surface crossing angle)/area	units = particles/cm^2
F4 cell flux tally = WGT*(track length)/(cell volume)	units = particles/cm^2
F5 point flux tally = WGT*exp(-mean free paths)*p(u)/(2*pi*radius^2)	units = particles/cm^2
F6 heating tally = (F4 tally)*(total macro xsec)*(heating #)/(gram density)	units = MeV/gram
F7 fission heating = (F4 tally)*(total macro fission xsec)*Q/(gram density)	units = MeV/gram
F8 pulse height tally = collective history weight deposited in the detector	units = pulses

*F converts weight to energy or other energy-deposition tally units

G. MCNP Interrupts (press <cr> after each entry)

1–15

(ctrl c)	problem status (run mode gives time, current history and collisions)
(ctrl c)s	problem status (run mode gives time, current history and collisions)
(ctrl c)m	make interactive tally plots (enter END or RETURN to return to calculation)
(ctrl c)q	quit and terminate normally after current history
(ctrl c)k	kill immediately (all files created for the problem are incomplete)

H. Example of an MCNP Fixed Source INP File

Fixed source requires: SDEF, SSR (with RSSA file), or user-defined source subroutine	3–53
Always plot the geometry and inspect OUTP file cell volumes and masses.	B–2
Use tips in manual for correct and efficient problems.	1–16
Inspect ten statistical check results for tally fluctuation chart bin (see TFn card).	2–132
Form valid statistical confidence intervals for result precision using statistical checks.	2–130

Example INP file for a Cf-252 SDEF fixed point source in a water cylinder
(no MESSAGE block):

```
point Cf-252 fission source in a cylinder of water (required title card)
c                                  begin cell cards for fixed source sample problem
1 1 -1.  -1 -2 3                       $ cylinder of water
2 0       1:2:-3                       $ all space outside the cylinder
c                                  end cell cards; next line is required blank line delimiter

c                                  begin surface specifications after blank line delimiter
1 cy  20.                              $ cylinder about the y axis
2 py  10.                              $ top plane of water cylinder
3 py -10.                              $ bottom plane of water cylinder
c  rcc  0 –10 0    0 20  0    20       $ equivalent macrobody definition commented out
c                                  end surface cards; next line is required blank line delimiter

c                                  begin data section after blank line delimiter
mode n p                               $ coupled neutron-photon problem
sdef erg=d1 pos=0 0 0                  $ cf-252 point source at origin; pos=0 0 0 is default
sp1 -3 1.025 2.926                     $ use a watt fission spectrum for cf-252
imp:n,p  1 0                           $ set both neutron and photon importances at once
m1  1001 .66667  8016 .33333           $ define h2o using h and o atom fractions
mt1 lwtr                               $ use light water S(a,b) thermal neutron treatment
```

```
f1:n  1 2 3 (1 2 3)          $ neutron current tally over each surface and total
f11:p 1 2 3 T                $ photon current tally over each surface and total
f4:n  1                      $ tally the average neutron flux in water cylinder cell
f14:p 1                      $ tally the average photon flux in water cylinder cell
nps  40000                   $ terminate after 40000 neutron histories
print                        $ print everything about the calculation
c                          end data section; optional blank line terminator follows
```

To run the problem, type: **mcnp inp=file ...** or **mcnp i=file ...** or **mcnp n=file**

I. Example of a k_{eff} Eigenvalue INP File

Requires KSRC card or SDEF card or SRCTP file for the initial spatial fission source. 3–78
Use enough settle cycles to reach fundamental spatial mode (see statistical checks, plots). 2–186
Always plot the geometry and inspect OUTP file cell volumes and masses. B–2
Use tips in manual for correct and efficient problems. 1–16
Inspect cell sampling of fission, k_{eff} data normality, batched data, and printed k_{eff} plots. 2–187
Form valid statistical confidence intervals for precision of the k_{eff} result. 2–180
A CONTINUE run requires only the RUNTPE file (no SRCTP file is required). 3–2

For help with KCODE, see Los Alamos National Laboratory report, LA-12827-M, “Criticality Calculations with MCNP: A Primer” (1994).

Following is an example k_{eff} INP file for Highly Enriched Uranium GODIVA (no MESSAGE block):

```
godiva (enriched uranium): skip 30, run a total of 130 keff cycles with 1000 neutrons per cycle
1    1  -18.74  -1  imp:n=1       $ enriched uranium sphere (godiva)
2    0             1  imp:n=0     $ zero importance; next line is required blank line delimiter

1    so 8.741                     $ radius of sphere; next line required delimiter

kcode 1000 1.0 30 130             $ kcode defines a criticality calculation
ksrc   0 0 0                      $ initial keff spatial distribution is one point at origin
m1     92235 -93.71   92238 -5.27   92234 -1.02  $ use weight fractions and default xsecs
c      tally the track length keff
f4:n   1                          track length in cell 1
fc4   cell 1 flux tally is converted into track length keff tally
fm4   -1. 1  -6 -7                $ multiply by atom density of material 1 times xs times nu
sd4    1.                         $ set tally divisor to 1 so tally is volume integrated
e4     .001 .01 .1 .5 1 18i 20    $ create energy bins (MeV) for track length keff tally
print                             $ print all possible tables;  optional delimiter follows
```

To run the problem, type: **mcnp i=file ...**

To continue the above problem for another 100 cycles (total of 230 cycles) and add automatic plotting, the CONTINUE file would be:

```
continue                          $ starting in column 1
kcode 1000   1.0   30   230
mplot   freq 10   kcode 16   scales 2  $ add automatic plotting of the three combined keff tally
```

For the execution line, type: **mcnp c i=file runtpe=file ...**

II. INPUT (INP) FILE COMMANDS

A. Input Command Formats

3–4

No distinction is made between upper and lower case: MCNP input is case insensitive.

Completely blank lines are reserved as delimiters between major input sections.

1. Horizontal 80-Character Input Format 3–4

Card names and cell and surface numbers begin in columns 1–5 followed by at least one space. Remaining columns through 80 are for free-field data separated by at least one space. Cards can be continued two ways:

- An ampersand (&) at the end of the present card; a continuation card can start anywhere (not allowed on C, FCn, SCn).
- Columns 1 through 5 of the next card are blank. (C card cannot be continued this way.)

Tabs are converted to the appropriate number of spaces. Unprintable characters (including ^M characters at the ends of lines in files created in DOS format) are converted to blanks.

Five shorthand features aid with input card preparation: 3–4

nr	repeat the immediately preceding entry on card n times (2 5r is 2 2 2 2 2 2)
ni	insert n linear interpolates between preceding and following numbers (1 2i 4 is 1 2 3 4)
nilog	insert n logarithmically spaced interpolates between preceding and following numbers (.01 2ilog 10. is .01 .1 1. 10.). Numbers must be nonzero and have the same sign.
nm	multiply the previous entry by n (1 3m 3m 3m is 1 3 9 27)
nj	jump over n items on the card and use the default values for the first n card entries

examples of some allowed combinations: 1 3m 2r (1 3 3 3), 1 3m i 5 (1 3 4 5), and 1 r 6m (1 1 6)

examples of some illegal combinations: 3j 4r, 1 4i 3m, and 1 4i j

2. Vertical (Column) Input Format for Cell Parameters and Source Distributions 3–5

Type a "#" sign in columns 1 to 5 followed by card names to column 80: # de4 df4
Cells, if any, begin in columns 1 to 5 followed by values to column 80: 1e-6 1
The # card can be used more than once: 1e-4 20

3. Particle Designators 3–7

Some commands require a particle designator: N=neutron, P=photon, E=electron.
The designator is a colon (:) followed by an N, P, or E after the command name.
One blank character must follow N, P, or E before data entries.
Multiple particle types are entered as follows: NPE or N,P,E (not separated by spaces)
The only tallies that can have multiple particle types are F6:N,P and F8:P,E.

Commands requiring a particle designator are:
CUT DXCm DXT ELPT ESPLT EXT Fn FnA FCL FICn FIPn FIRn
FMESHn IMP PERTm PHYS TSPLT WWE WWGE WWNi WWP

B. Input Commands

3–161

- n indicates a number is required
- m indicates a number for cards relating to materials is required
- :p means a particle type indicator N P or E is required
- I8 means that some entries on this card can be 8 byte integers. The characters “I8” should not be present in the input deck.

Card Name	Purpose [max no of entries] *describes meaning of *CARD		Ref. Page
AREA	whole surface area specifications	[number of surfaces]	3–25
AWTAB	user specified atomic weight in pairs: “ZAID atomic-weight-ratio”		3–127
BBREM	bias for high-energy bremsstrahlung photons		3–53
blank	blank lines separate MESSAGE, cell, surface, and data blocks		3–2
C	INP file comment card (no continuation is allowed)		3–4
Cn	cosine bins for a type 1 tally		3–97
cell cards	define geometry cells with materials (Mm card) or void (0)		3–9
CFn	tally contributions from flagged cells separately for tally n	[number of cells]	3–105
CMn	multipliers for cosine bins of tally n for type 1 tallies		3–105
CONTINUE	first card in file for continue run (C or CN on execute line)		3–3
CTME	computer time limit in minutes for the problem	[1]	3–142
CUT:p	time, energy, and implicit capture/weight cutoffs	[5]	3–139
data cards	define particles, physics, source, materials, variance reduction, tallies, ...		3–23
DBCN^{I8}	debug information card	[30]	3–146

DDn	detector and DXTRAN diagnostics and contribution card		3–112
DEn	dose energy card (use with the DFn card)		3–103,H–4
DFn	dose function card (use with the DEn card)		3–103,H–4
$ (dollar sign)	comment at end of input line; appears only in echo of input file in OUTP.		3–4
DRXS	discrete reaction neutron cross-section card		3–125
DSn	dependent source distribution card		3–66
DXCn:p	DXTRAN contribution for DXTRAN sphere n	[cells]	3–52
DXT:p	defines DXTRAN spheres	[53]	3–114
En	upper bounds of energy bins (MeV) for tally n		3–96
ELPT:p	cell energy cutoff (greater of ELPT:p or CUT:p applies)	[cells]	3–140
EMn	multipliers for energy bins of tally n on the En card		3–104
ESPLT:p	energy splitting and Russian roulette card	[40]	3–36
EXT:p	exponential transform (use weight window; FCL not allowed)	[cells]	3–41
Fn:p	create cell, surface, or point tally n (*F for energy)		3–81
FnA:p	symmetric ring detector flux tally, where A = X, Y, or Z axis		3–83
FCn	comment printed in OUTP for tally n (& continuation not allowed)		3–95
FCL:p	force collisions by cell	[number of cells]	3–43
FICn:p	flux image on a cylindrical image grid		3–83
FILES	user file creation card	[30]	3–148
FILL	fill cell or lattice elements with universes (*=rotation matrix in degrees)		3–29
FIPn:p	flux image through a pinhole to a planar rectangular image grid		3–84
FIRn:p	flux image radiograph on a planar rectangular image grid		3–83
FMn	tally multiplier card for tally n		3–99
FMESHn:p	create a mesh track length tally		3–118
FQn	print hierarchy card for ordering of OUTP tallies	[8]	3–98
FSn	subdivide cell or surface into segments for tallying	[surfaces]	3–106
FTn	special treatments for tally n		3–116
FUn	user-defined TALLYX tally input; required by some FTn options		3–109
HSRC	mesh for Shannon entropy of fission source distribution		3-78
IDUM	integer array available for user-modified code (see RDUM)	[50]	3–142
IMP:p	cell importances; required unless weight windows used	[cells]	3–34
KCODE	define a criticality eigenvalue (k_{eff}) problem	[8]	3–77
KSRC	starting source point locations for KCODE problem		3–78
LAT	defines a cell as a hexahedral (LAT=1) or hexagonal prism (LAT=2) lattice		3–28
LOST	lost particle abort/debug print control card	[2]	3–145
Mm	material definition card for cells containing material m		3–122,G-1
macrobody	solid geometry primitives for enclosed regions of space (see surfaces)		3–18
MESH	superimposed importance mesh for mesh-based weight window generator		3–49
MESSAGE	optional first line of INP file containing execution line		3–1
MGOPT	multigroup forward/adjoint transport option	[7]	3–129

MODE	definition of particles to be transported in the problem		3–24
MPLOT[I8]	produce plots of tallies while the problem is running		3–151,B–15
MPNm	define photonuclear table to use for each Mm ZAID/fraction pair		3-124
MTm	S(α,β) thermal neutron treatment for material m		3–138,G-5
NONU	treat fission as a capture as a function of cell	[number of cells]	3–126
NOTRN	do only direct (unscattered) type 5 detector tallies from N or P source		3–141
NPS[I8]	number of particles to run from the fixed source	[2]	3–141
#	vertical column input format; also complement geometry operator		3–5,3–9
PDn	detector contribution control by cell for tally n	[number of cells]	3–52
PERTn:p	perturbation of material density, composition, or reaction xs data		3–156
PHYS:p	control physics used for particle transport	[10]	3–131
PIKMT	photon-production bias card for coupled neutron-photon problems		3–128
PRDMP[I8]	print, dump, TFC, and rendezvous control	[5]	3–143
PRINT	control the printing of optional tables to the OUTP file		3–149
PTRAC[I8]	generate a file named PTRAC of user-filtered particle events		3–152,I–1
PWT	control neutron-induced photons produced by cell; MODE N,P or NPE	[cell]	3–40
RAND[I8]	selection and setting of pseudorandom number generator		3–145
RDUM	real array available to the user (see IDUM)	[50]	3–143
repeated structure commands: FILL, LAT, LIKE m BUT, TRCL, U			3–25
SBn	bias for source distribution n		3–62
SCn	comment for source distribution n for OUTP (& continuation not allowed)		3–67
SDn	tally divisors for volume or area, with or without FS card segments		3–108
SDEF	general fixed source specification		3–54
SFn	surface flagging card for tally n	[number of surfaces]	3–106
SIn	source information for distribution n		3–62
SPDTL	prevent or force lattice speed tally enhancements		3-120
SPn	source probability for distribution n		3–62,H–1
SSR	surface source read card for file RSSA		3–72
SSW	write surface source to WSSA file		3–70
surface cards	surface equation coefficients, surface by points, and macrobodies		3–11
Tn	create time bins in shakes (10^{-8} sec) for tally n		3–96
TALNP	tally no-print card to delete tally bin values from the OUTP file		3–151
tally cards	see Fn, FnA, FICn, FIPn, FIRn, and FMESHn cards		3–81
TFn	select one bin for tally n to be used in tally fluctuation chart	[8]	3–111
THTME	times for thermal neutron temperatures of cells on TMPn card(s)	[99]	3–137
title card	one line of required input as problem title		3–2
TMn	time bin multiplier card		3–104
TMPn	free-gas thermal temperature card for time t on THTME card	[cells]	3–136
TOTNU	total fission card to include delayed neutrons for steady state	[1]	3–126
TRn	surface transformation (*TRn = basis matrix in degrees)	[13]	3–30
TRCL	cell transformation (*TRCL = rotation matrix in degrees)	[13]	3–28
TSPLT:p	time splitting and Russian roulette card	[40]	3–38

U	describes what universe a cell belongs to (best put on cell card)	[cells]	3–26
URAN	stochastic geometry card for HTGRs		3-32
VECT	define any number of vectors for exponential transform or user patches		3–42
VOID	delete all cell materials to check geometry/sources, calculate volumes		3–128
VOL	whole cell volume specifications	[number of cells]	3–24
WWE:p	weight window energy or time intervals; use with WWN	[99]	3–45
WWG	weight window generation card	[9]	3–48
WWGE:p	weight window generation energy or time bounds; use with WWG	[15]	3–48
WWNi:p	cell based lower weight window bounds for i^{th} WWE; use with WWP	[cells]	3–45
WWP:p	weight window parameter card; use with WWE	[8]	3–46
XSn	load cross-section evaluation n not listed in XSDIR file directory	[11]	3–127
ZA,ZB,ZC	separate cards for inputting user data to user-modified code		

C. Input Commands by Function

3–161

This section groups cards by functionality. Within each function group, the cards are listed alphabetically followed by the purpose, the maximum number of entries is given in brackets [ ], an asterisk (*) describes the meaning of *NAME, and the reference page is to the far right.

- n indicates a number is required.
- m indicates a number for cards relating to materials is required.
- :p means a particle type indicator N P or E is required.
- I8 means that some entries on this card can be 8 byte integers. The characters “I8” should not be present in the input deck.

1. Problem Type

CONTINUE	first card in file for continue run (C or CN on execute line)		3–2
MODE	definition of particles to be transported in the problem		3–24

2. Geometry

AREA	whole surface area specifications	[number of surfaces]	3–25
FILL	fill cell or lattice elements with universes (*=rotation matrix in degrees)		3–29
LAT	defines a cell as a hexahedral (LAT=1) or hexagonal prism (LAT=2) lattice		3–28
macrobody	solid geometry primitives for enclosed regions of space (see surfaces)		3–18
surface cards	surface equation coefficients, surface by points, and macrobodies		3–11
TRn	surface transformation (*TRn = basis matrix in degrees)	[13]	3–30
TRCL	cell transformation (*TRCL = rotation matrix in degrees)	[13]	3–28
U	describe what universe a cell belongs to (best put on cell card)	[cells]	3–26
URAN	stochastic geometry card for HTGRs		3-32
VOL	whole cell volume specifications	[number of cells]	3–24

3. Source

(Subroutines SOURCE and SRCDX (3-79) are needed if SDEF, SSR, or KCODE are not used.)

DSn	dependent source distribution card		3–66
HSRC	mesh for Shannon entropy of fission source distribution		3-78
KCODE	define a criticality eigenvalue (k_{eff}) problem	[8]	3–77
KSRC	starting source point locations for KCODE problem		3–78
SBn	bias for source distribution n		3–62
SCn	comment for source distribution n for OUTP (& continuation not allowed)		3–67
SDEF	general fixed source specification		3–54
SIn	source information for distribution n		3–62
SPn	source probability for distribution n		3–62,H–1
SSR	surface source read card for file RSSA		3–72
SSW	write surface source to WSSA file		3–70

4. Variance Reduction

BBREM	bias for high-energy bremsstrahlung photons		3–53
CUT:p	time, energy, and implicit capture/weight cutoffs	[5]	3–139
DDn	detector and DXTRAN diagnostics and contribution card		3–112
DXCn:p	DXTRAN contribution for DXTRAN sphere n	[cells]	3–52
DXT:p	define DXTRAN spheres	[53]	3–114
ESPLT:p	energy splitting and Russian roulette card	[40]	3–36
EXT:p	exponential transform (use weight window; FCL not allowed)	[cells]	3–41
FCL:p	force collisions by cell	[number of cells]	3–43
IMP:p	cell importances; required unless weight windows used	[cells]	3–34
MESH	superimposed importance mesh for mesh-based weight window generator		3–49
PDn	detector contribution control by cell for tally n	[number of cells]	3–52
PIKMT	photon-production bias card for coupled neutron-photon problems		3–128
PWT	control neutron-induced photons produced by cell; MODE N,P or N,P,E	[cell]	3–40
TSPLT:p	time splitting and Russian roulette card	[40]	3–38
VECT	define any number of vectors for exponential transform or user patches		3–42
WWE:p	weight window energy or time intervals; use with WWN	[99]	3–45
WWG	weight window generation card	[9]	3–48
WWGE:p	weight window generation energy or time bounds; use with WWG	[15]	3–48
WWNi:p	cell-based lower weight window bounds for i^{th} WWE; use with WWP	[cells]	3–45
WWP:p	weight window parameter card; use with WWE	[8]	3–46

5. Tally

Cn	cosine bins for a type 1 tally	3–97
CFn	tally contributions from flagged cells separately for tally n [number of cells]	3–105
CMn	multipliers for cosine bins of tally n for type 1 tallies	3–105

DEn	dose energy card (use with the DFn card)	3–103,H–4
DFn	dose function card (use with the DEn card)	3–103,H–4
En	upper bounds of energy bins (MeV) for tally n	3–96
EMn	multipliers for energy bins of tally n on the En card	3–104
Fn:p	create cell, surface, or point tally n (*F for energy)	3–81
FnA:p	symmetric ring detector flux tally, where A= X, Y, or Z axis	3–83
FCn	comment printed in OUTP for tally n (& continuation not allowed)	3–95
FICn:p	flux image on a cylindrical image grid	3–83
FIPn:p	flux image through a pinhole to a planar rectangular image grid	3–84
FIRn:p	flux image radiograph on a planar rectangular image grid	3–83
FMn	tally multiplier card for tally n	3–99
FMESHn:p	create a mesh track length tally	3–118
FQn	print hierarchy card for ordering of OUTP tallies [8]	3–98
FSn	subdivide cell or surface into segments for tallying [surfaces]	3–106
FTn	special treatments for tally n	3–116
FUn	user-defined TALLYX tally input; required by some FTn options	3–109
NOTRN	do only direct (unscattered) type 5 detector tallies from N or P source	3–141
PERTn:p	perturbation of material density, composition or reaction cross-section data	3–156
SDn	tally divisors for volume or area, with or without FS card segments	3–108
SFn	surface flagging card for tally n [number of surfaces]	3–106
SPDTL	prevent or force lattice speed tally enhancements	3-120
Tn	create time bins in shakes (10^{-8} sec) for tally n	3–96
TALNP	tally no-print card to delete tally bin values from the OUTP file	3–151
TFn	select one bin for tally n to be used in tally fluctuation chart [8]	3–111
TMn	time bin multiplier card	3–104

6. Material

AWTAB	user specified atomic weight in pairs: “ZAID atomic-weight-ratio”	3–127
DRXS	discrete reaction neutron cross-section card	3–125
Mm	material definition card for cells containing material m	3–122,G-1
MGOPT	multigroup forward/adjoint transport option [7]	3–129
MPNm	define photonuclear table to use for each Mm ZAID/fraction pair	3-124
NONU	treat fission as a capture as a function of cell [number of cells]	3–126
TOTNU	total fission card to include delayed neutrons for steady state [1]	3–126
VOID	delete all cell materials to check geometry/sources, calculate volumes	3–128
XSn	load cross-section evaluation n not listed in XSDIR file directory [11]	3–127

7. Particle Physics

MTm	S(α,β) thermal neutron treatment for material m	3–138,G-5
PHYS:p	controls physics used for particle transport [10]	3–131
THTME	times for thermal neutron temperatures of cells on TMPn card(s) [99]	3–137
TMPn	free-gas thermal temperature card for time t on THTME card [cells]	3–136

8. Problem Cutoffs

CTME	computer time limit in minutes for the problem	[1]	3–142
CUT:p	time, energy, and implicit capture/weight cutoffs	[5]	3–139
ELPT:p	cell energy cutoff (greater of ELPT:p or CUT:p applies)	[cells]	3–140
NPS^{I8}	number of particles to run from the fixed source	[2]	3–141

9. User

C	INP file comment card (no continuation is allowed)		3–4
IDUM	integer array available for user-modified code (see RDUM)	[50]	3–142
RDUM	real array available to the user (see IDUM)	[50]	3–143
ZA,ZB,ZC	separate cards for inputting user data to user-modified code		

10. Peripheral

DBCN^{I8}	debug information card	[30]	3–146
FILES	user file creation card	[30]	3–148
LOST	lost particle abort/debug print control card	[2]	3–145
MESSAGE	optional first line of INP file containing execution line		3–1
MPLOT^{I8}	produces plots of tallies while the problem is running		3–151,B–15
PRDMP^{I8}	print, dump, TFC, and rendezvous control	[5]	3–143
PRINT	control the printing of optional tables to the OUTP file		3–149
PTRAC^{I8}	generate a file named PTRAC of user-filtered particle events		3–152,I–1
RAND^{I8}	selection and setting of pseudorandom number generator		3–145

11. Generic INP File

blank	blank lines separate MESSAGE, cell, surface, and data blocks	3–2
cell cards	define geometry cells with materials (Mm card) or VOID (0)	3–9
data cards	define particles, physics, source, materials, variance reduction, tallies, ...	3–23
#	vertical column input format; also complement geometry operator	3–5,3–9
surface cards	surface equation coefficients, surface by points, and macrobodies	3–11
title card	one line of required input as problem title	3–2

D. Concise Input Command Descriptions

Each input command has the following form:

NAMEn:p one-line description of purpose of card, [the maximum number of entries is given in brackets], (an asterisk describes the meaning of *NAME), reference page to far right.

- n indicates a number is required
- m indicates a number for cards relating to materials is required
- :p means a particle type indicator N P or E is required

list of parameters {default value, if any}
input only parameter values in order

list of keywords {default value, if any}
input: keyword=parameter value, in any order (= is optional)

Duplicate NAMEn:p commands are not allowed and result in a FATAL error.
Additional comments on the use of each NAMEn:p may follow input description.

AREA — surface area specifications in cm^2 [number of surfaces] 3–25

A_1 ... A_n {calculated areas if available}

AWTAB — user specified atomic weight in pairs 3–127

$ZAID_1$ AW_1 $ZAID_2$ AW_2 ... {cross-section file XSDIR}

$ZAID_i$ = ZAID used on the Mm card without the X for data class specification
AW_i = atomic weight ratio to neutron for neutrons or photons
atomic weight ratios that differ from XSDIR may lead to negative neutron energies

BBREM — bias of high-energy bremsstrahlung photons 3–53

B_1 B_2 ... B_{49} M_1 M_2 ... M_n

B_1 = any positive value (currently unused)
B_2...B_{49} = bias factors for bremsstrahlung energy spectrum, from low to high BBREM 1 1 46i 10 5 6 is gradually increasing enhancement for mats 5, 6
M_1...M_n = material numbers for which biasing is to be used; n = number of materials

blank — blank lines separate MESSAGE, cell, surface, and data blocks 3–2

C — INP file one line comment card. C must be in column 1 followed by a space, up to 80 characters long. Comment appears only in echo of input file in OUTP. 3–4
See $ at end of line or FCn (tally) or SCn (source).

Cn — cosine bins for a type 1 tally or t axis for type 5 image tally 3–97
Required if a CMn card is present.

B_1 B_2 ... B_k T or C

n = tally number ending in 1 or 5; 0 for type 1 tallies without Cn card
B_i = monotonically increasing upper cosine for the i^{th} type 1 bin
$B_0 = -1$ and is not entered. $B_1 > -1$ and $B_k = 1$ for type 1 tally
= monotonically increasing t-axis values for type 5 image tallies FIC, FIP, FIR
T = optional; creates a total over all type 1 cosine bins (not for image tallies)
C = optional; creates cumulative tally in cosine (not for image tallies)

cell cards define geometry cells. Cell number begins in columns 1-5. 3–9

J m D GEOM params or
J LIKE n BUT list

J	=	cell number; begins in columns 1-5; J = 1-99999; J = 1-999 with transformation)
m	=	material number on the Mm card
	=	0 for void cell
D	=	cell material density or absent if m = 0
	>	0 atom density in units of atoms/barn-cm (10^{-24} atoms/cm^3)
	<	0 mass density in units of grams/cm^3
GEOM	=	signed surface numbers and Boolean operators which are: blank intersection operator : union operator # complement operator - followed by one cell number #i space not in cell i or several cells: #i1 #i2 ... Many #'s can complicate cell specification for slow tracking. Parentheses control operation hierarchy: default is # intersection then union.
params	=	cell parameters with form: keyword = value. Allowed keywords are: U, TRCL, FILL, LAT (best placed on cell card) DXC, EXT, FCL, IMP, NONU, PD, PWT, TMP, VOL, WWN
LIKE n BUT	=	gives cell J all attributes of problem cell n except list n = name of another cell
list	=	params list above plus MAT (material number) and RHO (density)

CFn tally contributions from flagged cells separately for tally n [cells] 3–105

C_1 C_2 ...

n	=	tally number not ending in 5 (use FTn card option ICD) or 8
C_i	=	problem cells where tracks leaving are flagged for a second (subset) tally

CMn multipliers for cosine bins of tally n for type 1 tallies 3–105
Not available for type 5 FIC, FIP, FIR image tallies.

M_1 M_2 ... M_k (k = number of entries on the Cn card)

n	=	tally number ending in 1. CM0 for all type 1 tallies without own CMn card
M_i	=	multiplier for the i^{th} cosine bin

CONTINUE first card in continue run file. Data cards allowed in continue run are: 3–2

CTME, DBCN, DD, FQ, IDUM, KCODE, LOST, MPLOT,
NPS, PRDMP, PRINT, RDUM, ZA,ZB,ZC

CTME computer time limit in minutes for the problem [1] 3–142

T = problem time limit in CPU minutes (additional minutes for continuation)
This time is the total for all CPUs and not the wall-clock time for the problem.

CUT:p time, energy, and implicit capture/weight cutoffs [5] 3–139

T{large} E{0 for N; 0.001 for E and P} WC1{-0.5} WC2{-0.25} SWTM

p = N for neutrons, P for photons, E for electrons
T = time cutoff in shakes, 1 shake = 10^{-8}sec
E = lower energy cutoff in MeV
WC1 < 0 upper weight cutoff relative to source weight; default recommended
> 0 upper weight cutoff relative to cell importances
= 0 analog capture at all energies
WC2 = lower weight cutoff (negative value for relative to source weight)
SWTM = minimum source weight. Ignored for KCODE k_{eff} calculation.
rusroul off = for mode E or P, turns off rouletting (for IMP or WWN),
may be useful when using F8 tallies with variance reduction

data cards define particles, physics, source, materials, variance reduction, tallies, ... 3-23
Most of the input commands described in this appendix are data cards.

DBCN debug information card [30] 3–146

X_1{19073486328125} X_2 X_3 X_4 X_5{600} X_6 X_7{0}
X_8 X_9{0.0001 cm} X_{10}{100 sec} X_{11}{0} X_{12} X_{13}{152917}
X_{14} X_{15}{0} X_{16}{1.0} $X_{17\text{-}30}${0}

X_1 = the starting pseudorandom number (also see the RAND card)
X_2 = every X_2 particles, print “dbcn”, history number, collisions, total number of random numbers, history starting random number. DBUG n execution line option also prints this line every n histories. DBCN print is incompatible with multitasking (FATAL error).
X_3,X_4 = lower and upper history numbers for event log printing
Event logs are incompatible with multitasking (FATAL error).
X_5 = maximum number of events in the event log to print per history
X_6 = unused
X_7 = 1 detailed print from the volume and surface area calculations
X_8 = history number whose starting pseudorandom number will start problem (see RAND)
X_9 = closeness of coincident repeated structure surfaces
X_{10} = unused
X_{11} = 1 causes collision lines to print in lost particle event log
X_{12} = expected number of random numbers for tracking comparisons
X_{13} = random number stride between starting random numbers (see RAND card)

X_{14} = unused
X_{15} = 1 prints variance of variance and shifted confidence interval for all tally bins
X_{16} = number to scale history score grid for creating empirical f(x) pdf
X_{17} > 0 alternate angular treatment for secondary particle production
= 0 default angular treatment for partial electron substeps
< 0 MCNP4A angular treatment for secondary particle generation
X_{18} = 0 default "MCNP–style" Landau straggling sampling logic (bin-centered treatment)
1 "ITS–style" Landau straggling sampling logic (nearest-group-boundary treatment)
2 detailed Landau straggling sampling logic (energy- and step-specific treatment)
$X_{19\text{-}30}$ = Unused

DDn detector and DXTRAN diagnostics and contribution card 3–112

DDn eliminates tracks for DXTRAN and contributions for point detectors. Not used by point detector image tallies FIC, FIP, and FIR.

$K_1\{0.1\}$ $M_1\{1000\}$ K_2 M_2 ...

n = 0 or blank global DD card
1 neutron DXTRAN spheres
2 photon DXTRAN spheres
tally number ending in 5 for a specific non-image detector tally
K_i = criterion for small score tally contribution Russian roulette for detector i in tally n
> 0,<1 all contributions for first 200 histories are made; then > K_i*average
= 0 no Russian roulette game is played
< 0 contributions > -K_i are always made; otherwise use Russian roulette
M_i = criterion for printing large detector tally or DXTRAN contributions
= 0 no diagnostic prints
> 0, K_i>0 first 100 contributions after 200 histories>M_i*average tally
> 0, K_i<0 prints the first 100 contributions > M_i*(-K_i)

DEn dose energy card (used with the DFn card) 3–103,H–4

A{LOG} E_1 E_2 ... E_k (k must equal k on the DFn card)

n = tally number. 0 applies DE bins to all tallies without DEn and DFn cards.
A = blank or LOG or LIN interpolation method for energy table
E_i = monotonically increasing energy value in MeV

DFn dose function card (used with the DEn card) 3–103,H–4

A tally comment card FCn is recommended.

B{LOG} F_1 F_2 ... F_k (k must equal k on the DEn card)

n = tally number. 0 applies DF function to all tallies without DEn and DFn cards.
B = blank or LOG or LIN interpolation method for dose function table
F_i = the corresponding value of the dose function for DEn card

$ (dollar sign) comment at end of input line. Appears only in echo of input file in OUTP. See C comment card or FCn or SCn. 3–4

DRXS discrete reaction neutron cross-section card 3–125

blank or $ZAID_1$ $ZAID_2$ ...

blank = use 262 energy group discrete reaction cross sections for all nuclides
$ZAID_i$ = nuclide number of the form ZZZAAA.nn for discrete reaction. Continuous scattering kinematics are used in the discrete reaction treatment. See the MGOPT card for a true multigroup (group-to-group transfer) calculation.

DSn dependent source distribution card 3–66

option J_1 J_2 ... J_k {H} or
T I_1 J_1 I_2 J_2 ... I_k J_k or
Q V_1 S_1 V_2 S_2 ... V_k S_k

n = source distribution number from 1 to 999
option = blank or H (continuous scalar), L (discrete), or S (distributions)
J_j = values of the dependent source variable
T = dependent variable values follow independent (discrete scalar)
I_j = values of the independent source variable
Q = distribution numbers follow the independent variable (scalar)
V_j = monotonically increasing values of the independent variable
S_j = distribution numbers for the dependent variable

DXCm:p DXTRAN contribution card for DXTRAN sphere m [cells] 3–52
Consider using the DDn card.

P_1 P_2 ... P_I {m = 0; P_i = 1.}

m = DXTRAN sphere the DXC card applies to
0 or blank applies to all DXTRAN spheres in the problem
p = N for neutrons, P for photons, not available for electrons
P_i = probability of contribution to DXTRAN spheres from cell i

DXT:p define DXTRAN spheres
[10 sets of xyz RI RO entries for each particle type] 3–114
Carefully evaluate crosstalk between DXTRAN spheres.
Consider using the DXC:N, DXC:P or DD cards when using DXTRAN.

X_1 Y_1 Z_1 RI_1 RO_1 ... X_5 Y_5 Z_5 RI_5 RO_5 ... DWC_1{0}
DWC_2{0} DPWT{0}

p = N for neutrons, P for photons, not available for electrons
X_i,Y_i,Z_i = coordinates of the center of the i^{th} DXTRAN sphere
RI_i = radius of the i^{th} inner sphere in cm (to cover tally regions)
RO_i = radius of the i^{th} outer sphere in cm (to cover scattering regions)
DWC_1 = upper weight cutoff in the spheres
DWC_2 = lower weight cutoff in the spheres
DPWT = minimum photon weight; entered on DXT:N card only.

En upper bounds of energy bins in MeV for tally n 3–96
Required if an EMn card is present.

B_1 B_2 ... B_k NT or C

n = tally number. 0 applies bins to all tallies without an En card
B_i = monotonically increasing upper energy of i^{th} bin, B_0=energy cutoff
NT = optional; deletes the total energy bin
C = optional; causes bin values to be cumulative

ELPT:p energy cutoff by cell (> of E_i or global value E on CUT applies) [cells] 3–140

E_1 E_2 ... E_I {CUT:p card energy cutoff}

p = N for neutrons, P for photons, E for electrons
E_i = lower energy cutoff in MeV for cell i

EMn multipliers for the energy bins of tally n on the En card 3–104

M_1 M_2 ... M_k (k must equal k on the En card)

n = tally number. 0 applies multipliers to all tallies without an EMn card
M_i = multiplier applied to the i^{th} energy bin

ESPLT:p energy splitting and Russian roulette card [20 pairs of R_i E_i] 3–36
Intended to be used with time-dependent weight window.
Not recommended for energy-dependent window; use energy-dependent weight window instead.

R_1 E_1 R_2 E_2 ... R_{20} E_{20}

p = N for neutrons, P for photons, E for electrons
R_i > 1 number of tracks particle will be split into for energy decrease
R_i > 0 <1 Russian roulette survival probability
R_1 > 0 inverse energy importance game played for an energy increase
R_1 < 0 no energy importance game played for energy increase
E_i = energy in MeV at which splitting or Russian roulette occurs

EXT:p exponential transform [cell] 3–41
Use with weight windows. Not allowed with FCL.

A_1 A_2 ... A_I {all 0; no stretching}

p = N for neutrons, P for photons, not available for electrons
A_i = QVm, where
Q = constant stretching parameter between 0 and 1 or
Q = S where $S = \Sigma_a/\Sigma_t$, the capture cross section and
Vm= stretching direction given on the VECT card

Fn:p cell, surface, or point detector tally [100 or 20 if type 5] 3–81
(*Fn:p units of energy)

C_1 C_2 ... C_k T or C_1 (C_2 C_3 ... C_i) ... C_k T
C_i = problem number of cell or surface for tallying or T for total
(C_2 C_3 ... C_i) is union; unnormed if sum, normed if average.

n defines the tally type as follows, where n ≤ 998

1 current integrated over a surface; N P or E
2 flux averaged over a surface; N P or E
4 flux averaged over a cell; N P or E
6 energy deposition averaged over a cell (*F = jerks/g); N N,P or P
7 fission energy deposition averaged over a cell (*F = jerks/g); N only
8 pulse height tally; P E or P,E
+F8 = charge deposition tally; E only

5 flux at a point N or P

X Y Z R_0{0} ... ND

X Y Z coordinates of the detector location
$+R_0$ radius of sphere of exclusion in cm
$-R_0$ radius of sphere of exclusion in mean free paths (illegal in void)
R_0 should encompass only one material.
$R_0 = 0$ no sphere; use in a void.
ND do not print direct detector contributions in tally n

5X, 5Y or 5Z particle flux tally on a ring (FnA:p) N or P 3–83

a_o r R_0 ... ND

a_o distance along axis where ring plane intersects axis
r radius of ring in cm
R_0 and ND same as point detector above

Use ring detector only for symmetric geometry. Constant flux on ring is assumed. A ring detector is usually much more efficient than a point detector.

Repeated structure/lattice tallies (F1, 2, 4, 6, 7, 8): 3–92

S_1 (S_2 ... S_3) ((S_4 S_5) < (C_1 C_2 [I_1 ... I_2]) < (C_3 C_4 C_5)) ...

innermost level to the outermost level of geometry

S_i = problem number of cell or surface, U=universe number (FILL card), or T
C_i = problem number of a cell filled with a universe or U = universe number
I_i = index data for a lattice cell element with three possible formats:
I_1 = I_1^{th} lattice element of cell C_2 as defined in the FILL array
I_1:I_2 I_3:I_4 I_5:I_6 = range of lattice elements. Same format as FILL card.
I_1 I_2 I_3, I_4 I_5 I_6 = specific individual lattice elements (I_1,I_2,I_3) and (I_4,I_5,I_6)

SDn card is likely needed to enter volumes or areas 3–108

FCn user comment for tally n; n cannot be blank or zero and is followed by a space. 3–95
Columns 1-5 blank for continuation; & continuation not allowed.
Use especially when tally Fn has been modified in some manner.

FCL:p force collisions by cell [cells] 3–43

X_1 X_2 ... X_I {all 0}

p = N for neutrons, P for photons, not available for electrons
X_i = number of forced collisions in cell i. $-1 \le X_i \le 1$
> 0 forced collisions apply to entering and collided particles in cell i
= 0 no forced collisions
< 0 forced collisions apply only to particles entering cell i

FICn:p flux image on a cylindrical grid surface; only one image per card 3–83
Use FSn and Cn cards to define image grid.
Use TALNP to reduce size of OUTP.
Use NOTRN for direct (unscattered) contributions.

X_1 Y_1 Z_1 R_0 X_2 Y_2 Z_2 F_1 F_2 F_3

n = tally number ending in 5 for point detector tally
p = N for neutrons, P for photons, not available for electrons
X_1,Y_1,Z_1 = coordinates of the center of the cylindrical image grid
R_0 = always 0. Do not put image grid in scattering material.
X_2,Y_2,Z_2 = reference coordinates of axis of cylinder from (X_2,Y_2,Z_2 to X_1,Y_1,Z_1)
F_1 = 0 both direct source and scattered contributions made to the image grid
< 0 only scattered contributions scored. Use NOTRN for only direct.
F_2 = 0 radius of the cylindrical surface of the image grid
F_3 = 0 contributions are directed to center of each image grid bin (pixel)
≠ 0 contributions are made with random offset in pixel (constant for an event)

FILES — user file creation card — [6 sets of 5 entries each] — 3–148
See Cautions in manual.

unit filename access {S} form {F if S, U if D} record length

unit = 1 to 99
filename = name of the file to be created
access = sequential (S) or direct (D)
form = formatted (F) or unformatted (U)
record length = record length in a direct access file

FILL — fill cell or lattice elements with universe(s) — 3–29
(*=rotation matrix angle in degrees)

N (T) or I_1:I_2 I_3:I_4 I_5:I_6 N_1 N_2 ... N_t

N = universe number (see U card)
T = optional transformation number or the transformation itself
I_i = range of i,j,k lattice indices
N_i = universe for the i^{th} element of the lattice array with t elements

FIPn:p — flux image through a pinhole to a planar rectangular grid. — 3–84
One image per card.
Use FSn and Cn cards to define image grid.
Use TALNP to reduce size of OUTP.
Use NOTRN for only direct contributions.

X_1 Y_1 Z_1 R_0 X_2 Y_2 Z_2 F_1 F_2 F_3

n = tally number ending in 5 for point detector tally
p = N for neutrons, P for photons, not available for electrons
X_1,Y_1,Z_1 = coordinates of the center of the pinhole
R_0 = always 0. Do not put image grid in scattering material.
X_2,Y_2,Z_2 = coordinates for reference direction for grid normal (X_2,Y_2,Z_2 to X_1,Y_1,Z_1)
F_1 > 0 radius of cylindrical collimator for radial field of view through object
F_2 = 0 perfect point pinhole
> 0 radius of the pinhole perpendicular to the reference direction
F_3 = distance from pinhole at X_1,Y_1,Z_1 to image grid center on reference direction

FIRn:p — flux image radiograph to planar rectangular image grid — 3–83
One image per card.
Use FSn and Cn cards to define image grid.
Use TALNP to reduce size of OUTP.
Use NOTRN for only direct contributions.
Use second NPS entry to limit direct FIR contributions for simple sources.

X_1 Y_1 Z_1 R_0 X_2 Y_2 Z_2 F_1 F_2 F_3

n = tally number ending in 5 for point detector tally
p = N for neutrons, P for photons, not available for electrons
X_1,Y_1,Z_1 = coordinates of the center of the image grid
R_0 = always 0. Do not put image grid in scattering material.
X_2,Y_2,Z_2 = coordinates defining outward normal to image grid (X_1,Y_1,Z_1 to X_2,Y_2,Z_2)
F1 = 0 both direct source and scattered contributions made to the image grid
< 0 only scattered contributions are scored. Use NOTRN for only direct.
F2 = 0 radial field of view on the image grid
F3 = 0 contributions are directed to center of each image grid bin (pixel)
≠ 0 contributions are made with random offset in pixel (constant for an event)

FMn general tally multiplier card for tally n 3–99

(bin set 1) (bin set 2) ... T or C
n = tally number not ending in 8 and cannot be zero or blank
bin set i = ((multiplier set 1)(multiplier set 2)...(attenuator set))
T = total over all bin sets if present
C = cumulative tally bins

attenuator set = C –1 m_1 px_1 m_2 px_2 ...
–1 is the flag for attenuator set
px = density times thickness of attenuating material

multiplier set = C m_1 (reaction list 1) (reaction list 2) ...
C > 0 multiplicative constant
< 0 type 4 tally only; multiply by /C/ times tally cell atom density

m_i = material number identified on an Mm card

special case with only two entries: C –k
k = –1 tallies number of particle tracks (collisions for detectors)
k = –2 tallies neutron population integrated over time
reaction list i = sum and/or product of ENDF or special reaction numbers

Special nonstandard R numbers follow. Units are barns unless otherwise noted.

See Appendix G for a more complete list of ENDF reaction numbers.

Neutrons:
–1 total cross section without thermal
–2 absorption cross section
–3 elastic cross section without thermal
–4 average heating number (MeV/collision)

	–5	gamma-ray production cross section
	–6	fission cross section
	–7	fission ν (neutrons per fission)
	–8	fission Q (MeV/fission)
Photons:	–1	incoherent scattering cross section
	–2	coherent scattering cross section
	–3	photoelectric cross section
	–4	pair production cross section
	–5	total cross section
	–6	photon heating number (MeV/collision)
Multigroup:	–1	total
	–2	fission
	–3	nubar data
	–4	fission χ
	–5	absorption
	–6	stopping power
	–7	momentum transfer

FMESHn:p create a mesh track-length tally where n is the tally number. 3–118
Can be used with DEn, DFn, and FMn cards.
Caution: It is easy to create huge mesh tallies that can overflow computer memory.

Keywords GEOM{xyz} ORIGIN{0,0,0} AXS{0,0,1} VEC{1,0,0} IMESH IINTS{1} JMESH JINTS{1} KMESH KINTS{1} EMESH EINTS{1} FACTOR{1.} OUT{col} TR

GEOM	=	mesh geometry: Cartesian ("xyz" or "rec") or cylindrical ("rzt" or "cyl")
ORIGIN	=	x,y,z coordinates in MCNP cell geometry superimposed mesh origin (bottom center for cylindrical or bottom, left, behind for rectangular)
AXS	=	direction vector of the cylindrical mesh axis
VEC	=	direction vector, along with AXS that defines the plane for angle $\theta = 0$
IMESH	=	coarse mesh locations in x (rectangular) or r (cylindrical) direction
IINTS	=	number of fine meshes within corresponding coarse meshes
JMESH	=	coarse mesh locations in y (rectangular) or z (cylindrical) direction
JINTS	=	number of fine meshes within corresponding coarse meshes
KMESH	=	coarse mesh locations in z (rectangular) or θ (cylindrical) direction
KINTS	=	number of fine meshes within corresponding coarse meshes
EMESH	=	values of coarse meshes in energy
EINTS	=	number of fine meshes within corresponding coarse energy meshes

FACTOR = multiplicative factor for each mesh
OUT = "ij", "ik", or "jk" for 2-D matrices written to MESHTAL, where
ij = xy or rz 2-D matrices
= ik = xz or rθ 2-D matrices
= jk = yz or zθ 2-D matrices
= "col" column format for mesh tallies written to MESHTAL
= "cf" col output + mesh volumes and tallies multiplied by mesh volumes
TR = transformation number to be applied to the tally mesh

FQn tally print hierarchy card for ordering of printed output [8] 3–98

A_1 ... A_7 A_8 (A_7 is vertical and A_8 is horizontal) {default order below}

n = tally number or 0 to change print default for tallies without own FQn
A_i = F cell, surface, or detector tally
D direct or flagged tally
U user bins
S segment tallies
M multiplier bins
C cosine bins
E energy bins
T time bins

FSn subdivide cell or surface into segments for tallying [surfaces] 3–106
May require an SDn card. Should consider an FQn card.

S_1 S_2 ... T or C

n = tally number; not type 5 detector or type 8; cannot be zero or blank
S_i = signed problem number of a segmenting surface
= monotonically increasing s-axis values for type 5 image tallies FIC, FIP, FIR
T = optional total of all tallies (not active for image tallies)
C = cumulative tally in segments (not active for image tallies)

FTn special treatments for tally n 3–116

ID_1 $P_{1,1}$ $P_{1,2}$ $P_{1,3}$ ... ID_2 $P_{2,1}$ $P_{2,2}$ $P_{2,3}$ ...

n = tally number; cannot be zero or blank
IDi = alphabetic keyword identifier and $P_{i,j}$ parameters if any:
FRV $\boldsymbol{V_1}$ $\boldsymbol{V_2}$ $\boldsymbol{V_3}$ fixed reference direction $\boldsymbol{V}$'s for tally 1 cosine
GEB ***a b c*** Gaussian detector energy broadening of a tally result
TMC ***a b*** time convolution for a square wave pulse from time ***a*** to ***b***
INC tally by the number of particle collisions; FUn card required
ICD tally detector contributions by cell; FUn card required

SCX ***k***	tally by SI***k*** source distribution(s) plus total
SCD	tally specific source distributions; FUn card required
PTT	tally by multigroup particle type; FUn card required
ELC ***c***	electron current tally depending on ***c***: 1 negative electrons make negative scores 2 positrons/electrons put into separate user bins plus total 3 for the effect of ***c***=1 and ***c***=2 plus total

FUn — used with user-supplied TALLYX (3-110, 4-49) and with some FTn options — 3–109

X_1 X_2 ... X_k NT or C

n = tally number; cannot be zero or blank
no X_k's causes subroutine TALLYX to be called with no user bins
X_i = input parameter establishing user bin i
NT = optional; inhibits the total bin.
C = optional; causes cumulative tally in user bins.

HSRC — n_x x_{min} x_{max} n_y y_{min} y_{max} n_z z_{min} z_{max} — 3-78

n_x = number of mesh intervals in x-direction
x_{min} = minimum x-value for mesh
x_{max} = maximum x-value for mesh

(similar for y- and z-directions)

IDUM — integer array available for user-modified code (see RDUM) [50] — 3–142

I_1 I_2 ... I_{50} {all 0}
I_i = integer number for the i^{th} entry

IMP:p — define cell importances [number of cells] — 3–34

X_1 X_2 ... X_I

p = N for neutrons, P for photons, E for electrons, N,P or P,E or N,P,E
X_i = importance for cell i; positive number, can be noninteger
= 0 terminate particle when entering cell i

KCODE — define a criticality eigenvalue (k_{eff}) problem [8] — 3–77
Skip enough cycles (IKZ) so fundamental fission spatial mode is converged.
Tally values are for one fission neutron in problem: scale to power level with FMn
Multigroup adjoint KCODE is not allowed.

NSRCK{1000} RKK{1} IKZ{30} KCT{IKZ+100}
MSRK{>4499 or 2*NSRCK} KNRM{0} MRKP{651} KC8{1}

NSRCK = nominal neutron source size per cycle (neutron generation)
RKK = initial guess for k_{eff}. Used on first cycle only.
IKZ = number of cycles to be skipped before beginning tally accumulation
KCT = total number of cycles to be calculated
MSRK = number of neutron source points to allocate storage for
KNRM = method of tally normalization. 0 = weight, 1 = number
MRKP = number of k_{eff} cycles to be stored in RKPL array (prints, plots)
KC8 = 1 summary and tally information averaged over active cycles only
0 averaged over active and inactive cycles. Should not be used.

KSRC — first cycle KCODE neutron source points [NSRCK sets of triplets] — 3–78
See SRCTP file and SDEF card. If used, omit KSRC card.
Energy sampled from Watt fission spectrum for first cycle.

X_1 Y_1 Z_1 X_2 Y_2 Z_2 ...

X_i Y_i Z_i = location of initial neutron source points in fissile material

LAT — defines a cell as an infinite array of hexahedra or hexagonal prisms — 3–28

LAT = 1 lattice is made of hexahedra, solids with six faces
LAT = 2 lattice is made of hexagonal prisms, solids with eight faces

LOST — lost particle abort/debug print control card [2] — 3–145
The cause of lost particles should be found and corrected.

LOST1{10} LOST2{10}

LOST1 = number of particles which can be lost before the job aborts (bad trouble)
LOST2 = maximum number of debug prints made for lost particles

Mm — material definition card — 3–122,G-1
See thermal neutron MTm and photonuclear MPNm cards.
See http://www-xdiv.lanl.gov/PROJECTS/DATA/nuclear for nuclear data information.

$ZAID_1$ *fraction*$_1$ $ZAID_2$ *fraction*$_2$ ... keyword=value

m corresponds to the material number on a cell card.
$ZAID_i$ = a full ZZZAAA.nnX or partial ZZZAAA identifier for constituent i
ZZZ = atomic number,
AAA= atomic mass,
nn = library identifier,

X = data class

fraction$_i$ = atomic fraction (or weight fraction if negative) of constituent i

Keywords

GAS = m flag for density correction to electron stopping power
m = 0 material in the solid or liquid state. Default.
m = 1 material in the gaseous state

ESTEP = n n electron substeps per energy step (see print table 85)

NLIB = id change default XSDIR neutron table identifier to id

PLIB = id change default XSDIR photon table identifier to id

PNLIB = id change default XSDIR photonuclear table identifier to id

ELIB = id change default XSDIR electron table identifier to id

COND = set conductor state of a material for el03 evaluation
> 0 conductor if at least one conducting component
= 0 nonconductor if at least one nonconductor component; otherwise set to a conductor. Default.
< 0 nonconductor

macrobodies constructive solid geometry primitives for enclosed regions of space 3–18
names: ARB, BOX, ELL, HEX, RCC, REC, RHP, RPP, SPH, TRC, WED
facets labeled with ".1", ".2" .... View facets with plot command: mbody = off.

MESH superimposed importance mesh for mesh-based weight window generator 3–49

Keywords GEOM{xyz} REF ORIGIN{0,0,0} AXS{0,0,1} VEC{1,0,0} IMESH IINTS{1} JMESH JINTS{1} KMESH KINTS{1}

GEOM = mesh geometry: Cartesian ("xyz" or "rec") or cylindrical ("rzt" or "cyl")

REF = x,y,z coordinate of reference point. Keyword REF is ***required***.

ORIGIN= x,y,z coordinates of superimposed mesh origin

AXS = direction vector of the cylindrical mesh axis

VEC = vector, along with AXS, that defines the plane for θ = 0

IMESH = coarse mesh locations in x (rectangular) or r (cylindrical) direction

IINTS = number of fine meshes within corresponding coarse meshes

JMESH = coarse mesh locations in y (rectangular) or z (cylindrical) direction

JINTS = number of fine meshes within corresponding coarse meshes

KMESH= coarse mesh locations in z (rectangular) or θ (cylindrical) direction

KINTS = number of fine meshes within corresponding coarse meshes

MESSAGE optional first line(s) of INP file containing execution information 3–1
Must end with blank line delimiter before the title card.

starts with string MESSAGE: followed by a space, then:

default_filename=newname exec_options other_options

where
exec_options: i p x r z

other_options: C m CN DBUG n NOTEK FATAL PRINT TASKS nxm BALANCE

See Chapter 1 for details of execution and other options.

MGOPT multigroup forward/adjoint transport option [7] 3–129

MCAL IGM IPLT{0} ISB{0} ICW{0} FNW{1} RIM{1000}

MCAL = "F" forward problem, "A" adjoint problem – not adjoint KCODE
IGM = total number of energy groups (negative=special electron-photon)
IPLT = 0 IMP sets cell importances (weight windows are ignored)
1 weight windows that become energy-dependent cell importances
2 weight windows with the standard treatment
ISB = 0 adjoint collisions are biased by infinite-medium fluxes
1 adjoint collisions are biased by weight windows functions
2 adjoint collisions are not biased
ICW = 0 weight windows are not generated
≠ 0 reference cell for generated weight windows. Requires cell volumes.
FNW = normalization value for generated weight windows
RIM = generated weight windows compression limit

MODE definition of particles to be transported in the problem 3–24

X_1{N} X_2 X_3

X_i = N neutron transport
P photon transport
E electron transport

In multiparticle problems, the starting source particle can be changed from default with PAR keyword on SDEF.

MPLOT produce plots of tallies while the problem is running 3–151,B–15

MCPLOT keyword = parameter

frequency of plotting is set by FREQ n entry {nps 5000 or 5 cycles}
MCPLOT commands not allowed: END, RMCTAL, RUNTPE, DUMP
See Appendix B page B-15 for lists of keywords.

MPNm define photonuclear table to use for each Mm ZAID/fraction pair 3-124

$PNZA_1$ $PNZA_2$ ...

$PNZA_i$ = ZAID of photonuclear replacement table for the i^{th} Mm ZAID/fraction pair
= 0 turns off photonuclear reactions for the i^{th} ZAID on the Mm card

MTm S(α,β) thermal neutron treatment for material m on Mm card 3–138,G-5
S(α,β) identifiers for the MTm card are listed in Appendix G

X_1 ...

X_i = S(α,β) identifier corresponding to an isotope in Mm

NONU treat fission as capture as a function of cell [cells] 3–126

A_1 A_2 ... A_I or blank {0}

A_i = 0 fission in cell i treated as capture; gammas produced
1 fission in cell i treated as real; gammas produced
2 fission in cell i treated as capture; gammas not produced
blank means that all A_i's = 0 and all fission is treated as capture

NOTRN do only direct (unscattered) type 5 detector tallies from N or P source 3–141

NPS number of particles to run in a fixed source problem [2] 3–141

N NPSMG

N = total number of histories to be run in both an initial and CONTINUE run
< 0 in CONTINUE run: reprint OUTP from RUNTPE and quit
NPSMG = number of direct source contributions to make to FIR image tallies

(pound sign) input by vertical (column) format or complement geometry operator 3–5,3–9

data card names or source distributions
optional cell name data values or SI, SP, SB values

"#" and optional cell name begin in columns 1 to 5 followed by a blank.

complement operator format: #***n*** where ***n*** is a cell number.
#***n*** defines the space not in cell ***n.*** Too many #'s will result in slow tracking.

PDn detector contribution control by cell for tally n [number of cells] 3–52

P_1 P_2 ... P_I {all P_i's = 1}

n = tally number ending in 5. 0 applies to all type 5 tallies without PDn card.
P_i = probability from 0 to 1 of contributing to a detector from cell i
(P_i = 0 is valid)

PERTn:p perturbation number n for perturbed tally estimates 3–156

n = unique perturbation number ≤ 999
p = N, P or N,P Electrons not allowed; FATAL error.

Keywords: CELL MAT RHO METHOD{1} ERG{all} RXN {total xsec: all}

CELL = required list of perturbed cell(s), comma or space delimited
MAT = perturbation material number on Mm card
RHO = perturbed density of cells on CELL keyword
either MAT or RHO card is required to define perturbation
METHOD = 1 first and second order terms in differential change to unperturbed tally

= 2 only first order term for differential tally change
= 3 only second order term for differential tally change
= –1,–2, or –3 ***adds*** perturbation change to unperturbed tally

ERG = lower and upper energy entries to specify energy range for perturbation

RXN = ENDF/B reaction types to perturb (see Appendix G)

PHYS:E electron physics card [9] 3–131

EMAX{100 MeV} IDES{0} IPHOT{0} IBAD{0} ISTRG{0}
BNUM{1} XNUM{1} RNOK{1} ENUM{1} NUMB{0}

EMAX = upper limit for electron energy in MeV
IDES = 0/1 photons will/will not produce electrons
IPHOT = 0/1 electrons will/will not produce photons
IBAD = 0 full bremsstrahlung tabular angular distribution
1 simple bremsstrahlung angular distribution approximation
ISTRG = 0/1 sampled/expected value straggling for electron energy loss
BNUM > 0 produces BNUM times the analog number of bremsstrahlung photons
0 bremsstrahlung photons will not be produced
< 0 special bremsstrahlung treatment for el03 evaluation
XNUM > 0 produces XNUM times analog number of electron-induced x-rays
0 x-ray photons will not be produced by electrons
RNOK > 0 produces RNOK times the analog number of knock-on electrons
0 knock-on electrons will not be produced
ENUM > 0 makes ENUM times analog # of photon-induced secondary electrons
0 photon-induced secondary electrons will not be produced
NUMB > 0 produce bremsstrahlung on each substep
0 nominal bremsstrahlung production
|BNUM| ≥ 1 and NUMB > 0 are incompatible (FATAL error)

PHYS:N neutron physics card [4] 3–131

EMAX{very large} EMCNF{0 MeV} IUNR{0} DNB{–1} FISNU{0}

EMAX = upper limit for neutron energy. cross sections > EMAX expunged
EMCNF = energy boundary; > receives implicit capture; < gets analog capture
IUNR = 0/1 on/off unresolved resonance range probability tables
DNB = –1/0/>0 natural/none/DNB delayed neutrons per fission event
FISNU < 0 negative of the Gaussian width to be used for sampling fission neutron multiplicities for all fissionable isotopes.
= 0 sample fission neutron multiplicity using bounded integers (default).
= 1 use reevaluated Gaussian widths by isotope (recommended for non-bounded integer sampling).
= 2 use original Terrell Gaussian widths by isotope.

PHYS:P photon physics card [5] 3–131

EMCPF{100 MeV} IDES{0} NOCOH{0} ISPN{0} NODOP{0}

EMCPF = upper energy limit for detailed photon physics treatment
IDES = 0 photons make electrons in MODE E or bremsstrahlung (thick target)
1 photons will not produce electrons as above
NOCOH = 0/1 coherent scattering will/will not occur
ISPN = 1/0/–1 biased/none/analog photonuclear interactions turned on
NODOP = 0/1 Doppler photon energy broadening will/will not occur

PIKMT photon-production bias card for coupled neutron-photon problems 3–128

Z_1 $IPIK_1$ $MT_{1,1}$ $PMT_{1,1}$ ... $MT_{1,IPIK1}$ $PMT_{1,IPIK1}$ Z_2 $IPIK_2$ ...

Z_i = full or partial ZAID of the i^{th} data set entry
$IPIK_i$ = 0 no biasing of photon-production for ZAID Z_i
> 0 photon-production biasing for $ZAID_i$ with $IPIK_i$ pairs of data
= –1 no photons are produced from $ZAID_i$
$MT_{i,j}$ = identifiers for photon-production reactions to be sampled ($IPIK_i > 0$)
$PMT_{i,j}$ = numbers that control the frequency of $MT_{i,j}$ sampling ($IPIK_i > 0$)

Use ASCII file DISCEGAM to select neutron-photon reactions at the website:
http://www-xdiv.lanl.gov/PROJECTS/DATA/nuclear/photon/photon.html

PRDMP print, dump, and rendezvous control card [5] 3–143

NDP{end of problem} NDM{60 minutes} MCT{0} NDMP{large} DMMP{0}

NDP > 0 print after every NDP ***histories*** or NDP criticality ***cycles***
< 0 print after NDP ***minutes*** of computer time
NDM > 0 dump to RUNTPE file every NDM ***histories*** or criticality ***cycles***
< 0 dump to RUNTPE file every NDM ***minutes***
MCT > 0 write a MCTAL file at the end of the problem
< 0 write MCTAL with no time-dependent quantities for SQA comparisons
NDMP > 0 keep only the last NDMP dumps on the RUNTPE file
DMMP< 0 makes TFC entry every 1000 histories to 20000, then 2000 to 40000, ...
= 0 is same as <0 for sequential MCNP operation
= 0 makes 10 TFC entries during run for multiprocessing; if detectors or DXTRAN are present with default Russian roulette, same as <0 entry
> 0 makes TFC entry every DMMP histories

PRINT control the printing of output tables to the OUTP file 3–149

X_1 X_2 ... or blank or Keyword ALL {basic tables printed}

blank produces the full output print of all tables
ALL produces full output print (plus, in the future, special code diagnostics tables)
X_1 X_2 ... prints basic output plus tables X_1, X_2 ...
$-X_1$ $-X_2$ ... prints the full output except tables X_1, X_2 ...
the X_i's can be entered in any order; either all positive or all negative.

PTRAC generate a file named PTRAC of user-filtered particle events 3–152,I–1
PTRAC is incompatible with multiprocessing and multitasking (FATAL error)

Keyword = parameter(s)

Output Control Keywords (one entry for each keyword):

BUFFER	=	amount of storage available{100}
FILE	=	asc/bin for ASCII/binary file {bin is default}
MAX	=	maximum number of events to write to the PTRAC file {10000}
MEPH	=	maximum number of events per history to write {write all}
WRITE	=	POS for only x,y,z locations, cells, and materials {default}
		ALL is POS plus direction cosines, energy, weight, and time

Event Filter Keywords:

EVENT	=	specify type of events written (one or more can be used)
	=	SRC initial source events
BNK	=	bank events
SUR	=	surface events
COL	=	collision events
TER	=	terminal events
FILTER	=	specifies additional MCNP variables for filtering
TYPE	=	N, P, and/or E to filter by particle type {default all}

History Filter Keywords:

NPS	=	A,B range of histories written to file (A<B)
	=	A write only history A to the file
CELL	=	number list of cells that will contribute to file
SURFACE	=	number list of surfaces that will contribute to file (real, integer)
TALLY	=	number list of tallies that will contribute to file
		negative number after TALLY indicates entry is a multiplier
VALUE	=	cutoff for TFC bin below which history events not written

PWT control neutron-induced photons produced; MODE N,P or N,P,E [cell] 3–40

W_1 W_2 ... W_I {all –1}

W_i	>	0	photons produced with weights > W_i times source to cell importance ratio
	=	0	creates one photon per neutron collision in cell i (if possible)
	<	0	makes photon production relative to the starting source weight
	=	–1.0e6	turns off neutron-induced photon production in cell i

PWT card is ignored with photon weight windows (photons produced in window)

RAND selection and setting of pseudorandom number generator 3–145

Keywords: GEN{1} SEED{19073486328125} STRIDE{152917} HIST{1}

GEN = type of pseudorandom number generator to be used by MCNP
1 MCNP Lehmer 48-bit congruential generator (period=7.0×10^{13} numbers)
2 L'Ecuyer 63-bit generator number 1 (period = 9.2×10^{18} numbers)
3 L'Ecuyer 63-bit generator number 2 (period = 9.2×10^{18} numbers)
4 L'Ecuyer 63-bit generator number 3 (period = 9.2×10^{18} numbers)
SEED = initial random number generator seed (must end with an odd digit)
STRIDE= number of random numbers between source particles
HIST = n advance generator to start first history with history n random number

i^{th} source particle always starts with same random number; this correlated source sampling enables faster evaluation of small problem differences where the problems have identical source distributions.

Random number generators will not repeat when period is exceeded, but longer periods are preferred. Next default MCNP generator will be GEN = 2.

RAND entries take precedence over DBCN(1), DBCN(8), and DBCN(13).

RDUM real array available for user-modified code (see IDUM) [50] 3–143

R_1 R_2 ... R_{50} {all 0.}

R_i = real number for the i^{th} entry

repeated structure commands see FILL, LAT, LIKE m BUT, TRCL, U 3–25

SBn bias for source distribution n. See SIn and SPn cards. 3–62

option B_1 ... B_k or f A B

n = source distribution number where $1 \le n \le 999$
option = D bin probabilities for an H or L distribution on SIn card
C cumulative bin probabilities for H or L distribution on SIn
V proportional to cell volumes (times cell probability if present)
omitted–same as D for an H or L distribution on SIn card.
Probability density for A on SIn card.
B_i = source variable biased probability
f = built-in function where A and B are parameters for the built-in function
= –21 power law $p(x) = x^A$ (DIR, RAD, or EXT)
= –31 exponential exp (Ax) (DIR or EXT)

SCn comment card for source distribution n for OUTP (no & continuation) 3–67

comment is entered after SCn followed by a space
n = distribution number $1 \le n \le 999$ and cannot be zero or blank

SDn tally divisors for volume or area, with or without FS card segments 3–108

$(D_{11}\ D_{12}\ ...\ D_{1m})\ \ (D_{21}\ D_{22}\ ...\ D_{2m})\ \ ...\ \ (D_{k1}\ D_{k2}\ ...\ D_{km})$

n = tally number not ending in 5 or 8 and cannot be zero or blank
k = number of cells or surfaces on the Fn card including T if present
m = number of segmenting bins on FSn card including remainder segment and T
D_{ij} = area, volume, or mass of j^{th} segment of i^{th} surface or cell bin

SDEF general fixed source specification 3–54

keyword=explicit value or distribution number Dn or another keyword
No keywords default: 14 MeV point isotropic at 0,0,0, time = 0, weight = 1.
Available keywords followed by meaning and {default if any}:

CEL = starting source cell or cell rejection
SUR = starting source surface {0 for cell source}
ERG = source energy {14 MeV}
TME = source time {0 shakes}
WGT = source weight, explicit value only {1}
WGT units of particles per unit time for steady state, particles for pulse. It is illegal to change WGT for a KCODE calculation (FATAL error).
PAR = 1 or N for neutron, 2 or P for photon, 3 or E for electron, 4 or F for positron. Explicit value only.
{1 if MODE=N N,P or N,P,E; 2 if MODE=P or P,E; 3 if MODE=E}
DIR = cosine of polar angle relative to VEC (azimuthal angle uniform 0^o to 360^o) {isotropic if volume or cosine if surface}
VEC = reference vector for DIR
{required unless volume is isotropic; normal to surface if surface source}
NRM = 1/–1 sign of surface normal {+1}
POS = x,y,z vector for reference point for position sampling {0,0,0}
RAD = radial distance of the position from POS or AXS {0}
EXT = distance from POS along AXS (cell); cosine of angle from AXS (surface) {0}
AXS = reference vector for EXT and RAD {no direction}
X = x-coordinate of position {no x}
Y = y coordinate of position {no y}
Z = z coordinate of position {no z}
CCC = cookie-cutter cell for rejection
ARA = surface area for direct contributions to detectors from plane surface
EFF = rejection efficiency for position sampling, explicit value only {0.01}
TR = source particle transformation by TRn or by a distribution of TRn's

Individual repeated structure/lattice sources

general form: S_1 (S_2 ... S_3) ((S_4 S_5) < (C_1 C_2 [I_1 ... I_2]) < (C_3 C_4 C_5)) ... innermost level to the outermost level

S_i = problem number of cell or surface, U=universe number (FILL card), or T

C_i = problem number of a cell filled with a universe or U=universe number

I_i = index data for a lattice cell element with three possible formats:
- I I^{th} lattice element of cell C_2 as defined in the FILL array
- I_1:I_2 I_3:I_4 I_5:I_6 range of lattice elements (defined in FILL array)
- I_1 I_2 I_3, I_4 I_5 I_6 specific lattice elements (I_1,I_2,I_3) and (I_4,I_5,I_6)

SFn surface flagging card for tally n [number of surfaces] 3–106

S_1 S_2 ... S_k

n = tally number not ending in 5 or 8 and cannot be zero or blank

S_i = problem surface numbers whose tally contributions are to be flagged when a particle crosses any of the S_i surfaces including macrobody facets

SIn source information for distribution n. Requires SPn card. 3–62

option{H} I_1 I_2 ... I_k

n = source distribution number from 1 to 999

option = H or blank for bin boundaries I_i of a histogram probability distribution
- L for discrete source variable probability values
- A for points at which a linear probability distribution is defined
- S for other source distribution numbers (these can also have the S option)

I_i = source variable values or distribution numbers

SPn source probability for distribution n 3–62,H–1

option{D} P_1 P_2 ... P_k or f A B

n = source distribution number from 1 to 999

option =
- D bin probabilities for an H or L distribution on SIn card
- C cumulative bin probabilities for H or L distribution on SIn
- V probability is proportional to cell volumes times P_i (for cell distributions)
- omitted–same as D for H or L and is a probability density for A

P_i = source variable probabilities

f = built-in function where *a* and *b* are parameters for the built-in function
- = –2 Maxwell fission spectrum (ERG) - uses *a*{1.2895 MeV}

= –3 Watt fission spectrum (ERG) - uses *a* {0.965 MeV} and *b* {2.29 1/MeV}
= –4 Gaussian fusion spectrum (ERG) - uses *a* {–0.01 MeV} and *b* {–1}
= –5 evaporation spectrum (ERG) - uses *a* {1.2895 MeV}
= –6 Muir velocity Gaussian fusion spectrum (ERG) - uses *a* {–.01 MeV} and *b* {–1}
= –7 spare function for the user to add one (ERG) - uses *a* and *b*
= –21 power law p(x)= x^a (DIR,RAD, or EXT) - uses *a* {DIR,1;RAD,1 or 2;EXT,0}
= –31 exponential exp(*a*x) (DIR or EXT) - uses *a* {0}
= –41 Gaussian distribution in time (TME) or position (X,Y,Z) - uses *a*, *b* {0}

SSR surface source read card for file RSSA 3–72

keyword=values
Available keywords followed by meaning and {default if any}:

OLD = list of surface numbers including facets that wrote SSW card {all}
CEL = like OLD but cells where KCODE fission particles were written {all}
NEW = surface numbers to start particles from in this run {OLD}
S_{a1} S_{a2} ... S_{ak} S_{b1} S_{b2} ... S_{bk} (start source at a, b, ...)
Surfaces S_{bi}, S_{ci}, ... require TR_j transformations.
PTY = N P and/or E; blank delimited; all source particle types are allowed {all}
COL = 1 start only particles with collisions before crossing the surface
= 0 start particles without regard to collisions {default = 0}
= –1 start only those particles directly from source (no collisions)
WGT = constant particle weight multiplier for accepted particles {default = 1}
TR = a transformation number (TRn) or distribution number Dn (SIn,SPn,SBn)
PSC ≥ 0 power of polar angle cosine (sphere) for source to detector and DXTRAN p(μ)
AXS = direction cosines for reference vector for EXT (sphere only)
EXT Dn= distribution n to bias sampling of cosine from AXS (sphere only)
POA = minimum polar angle cosine(sphere) for particle acceptance {default = 0}
BCW = r zb ze (0<zb<ze); cylindrical window of rad r, from zb to ze from sphere center

SSW write surface source(s) to WSSA file 3–70
surface source writes and multitasking are incompatible (FATAL error)

S_1 S_2 (C_1 ... C_k) S_3 ... S_j keyword=values

S_i = surface number with sense for which crossing info is written, including facets
Crossing from negative side of surface to positive would be: S_i
C_i = problem cell number: + or blank for other-side cell,– for just-exited cell
SYM = 0 assumes no symmetry for S_i's {default = 0}
= 1 for spherical symmetry with j = 1 and S_1 is spherical surface
= 2 for writing particles bidirectionally crossing the surface(s)
PTY = tracks to record: N P and/or E {default = all tracks}
CEL = list of cells for KCODE fission volume source neutrons (active cycles only)

surface cards surface equation coefficients, surface by points, and macrobodies 3–11

J n A ***list*** or J n B ***points*** or J n C ***list***

J = surface number in first 5 columns ($1 \le J \le 99999$, with TRCL, $1 \le J \le 999$)
*J is specular reflecting surface and +J is white boundary condition reflector. Point detectors, DXTRAN spheres should generally not be used with reflectors.
n = absent if no coordinate transformation
> 0 specifies number of TRn card
< 0 surface J periodic with surface n where J and n are both planes

A = equation mnemonic from following list:

P	general plane requires a b c d coefficients (ax+by+cz-d=0)
PX,PY,PZ	plane normal to x,y, or z axis: requires d coefficient (e.g., x – d=0)
SO	sphere at origin: requires radius r ($x^2+y^2+z^2-r^2=0$)
S	general sphere: requires x y z center and radius r coefficients
SX,SY,SZ	sphere centered on x,y, or z axis: requires x,y, or z r
CX,CY,CZ	cylinder on x,y, or z axis: requires radius r (e.g., $x^2+y^2-r^2=0$)
C/X,C/Y,C/Z	cylinder parallel to x,y,or z axis: requires y z, x z, or x y r
KX,KY,KZ	cone on x,y, or z axis: requires x, y, or z t^2 (+1/-1)
K/X,K/Y,K/Z	cone parallel to x,y,or z axis: requires x y z t^2 (+1/-1)
SQ	special quadratic: axes parallel to major axis (a b c d e f g x y z)
GQ	general quadratic: no parallel axes (a b c d e f g h j k)
TX,TY,TZ	torus with axis parallel to x,y,or z axis: requires x y z a b c

list = one to ten equation coefficients as required by the mnemonic above

B = the letter X, Y, Z, or P
X,Y,Z symmetric surfaces around x,y,or z axis (x_1,y_1, or z_1 r_1 ...)
P general plane specified by points (x_1 y_1 z_1 x_2 y_2 z_2 x_3 y_3 z_3)
points = 1 to 3 sets of axis-radius (X,Y,Z) or point (P) x_1,y_1,z_1 ...
coordinates with *, do not use point detectors and DXTRAN spheres

C = macrobody name from following list:
ARB arbitrary polyhedron (Ax Ay Az Bx By Bz ... Hx Hy Hz N1 N2 ... N6)

BOX arbitrary box (Vx Vy Vz A1x A1y A1z A2x A2y A2z A3x A3y A3z)
ELL ellipsoid (V1x V1y V1z V2x V2y V2z Rm)
HEX see RHP right hexagonal prism below
RCC right circular cylinder (Vx Vy Vz Hx Hy Hz R)
REC right elliptical cylinder (V1 V2 V3 Hx Hy Hz V1x V1y V1z V2x V2y V2z)
RHP right hexagonal prism (V1 V2 V3 H1 H2 H3 R1 R2 R3 S1 S2 S3 T1 T2 T3)
RPP rectangular parallelepiped (Xmin Xmax Ymin Ymax Zmin Zmax)
SPH sphere (Vx Vy Vz R)
TRC truncated right-angle cone (Vx Vy Vz Hx Hy Hz R1 R2)
WED wedge (Vx Vy Vz V1x V1y V1z V2x V2y V2z V3x V3y V3z)

list = numerical values as required by the selected macrobody
A macrobody is 1 surface: facets labeled with ".1", ".2" ...
(see MBODY plot card)

Tn — create time bins in shakes where 1 shake = 10^{-8} seconds — 3–96
Required if a TMn card is present

B_1 B_2 ... Bj NT or C

n = tally number. 0 applies bins to all tallies without a Tn card
B_i = monotonically increasing upper time of i^{th} bin (B_0= – large)
NT = optional and will delete the total created over the time bins
C = creates a cumulative tally in time

TALNP — tally no-print card to delete tally bin values from the OUTP file — 3–151

n_1 n_2 ... or blank

blank means delete bin prints for all tallies
n_i = problem tally numbers, either all positive or all negative
> 0 remove bin values from this tally number from OUTP file
= 0 restore bin prints in a CONTINUE run. 0 must be the only entry
< 0 keep tally bin values in OUTP file and remove tallies not listed

tally cards — See Fn, FnA, FICn, FIPn, FIRn, and FMESHn cards — 3–81

TFn — define one bin of tally n to be used in tally fluctuation chart — [8] — 3–111

I_1 ... I_8

n = tally number and cannot be zero or blank
I_i = bin number for bin of type i. The description of I and each default follow:
1 {first cell, surface or detector on Fn}
2 {total rather than flagged or uncollided flux}
3 {last user bin}
4 {last segment bin}
5 {first FMn multiplier bin}

6 {last cosine bin}
7 {last energy bin}
8 {last time bin}

THTME times for thermal neutron temperatures of cells on TMPn card(s)[99] 3–137

T_1 T_2 ... T_k {0, temperature is not time dependent}

T_i = monotonically increasing time (1 shake=10^{-8} sec) for TMPn temperatures

title card one line of required input not to exceed column 80 3–2
First line in INP or after MESSAGE block blank line delimiter.

TMn time bin multiplier card 3–104

M_1 M_2 ... M_k (k = number of entries on the Tn card)

n = tally number. 0 applies bins to all tallies without a TMn card
M_i = multiplier to be applied to the i^{th} time bin

TMPn free-gas thermal temperature card for time on THTME card [cells] 3–136
A zero temperature in a nonvoid cell is a FATAL error.
See MTm card for a possible better thermal neutron treatment for light isotopes.

T_{1n} T_{2n} ... T_{in} {room temperature of 2.53x10^{-8} MeV}

n = index of time on the THTME card
T_{in} = temperature in kT (MeV) of cell i at time n on THTME
kT = 8.617x10^{-11}*(T+273.15), T in degrees Celsius;
= 4.787x10^{-11}*(T+459.67), T in degrees Fahrenheit;
k is the Boltzmann constant.

TOTNU total fission card to include delayed neutrons [1] 3–126

blank or NO

blank means use total ν for all fissionable isotopes {KCODE default}
"NO" means use prompt ν for all fissionable isotopes {fixed source default}
All steady-state fixed-source problems should use the blank form of this card.

TRn surface coordinate transformation card (*TRn is for B_i in degrees)[13] 3–30

O_1	O_2	O_3	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	M	
{0}	{0}	{0}	{1}	{0}	{0}	{0}	{1}	{0}	{0}	{0}	{1}	{1}	defaults

n = number of the transformation ($1 \le n \le 999$)
O_1 O_2 O_3 = displacement vector of the transformation
B_1 ... B_9 = rotation matrix of the transformation
M = 1/–1 vector is origin of aux/main coordinate system in main/aux system periodic boundary surfaces cannot have surface transformations

TRCL — cell transformation card (*TRCL is for B_i degrees) — 3–28

Intended to be used with the LIKE m BUT and LAT commands on a cell card.

N or (in parentheses, the actual transformation itself, see TRn above)

N = integer to select the TRn transformation

TSPLT:p — time splitting and Russian roulette card [20 pairs of entries] — 3–38

Intended to be used with energy-dependent weight window. Not recommended for time-dependent window; use time-dependent weight window instead. Induced particles may require both parent and daughter TSPLT, e.g., neutron induced photon.

R_1 T_1 R_2 T_2 ... R_k T_k

p = N for neutrons, P for photons, E for electrons
R_i > 1 is number of tracks particle will be split into
$0 < R_i < 1$ is the Russian roulette survival probability
T_i = time (shakes) at which splitting or Russian roulette occur
Cannot be used in a multigroup calculation (FATAL error).

U — define what universe cells and lattices are in [cells] — 3–26

N = universe number to which a cell belongs. Recommend put on cell card.
–N = cell not truncated by higher level cell

For a lattice or collection of cells (see FILL command)

URAN — stochastic geometry card for HTGRs — 3-32

n_1 = Universe number for applying stochastic transformation (only when used to fill a lattice element)
dx_1 = maximum translation in +/- x-direction
dy_1 = maximum translation in +/- y-direction
dz_1 = maximum translation in +/- z-direction

n_2, dx_2, dy_2, dz_2 – optional second stochastic transformation universe and parameters

VR — Variance reduction card

RR=s, where s = ‘off’ or ‘no’ to turn off the Russian roulette game for weight windows, and cell/time/energy importances.

VECT — define any number of vectors for exponential transform or user patches — 3–42

V_j X_j Y_j Z_j ... V_m X_m Y_m Z_m ...

V_j = vector number j that is referenced on the EXT:p command
X_j Y_j Z_j = coordinate triplets to define vector V_j
V_j entries are used for exponential transforms and user-modified code

VOID — delete all cell materials to check geometry/sources, calculate volumes — 3–128

blank or C_1 C_2 ... C_j (j not greater than the number of cells)

blank means void all cells in the problem
C_i = remove material from problem cell C_i

VOL — whole cell volume specifications — [cells] — 3–24

X_1 ... X_K or NO {calculated volumes if available}

X_i = volume of the i^{th} cell in cm^3
= 0 use the calculated cell volume
NO = do not perform any cell volume or surface area calculations

WWE:p — weight window energies (or times) (use only with WWNi:p) — [99] — 3–45

E_1 E_2 ... E_k (k<100) {one energy (or time) interval}

p = N for neutrons, P for photons, E for electrons
E_i = monotonically increasing upper energy (or time) of i^{th} weight window
E_{i-1} = lower energy (or time) of i^{th} weight window, E0=0.

WWG — weight window generation card — [9] — 3–48

IT IC WG J J J J IE

IT = tally number (n on Fn card): optimizing bin defined by TFn card
IC > 0 use cell-based weight window generator, IC = reference cell (e.g., source cell)
= 0 use mesh-based weight window generator (see MESH card)
WG = value of generated lower weight window bound for cell IC or for the reference mesh (see MESH card)
= 0 generated lower weight window is half of average source weight
J = unused
IE = 0/1 interpret WWGE entries as energy/time bins

WWGE:p — weight window generation energies (or times) — [15] — 3–48

blank or E_1 E_2 ... E_j ($j \leq 15$)

p = N for neutrons, P for photons, E for electrons
blank will automatically generate ten decades (j = 10) of energies (or times)
E_i = upper energy (or time) bound for i^{th} weight window to be generated ($E_0 = 0$)

WWNi:p — lower weight window bounds by cell for i^{th} WWE:p energy (time) bin — [cells] — 3–45

W_{i1} W_{i2} ... W_{iJ}

i = weight window number corresponding to energy (time) bins on WWE:p card
If there is no WWE:p card, then i = 1.
p = N for neutrons, P for photons, E for electrons
W_{ij} = lower weight bound in cell j and energy(time) interval $E_{i-1}<E<E_i$ on WWE:p
> 0 particles entering/colliding in j are split or rouletted by WWP:p
= 0 weight window off in cell j and energy bin i-weight cutoff is on
< 0 any type p particle entering cell j in energy bin i is terminated

Use with WWP:p and WWE:p cards.
Do not use WWN:p and IMP:p for the same particle type p.

WWP:p weight window parameter card [8] 3–46

WUPN{5} WSURVN{0.6*WUPN} MXSPLN{5} MWHERE{0}
SWITCHN{0} MTIME{0} WNORM{1.} ETSPLT{0}

p = N for neutrons, P for photons, E for electrons
WUPN = number (≥ 2) that multiplies lower weight bound to check for splitting
WSURVN = number (1<WSURVN<WUPN) for Russian roulette game
MXSPLN = # (>1) maximum split (MXSPLN to 1), Russian roulette (1 in MXSPLN)
MWHERE = 1/0/–1 check the weight at surfaces/(surfaces and collisions)/ collisions
SWITCHN > 0 lower weight bounds are SWITCHN divided by cell importance
= 0 lower weight bounds from WWNi commands
< 0 lower weight bounds from WWINP file (requires IMP:p cards)
MTIME = 0/1 energy/time-dependent weight window (WWE card)
WNORM > 0 multiplier for weight window lower bounds (WWNi:p, WWINP)
ETSPLT = 0/1 ESPLT, TSPLT entries scale weight windows/and do split, roulette

XSn load cross-section evaluation n not in XSDIR file directory [11] 3–127

same entries as XSDIR except no "+" for continuation and no ZA/atomic weight

n = a number from 1 to 999 to describe one cross-section set on XSn card
See Appendix F page F-2 for description of XSDIR entries.

ZA,ZB,ZC separate cards for inputting data to user-modified code; data must be stored by user. Can use “j” jump feature. Cards are legal in CONTINUE run.

III. GEOMETRY PLOTTING COMMANDS

A. Geometry Plotting Command Formats

mcnp ip ... IP means read INP, perform consistency checks, and plot.

mcnp p ... P means plot from an existing RUNTPE file.

? or help or options displays plot commands.

User need type only enough of command to make it unique: ex for extent

B. Geometry Plotting Commands

&	continue reading commands from next line. Must be last character on line.	B–5
?	display list of graphics commands and available plot colors	B–6
BASIS	define plot orientation. See also PX, PY and PZ.	B–6
CENTER	change the origin by a shift in the horizontal and vertical directions	B–9
COLOR	turn color on/off, set resolution, and select physical property for shading	B–8
CURSOR	present cursor to enlarge an area. Only command on line. See RESTORE.	B–9
END	terminate plotting	B–6
EXTENT	define the horizontal and vertical extent of the plot	B–6
FACTOR	enlarge the plot view by the factor 1/F ($F>10^{-6}$)	B–9
FILE	send/do not send plot to file PLOTM.PS	B–5
FMESH n	plot mesh tally n	B–8
HELP	display list of graphics commands and available plot colors	B–6
INTERACT	return to interactive mode from terminal window input mode	B–5
LABEL	define label size and cell quantity to display	B–7
LEVEL	plot only level n of a repeated structure geometry (can save plot time)	B–7
LOCATE	display x y z coordinates of cursor	B–9
MBODY	off = display macrobody surface facet numbers	B–7
MCPLOT	call or return to the tally/cross-section plotter MCPLOT	B–6
MESH	superimposed weight window mesh plotting (–1/0/1 = no lines/off/on)	B–8
OPTIONS	display list of graphics commands and available plot colors	B–6
ORIGIN	define the origin of the center of the plot	B–6
PAUSE	hold each displayed plot n seconds. Use with COM option.	B–6
PX VX	plot plane perpendicular to x axis at VX (BASIS = 0 1 0 0 0 1)	B–6
PY VY	plot plane perpendicular to y axis at VY (BASIS = 1 0 0 0 0 1)	B–7
PZ VZ	plot plane perpendicular to z axis at VZ (BASIS = 1 0 0 0 1 0)	B–7
RESTORE	restore ORIGIN and EXTENT to their values before CURSOR command	B–9
RETURN	returns program control to MCPLOT	B–5
RUNTPE	open the specified RUNTPE file with **p** option and plot the geometry	B–2
SCALES	put scales and grid on plot (not with VIEWPORT SQUARE)	B–8
SHADE	select cell color by material number	B–8
STATUS	display the current values of the plotting parameters	B–6
TERM	prevent plots from being drawn at the terminal	B–5
THETA	rotate the plot counterclockwise TH degrees	B–9

VIEWPORT select the viewport region as rectangular or square B–5

C. Geometry Plotting Commands By Function

1. Device

FILE	send/do not send plot to file PLOTM.PS	B–5
TERM	prevent plots from being drawn at the terminal	B–5
VIEWPORT	select the viewport region as rectangular or square	B–5

2. General

&	continue reading commands from next line. Must be last thing on line.	B–5
END	terminate plotting	B–6
MCPLOT	call or return to the tally/cross-section plotter MCPLOT	B–6
PAUSE	hold each displayed plot n seconds. Use with COM option.	B–6
RETURN	returns program control to MCPLOT	B–5

3. Inquiry

? or HELP or OPTIONS	display list of graphics commands and available plot colors	B–6
STATUS	display the current values of the plotting parameters	B–6

4. Plot

BASIS	define plot orientation. See also PX, PY and PZ.	B–6
COLOR	turn color on/off, set resolution, and select physical property for shading	B–8
EXTENT	define the horizontal and vertical extent of the plot	B–6
FMESH n	plot mesh tally n	B–8
INTERACT	return to interactive mode from terminal window input mode	B–5
LABEL	define label size and cell quantity to display	B–7
LEVEL	plot only level n of a repeated structure geometry (can save plot time)	B–7
MBODY	off = display macrobody surface facet numbers	B–7
MESH	superimposed weight window mesh plotting (–1/0/1=no lines/off/on)	B–8
ORIGIN	define the origin of the center of the plot	B–6
PX VX	plot plane perpendicular to x axis at VX (BASIS=0 1 0 0 0 1)	B–6
PY VY	plot plane perpendicular to y axis at VY (BASIS=1 0 0 0 0 1)	B–7
PZ VZ	plot plane perpendicular to z axis at VZ (BASIS=1 0 0 0 1 0)	B–7
RUNTPE	open the specified RUNTPE file with **p** option and plot the geometry	B–2
SCALES	put scales and grid on plot (not with VIEWPORT SQUARE)	B–8
SHADE	select cell color by material number	B–8

5. Zoom

CENTER	change the origin by a shift in the horizontal and vertical directions	B–9
CURSOR	present cursor to enlarge an area. Only command on line. See RESTORE.	B–9
FACTOR	enlarge the plot view by the factor 1/F ($F>10^{-6}$)	B–9
LOCATE	display x y z coordinates of cursor	B–9
RESTORE	restore ORIGIN and EXTENT to their values before CURSOR command	B–9

THETA rotate the plot counterclockwise TH degrees B–9

D. Concise Geometry Plotting Command Descriptions

mcnp ip options (initiate and plot) or **mcnp p options** (plot from existing RUNTPE)

Execution line options:
NOTEK = suppress terminal plotting and send plots to file PLOTM.PS
COM = file containing plot commands. Never end with a blank line: use "end"
PLOTM = graphics postscript file name {plotm.ps}
COMOUT= file of terminal plot commands. Later used as COM file. {comout}
RUNTPE = open specified RUNTPE file and plot with **p** (not **ip**) option {runtpe}

& continue reading commands from next line. Must be last thing on line. B–5

? display list of graphics commands and available plot colors B–6

BASIS define plot orientation. See also PX, PY and PZ. B–6
Do not plot on a problem geometry plane.

$U_1\ V_1\ W_1 \quad U_2\ V_2\ W_2$ {0 1 0 0 0 1}

$U_1\ V_1\ W_1$ are cosines for the direction pointing to the right on the plot
$U_2\ V_2\ W_2$ are cosines for the direction pointing up on the plot

CENTER change the origin by a shift in the horizontal and vertical directions B–9

DH DV

DH = change in the origin of the plot in the horizontal direction
DV = change in the origin of the plot in the vertical direction

COLOR turn color on/off, set the resolution, or select physical property for shading B–8

N{300} or "by M" {mat}

N = off/on color off/on with default resolution of 300
$50 \le n \le 3000$ set color resolution to N
M = mat color by cell material number
= den color by cell material gram density
= rho color by cell material atomic density
= tmp color by cell material temperature
= grad plot using a continuous gradient of 256 colors
= solid plot using a solid color to represent a range of values
A color bar with upper/lower scale values is displayed on the plot for all but mat.
COLOR can be toggled on/off with interactive plotter button.

CURSOR present cursor to enlarge an area. Only command on line. See RESTORE. B–9

END terminate plotting B–6

EXTENT define the horizontal and vertical extent of the plot B–6

EH{100 cm} EV{EH}

EH = the horizontal distance (cm) from origin to either side of the plot
EV = the vertical distance (cm) from origin to either side of the plot

FACTOR F enlarge the plot view by the factor 1/F ($F>10^{-6}$) B–9

FILE A send/do not send plot to file PLOTM.PS B–5

A = blank only the current plot is sent to the graphics metafile
A = ALL current and all subsequent plots sent to graphics metafile
A = NONE current and all subsequent plots not sent to graphics metafile

FMESH n plot mesh tally n B–8

HELP display list of graphics commands and available plot colors B–6

INTERACT return to interactive mode from terminal window input mode B–5

LABEL select labels and cell quantities to be displayed on geometry plot B–7

S{1} C{0} DES{CEL}

S = 0 omit surface label
0.2 to 100 controls the size of the surface numbers
C = 0 omit cell label
0.2 to 100 controls the size of the cell quantities
DES = keyword to plot specific cell quantity. C ≠ 0

CEL	cell number
DEN	cell mass density (g/cm^3)
DXC:p	probability of DXTRAN cell contribution
EXT:p	exponential transform by cell
FCL:p	forced collision by cell
FILL	filling universe by cell
IMP:p	cell importance
LAT	cell lattice type
MAS	cell mass (grams)
MAT	cell material number
NONU	fission treated as capture by cell
PDn	probability of detector contribution by cell for tally n

PWT	neutron-induced photon production weight control by cell
RHO	cell atom density (atoms/barn-cm or 10^{-24} atoms/cm^3)
TMPj	cell temperatures for the j^{th} time on the THTME card
U	universe number by cell
VOL	cell volume
WWNi:p	i^{th} WWE:p energy lower weight window bound

LEVEL n — plot only level n of a repeated structure geometry; can save plot time. {all} — B–7

LOCATE — locate x y z coordinates in a plot using cursor with appropriate terminals — B–9

MBODY S — S = on/off display macrobody surface number/facet numbers {on} — B–7

MCPLOT — call or return to MCPLOT — B–6

MESH — superimposed weight window mesh plotting (–1/0/1=no lines/off/on) — B–8
The mesh must be read with weight window bounds from WWINP file.

OPTIONS — display list of graphics commands and available plot colors — B–6

ORIGIN — define the origin of the center of the plot — B–6

VX VY VZ are the x, y, and z locations of the plot center {0 0 0}

PAUSE T — hold each displayed plot for T seconds. Use with COM option. — B–6
Blank means keep plot until the return key is pressed.

PX VX — plot plane perpendicular to x axis at VX; gives y-z view. — B–6

PY VY — plot plane perpendicular to y axis at VY; gives x-z view. — B–7

PZ VZ — plot plane perpendicular to z-axis at VZ. Gives x-y view. — B–7
Do not plot on a problem geometry plane. See BASIS command.
The XY, XZ, and YZ interactive buttons are PZ 0, PY 0, and PX 0 equivalents.

RESTORE — restore ORIGIN and EXTENT to their values before CURSOR command — B–9

RETURN — return program control to MCPLOT — B–5

RUNTPE — open the specified RUNTPE file with **p** option and plot the geometry — B–2

SCALES N — put scales and grid on plot (not with VIEWPORT SQUARE) {0} — B–8

N = 0 no scales on the edges and no grid on the plot {default}
= 1 scales on the edges and no grid on the plot
= 2 scales on the edges and grid on the plot

SHADE select cell color by material number; works only in "color by mat" mode B–8

M_1 = color$_1$ M_2 = color$_2$ ...

M_i = number of the i^{th} material in the problem
color$_i$ = color_name from list of 64. Type "?" for available colors.

STATUS display the current values of the plotting parameters B–6

TERM N prevent plots from being drawn at the terminal {1} B–5

N = 0 no plots are drawn; equivalent to NOTEK
= 1 restore visible terminal plotting window on next plot request

THETA TH rotate the plot counterclockwise TH degrees B–9

VIEWPORT A select the viewport region with or without legends {RECT} B–5

A = "RECT" for legend space and scales or
A = "SQUARE" for no legend space and scales

IV. TALLY AND CROSS-SECTION PLOTTING COMMANDS

A. Tally and Cross-Section Plotting Command Formats

There are two forms of the MCNP execute line, one each for tally and cross-section plotting:

mcnp z ... tally plots from RUNTPE and MCTAL files
mcnp ixz ... cross-section plots from INP file only, not from RUNTPE. See XS, MT, and PAR.
Can use smallest number of letters to uniquely identify command (cop = coplot).
Enter a **?** at prompt to display list of tally and cross-section plotting commands.
Enter **xs ?** at prompt to see a primer in cross-section plotting.
(ctrl c) m allows interactive tally plots. RETURN or END to exit. See MPLOT.

B. Tally and Cross-Section Plotting Commands

& continue reading commands from next line. Must be last character on line. B–18
? display list of tally and cross-section plotting commands B–19
BAR make bar plots of tally data B–23
BELOW put the main title below the plot instead of above it B–20

CONTOUR specify the form for contour plots. See WASH. B–23
COPLOT make plot of data so far and keep plot open for more plots. 2-D only. B–18
DUMP N read the specified dump N from the current RUNTPE B–19

EBIN n	plot energy bin n of the current mesh tally	B–25
END	terminate plotting	B–18
FACTOR	before plotting, scale the data for the current plot only	B–20
FILE	send/do not send plot to file PLOTM.PS	B–18
FIXED	define a fixed bin for the specified variable	B–21
FMESH n	plot mesh tally n	B–25
FMRELERR n	plot the relative errors of mesh tally n	B–25
FREE	specify one or two independent variables for the plot	B–21
FREQ	specifies interval between automatic runtime plots. See MPLOT.	B–18
HELP	display list of tally and cross-section plotting commands	B–19
HIST	plot data as a histogram {default for cosine, energy, or time}	B–23
IPTAL	display the tally bin array IPTAL for the current TALLY n	B–19
KCODE	plot individual or average k_{eff} or prompt removal lifetimes by cycle number	B–22
LABEL "A"	use A as legend label for current curve (not contour)	B–20
LEGEND	specify the location of the plot curve legend	B–23
LETHARGY	divide tally bin by lethargy bin width for log energy abscissa	B–28
LINLIN	use linear *x*-axis and linear *y*-axis for plots	B–23
LINLOG	use linear *x*-axis and logarithmic *y*-axis for plots {default}	B–23
LOGLIN	use logarithmic *x*-axis and linear *y*-axis for plots	B–23
LOGLOG	use logarithmic *x*-axis and logarithmic *y*-axis for plots	B–23
MT	plot reaction R of material XS M	B–22
NOERRBAR	suppress statistical error bars {include error bars}	B–23
NONORM	do not divide the tally bin by the bin width or area	B–20
OPTIONS	display a list of the tally graphics commands keywords	B–19
PAR p	define particle type N, P, or E for cross-section data plot of XS, MT	B–22
PAUSE	hold each displayed plot for T seconds. Use with COM option.	B–18
PERT n	plot the PERTn perturbation for a tally (n = 0 resets PERT n)	B–19
PLINEAR	piecewise linear plots {default for all but cosine, energy, or time}	B–23
PLOT	call or return to the PLOT geometry plotter	B–18
PRINTAL	display the tally numbers in current RUNTPE or MCTAL file	B–19
PRINTPTS	display the X-Y coordinates of points in the current plot (2D only)	B–19
RESET A	reset command A parameters to default. "ALL" resets all commands.	B–20
RETURN	end interactive plotting when running histories	B–18
RMCTAL F	read MCTAL file F	B–19
RUNTPE	open the specified RUNTPE file and read the specified dump	B–19
SCALES	select the type of scales and/or grid to put on the plot	B–23
SET	define free and fixed bin for the eight variables. See FIXED.	B–21
STATUS	display the current values of the plotting parameters	B–19
SUBTITLE	write a subtitle anywhere on the plot within screen limits	B–20

TALLY n	define tally n (n of Fn) as the current tally {first tally}	B–19
TERM	plot to the terminal or send plots to graphics file	B–18
TFC	select a tally fluctuation chart value of current tally to plot	B–21
THICK	set the thickness of the plot curves to X from 0.01 to 0.1 {0.2}	B–23
THIN	set the thickness of the plot curves to the minimum 0.01	B–23
TITLE	create a one or two line title for the plot	B–20
WASH A	set/unset z(x,y) plotting to use color-wash instead of contour	B–23
WMCTAL F	write the tally data in the current RUNTPE dump to MCTAL file F	B–19
XLIMS	defines lower and upper limits and number of subdivisions of x variable	B–23
XS M	plot a cross section according to M: material or nuclide	B–22
XTITLE "A"	use A as the title for the X axis {name of X-axis variable}	B–20
YLIMS	define lower and upper limits and number of subdivisions of y variable	B–23
YTITLE "A"	use A as the title for the Y axis {name of Y-axis variable}	B–20
ZLEV n_1 n_2 n_3	controls the scale of the mesh tally results	B–25

C. Tally and Cross-Section Plotting Commands By Function

1. Device

FILE	send/do not send plot to file PLOTM.PS	B–18
TERM	plot to the terminal or send plots to graphics file	B–18

2. General

&	continue reading commands from next line. Must be last character on line.	B–18
COPLOT	make plot of data so far and keep plot open for more plots. 2-D only.	B–18
END	terminate plotting	B–18
FREQ	specify interval between automatic runtime plots. See MPLOT.	B–18
PAUSE	hold each displayed plot for T seconds. Use with COM option.	B–18
PLOT	call or return to the PLOT geometry plotter	B–18
RETURN	end interactive plotting when running histories	B–18

3. Inquiry

? or HELP or OPTIONS	display list of tally and cross-section plotting commands	B–19
IPTAL	display the tally bin array IPTAL for the current TALLY n	B–19
PRINTAL	display the tally numbers in current RUNTPE or MCTAL file	B–19
PRINTPTS	display the X-Y coordinates of points in the current plot (2D only)	B–19
STATUS	display the current values of the plotting parameters	B–19

4. File Manipulation

DUMP N	read the specified dump N from the current RUNTPE	B–19
RMCTAL F	read MCTAL file F	B–19

RUNTPE	open the specified RUNTPE file and read the specified dump	B–19
WMCTAL F	write the tally data in the current RUNTPE dump to MCTAL file F	B–19

5. Parameter-setting

FACTOR	before plotting, scale the data for the current plot only	B–20
LETHARGY	divide tally bin by lethargy bin width for log energy abscissa	B–28
NONORM	do not divide the tally bin by the bin width or area	B–20
PERT n	plot the PERTn perturbation for a tally (n = 0 resets PERT n)	B–19
RESET A	reset command A parameters to default. "ALL" resets all commands.	B–20
TALLY n	define tally n (n of Fn) as the current tally {first tally}	B–19

6. Titles

BELOW	put the main title below the plot instead of above it	B–20
LABEL "A"	use A as legend label for current curve (not contour)	B–20
SUBTITLE	write a subtitle anywhere on the plot within screen limits	B–20
TITLE	create a one or two line title for the plot	B–20
XTITLE "A"	use A as the title for the X axis {name of X-axis variable}	B–20
YTITLE "A"	use A as the title for the Y axis {name of Y-axis variable}	B–20

7. What to Plot

FIXED	define a fixed bin for the specified variable	B–21
FREE	specify one or two independent variables for the plot	B–21
KCODE	plot individual or average k_{eff} or prompt removal lifetimes by cycle number	B–22
SET	define free and fixed bin for the eight variables. See FIXED.	B–21
TFC	select a tally fluctuation chart value of current tally to plot	B–21

8. Form

BAR	make bar plots of tally data	B–23
CONTOUR	specify the form for contour plots. See WASH.	B–23
HIST	plot data as a histogram {default for cosine, energy, or time}	B–23
LEGEND	specify the location of the plot curve legend	B–23
LINLIN	use linear *x*-axis and linear *y*-axis for plots	B–23
LINLOG	use linear *x*-axis and logarithmic *y*-axis for plots {default}	B–23
LOGLIN	use logarithmic *x*-axis and linear *y*-axis for plots	B–23
LOGLOG	use logarithmic *x*-axis and logarithmic *y*-axis for plots	B–23
NOERRBAR	suppress statistical error bars {include error bars}	B–23
PLINEAR	piecewise linear plots {default for all but cosine, energy, or time}	B–23
SCALES	select the type of scales and/or grid to put on the plot	B–23
THICK	set the thickness of the plot curves to X from 0.01 to 0.1 {0.2}	B–23
THIN	set the thickness of the plot curves to the minimum 0.01	B–23
WASH A	set/unset z(x,y) plotting to use color-wash instead of contour	B–23
XLIMS	define lower and upper limits and number of subdivisions of *x* variable	B–23

YLIMS	define lower and upper limits and number of subdivisions of *y* variable	B–23

9. Cross Sections

MT	plot reaction R of material XS M	B–22
PAR p	define particle type N, P, or E for cross-section data plot of XS, MT	B–22
XS M	plot a cross section according to M: material or nuclide	B–22

10. Mesh Tally Plots

EBIN n	plot energy bin n of the current mesh tally	B–25
FMESH n	plot mesh tally n	B–25
FMRELERR n	plot the relative errors of mesh tally n	B–25
ZLEV n_1 n_2 n_3 ...	controls the scale of the mesh tally results	B–25

D. Concise Tally and Cross-Section Plotting Command Descriptions

mcnp z options (tally plots) or **mcnp ixz options** (cross section plots)
default: LINLOG histogram plot of tally/MeV vs. energy for first tally if more than one energy bin

Execution line options:

NOTEK	=	suppress terminal plotting and send plots to file PLOTM.PS
COM	=	file containing plot commands. Never end with a blank line: use “end”
PLOTM	=	graphics postscript file name {plotm.ps}
COMOUT	=	file of terminal plot commands. Later used as COM file. {comout}
RUNTPE	=	read file specified as source of tally data {runtpe}

Default tally bin is the total bin if present; otherwise, the first bin is the default.
PAR, XS, and MT are the three cross-section commands. Type XS ? for primer.
(ctrl c) m allows interactive tally plots; follow with “RETURN” to continue.
See MPLOT card for automatic tally plotting as problem runs.
You can use smallest number of letters to uniquely identify command (cop=coplot).

&	continue reading commands from next line. Must be last character on line.	B–18
?	display list of tally and cross-section plotting commands	B–19
BAR	make bar plots of tally data	B–23
BELOW	put the main title below the plot instead of above it	B–20
CONTOUR	specify the form for contour plots. See WASH.	B–23
	CMIN{5} CMAX{95} CSTEP{10} %{include}	

CMIN, CMAX, CSTEP = minimum, maximum, and step values for the contours. % means interpret the first three values as percents of the minimum and maximum values.

COPLOT	make plot of data so far and keep plot open for more plots. 2D only.	B–18
DUMP N	read the specified dump N from the current RUNTPE	B–19
EBIN n	plot energy bin n of the current mesh tally. The total energy bin is the last bin of the tally	B–25
END	terminate plotting	B–18
FACTOR	before plotting scale the data for the current plot only	B–20

A F S{0}

A = x, y or z axis of the plot to be scaled
F = number the data on the A axis is multiplied by
S = optional number to add to the scaled (F) data

FILE A	send/do not send plot to file PLOTM.PS	B–18

A = blank only the current plot is sent to the graphics metafile
A = ALL current and all subsequent plots sent to graphics metafile
A = NONE current and all subsequent plots not sent to graphics metafile

FIXED Q N	define a fixed bin for the specified variable	B–21

N = bin number for fixed variable Q. Symbols for Q and bins they represent:

Q = F cell, surface, or detector bin
= D total bin versus direct or flagged bin versus unflagged
= U user-defined bin
= S segmented bin
= M multiplier bin
= C cosine bin
= E energy bin
= T time bin

FMESH n	plot mesh tally n	B–25
FMRELERR n	plot the relative errors of mesh tally n. If n is not provided, will plot the relative error for the current mesh	B–25
FREE XY	specify one or two independent variables for the plot	B–21

X = letter designator (see FIXED) for first independent variable. {default=E}
Y = letter for second independent variable (contour plot)

FREQ N — specifies interval between automatic runtime plots. See MPLOT. B–18

N > 0 plot every N histories or KCODE cycles
< 0 plot every N minutes
= 0 do not call MCPLOT {default = 0}

HELP — display list of tally and cross-section plotting commands B–19

HIST — plot data as a histogram {default for cosine, energy, or time} B–23

IPTAL — display the tally bin array IPTAL for the current TALLY n B–19

KCODE I — plot individual or average k_{eff} or prompt removal lifetimes I by cycle number B–22

I = 1 collision estimator
= 2 absorption estimator
= 3 track-length estimator
= 4 collision estimator for prompt removal lifetime
= 5 absorption estimator for prompt removal lifetime
6 Shannon entropy of fission source distribution
(Can be plotted only from runtpe, not mctal file)
= 11 to 15 quantities 1–5 averaged over the active cycles
= 16 average combined col/abs/trk-len k_{eff}
= 17 average combined col/abs/trk-len k_{eff} by k_{eff} cycles skipped
= 18 average combined col/abs/trk-len k_{eff} figure of merit
= 19 average combined col/abs/trk-len k_{eff} relative error

LABEL A — use A as legend label for current curve (not contour) B–20

LEGEND X Y — specify the location of the plot curve legend B–23

X and Y blank put legend in the normal place {default}
X = 0 and no Y omit legend
X > 0 and Y > 0 put plot line labels at X,Y. 2-D plots only.

LETHARGY — divide tally bin by lethargy bin width for log energy abscissa. B–28
Produces visually accurate area plots for a 2-D LOGLIN energy abscissa (FREE E). A lethargy-normed plot is equivalent to plotting $ef(e)$ (see Appendix B, Section III-F)

LINLIN — use linear *x*-axis and linear *y*-axis B–23

LINLOG — use linear *x*-axis and logarithmic *y*-axis {default} B–23

LOGLIN	use logarithmic *x*-axis and linear *y*-axis	B–23
LOGLOG	use logarithmic *x*-axis and logarithmic *y*-axis	B–23
MT R	plot reaction R of material XS m {total cross section}	B–22
	R = reaction number, listed in Appendix G.	
NOERRBAR	suppress statistical error bars {include error bars}	B–23
NONORM	do not divide the tally bin by the bin width or area 2D plot default is to divide by cosine, energy, and time bin widths normed values: cosine, $1/(2\pi(\Delta\mu))$; energy, $1/(\Delta E)$; time, $1/(\Delta T)$ With NONORM, cosine, energy, time binned tallies will be the same as in OUTP.	B–20
OPTIONS	display a list of the tally graphics command keywords	B–19
PAR p	define particle type N, P, or E for cross-section data plot of XS, MT	B–22
PAUSE T	hold each displayed plot for T seconds. Use with COM option. Blank means keep plot until the return key is pressed.	B–18
PERT n	plot the PERTn perturbation for a tally (n = 0 resets PERT n)	B–19
PLINEAR	piecewise linear plots {default for all but cosine, energy, or time}	B–23
PLOT	call or return to the PLOT geometry plotter	B–18
PRINTAL	display the tally numbers in current RUNTPE or MCTAL file	B–19
PRINTPTS	display the X-Y coordinates of points in the current plot (2D only)	B–19
	blank displays the plot points to the terminal = filename points are written to filename, one file per set of points	
RESET A	reset command A parameters to default. "ALL" resets all commands.	B–20
RETURN	end interactive plotting when running histories. Leaves plot window.	B–18
RMCTAL F	read MCTAL file F	B–19
RUNTPE F N	from RUNTPE file F, read dump N {last dump}	B–19
SCALES N	select the type of scales and/or grid to put on the plot {default=1}	B–23
	N = 0 no scales on the edges and no grid = 1 scales and no grid	

= 2 scales and grid

SET define free variable(s) and bin numbers of fixed variables. See FIXED. B–21

F D U S M C E T

Each parameter can have a bin number to indicate a fixed variable or a * to indicate a free variable. One * for 2D plot, two *'s for contour.

STATUS display the current values of the plotting parameters B–19

SUBTITLE write a subtitle anywhere on the plot B–20

X Y "A"

X Y is the location to put the subtitle
A in quotation marks is text for subtitle line (up to 40 characters)

TALLY n define tally n (n of Fn) as the current tally {first tally} B–19

TERM N plot to the terminal or send plots to graphics file {plot to terminal} B–18

N = 1/0 plot to terminal / send plots to file; equivalent to NOTEK

TFC X plot the tally fluctuation chart values for the current tally B–21

X = M mean vs. history number
= E relative error vs. history number
= F figure of merit vs. history number
= L up to 201 largest tallies ***f(x)*** vs. ***x*** (NONORM for freq. vs. ***x***)
= N cumulative number fraction of ***f(x)*** vs. ***x***
= P history score prob density function ***f(x)*** vs. ***x*** (NONORM for freq. vs. ***x***)
= S slope of history score probability density function ***f(x)*** vs. ***x***
= T cumulative tally fraction of ***f(x)*** (first moment of ***f(x)***)
= V relative variance of variance vs. history number
= 1 to 8 1st to 8th moment of ***f(x)*** vs. history score ***x***
= 1C to 8C 1st to 8th cumulative moment of ***f(x)*** vs. ***x***

THICK X set the thickness of the plot curves to X (X from 0.01 to 0.1) {0.2} B–23

THIN set the thickness of the plot curves to the minimum 0.01 B–23

TITLE N "A" use "A" as line N of the main title at top of plot B–20

default: FCn comment or name of current RUNTPE or MCTAL plus tally name
N = 1 or 2 to put "A" on the first or second main title line
A in quotation marks is text for main title line (up to 40 characters)

WASH A — A = on/off to use color-wash instead of contour {off} — B–23

WMCTAL F — write the tally data in the current RUNTPE dump to MCTAL file F — B–19

XLIMS — define lower and upper limits and number of subdivisions of x variable — B–23

MIN MAX NSTEPS

MIN,MAX = lower and upper limits for the x variable
NSTEPS = number of subdivisions on linear x axis (no effect on logarithmic)

XS M or ? — plot a cross section according to M: material # or nuclide complete ZAID — B–22

? print a short cross-section plotting primer to the terminal

XTITLE "A" — use A as the title for the X axis {name of X-axis variable} — B–20

YLIMS — define lower and upper limits and number of subdivisions of y variable — B–23

MIN MAX NSTEPS

MIN,MAX = lower and upper limits for the y variable
NSTEPS = number of subdivisions on linear y axis (no effect on logarithmic)

YTITLE "A" — use A as the title for the Y axis {name of Y-axis variable} — B–20

ZLEV n_1 n_2 n_3... — controls the scale of the mesh tally results. The parameters n_i can have the following values: — B–25

log sets the tally data scaling to logarithmic (default)
lin sets the tally data scaling to linear numeric value

If no values are given, sets scale to the default for the particular color mode.
If only one value is given, sets the lower limit of the plot.
If two values are given, sets the lower and upper limits of the plot.
If three or more values are given, sets the values of the color gradients.

APPENDIX B - MCNP GEOMETRY AND TALLY PLOTTING

MCNP has two plotting capabilities. The first, PLOT, is used to plot 2-dimensional slices of a problem geometry specified in the INP file. The second, MCPLOT, plots tally results produced by MCNP and cross-section data used by MCNP. Section I of this appendix addresses system issues external to MCNP related to graphics. Section II discusses how to invoke the PLOT features. Section III discusses how to invoke the MCPLOT features. A complete explanation of each set of input commands is given. Lines the user will type are shown in `lowercase typewriter font`. The ENTER key must be pressed after each input line.

I. SYSTEM GRAPHICS INFORMATION

X Windows is the only graphics system supported by MCNP. This graphics library is device-independent in general and gives considerable flexibility in processing graphical output.

A. X Windows

The X Window graphics library (http://www.x.org) allows the user to send/receive graphics output to/from remote hosts as long as the window manager on the display device supports the X protocol (for example, OpenLook window manager, Motif window manager, Cygwin [PC Windows], etc.). Prior to running MCNP, perform the following steps to use these capabilities. Note that these steps use UNIX C-shell commands. Other shells may require different syntax.

1. On the host that will execute MCNP, enter:

```
setenv DISPLAY displayhost:0
```

where *displayhost* is the name of the host that will receive the graphics. If the *displayhost* is the same as the execution host (*executehost*), set DISPLAY to

‘`localhost:0`’ or just ‘`:0`’.

2. If the two hosts are different, in a CONSOLE window of the display host enter:

```
xhost executehost
```

where *executehost* is the name of the host that will execute MCNP.

With either the ‘`setenv`’ or ‘`xhost`’ commands, the host IP address can be used in place of the host name. This is useful when one remote system does not recognize the host name of another; for example,

```
setenv DISPLAY 128.10.1:0
```

Note: On some systems, including the Los Alamos Integrated Computing Network (ICN) and other LANL local area networks, use of the `'xhost'` command is strongly discouraged. This is because it creates a security problem. In place of using the xhost, the secure shell (SSH) can be used to log into remote hosts and provide X Windows forwarding. This is considered to be more secure, and it handles setting the DISPLAY variable for the user. If SSH is used, do not manually set DISPLAY as this will interfere with the secure forwarding. On local systems (where *displayhost* and *executehost* are the same), this warning does not apply.

II. THE GEOMETRY PLOTTER

The geometry plotter is used to plot 2-dimensional slices of a problem geometry specified in an INP file or RUNTPE. This feature of MCNP is invaluable for debugging geometries. You should first verify your geometry model with the MCNP geometry plotter before running the transport part of MCNP, especially with a complicated geometry in which it is easy to make mistakes. The time required to plot the geometry model is small compared to the potential time lost working with an erroneous geometry.

In this appendix, plot options and keywords are shown in UPPER CASE, but are usually typed by the user in lower case.

A. Geometry PLOT Input and Execute Line Options

To plot geometries with MCNP, enter the following command:

`mcnp ip inp=`*`filename`* *`options`*

where '`ip`' stands for initiate and plot. `'options'` is explained in the following paragraphs. The most common method of plotting is with an interactive graphics terminal. MCNP will read the input file, perform the normal checks for consistency, and then display the interactive geometry plotting window on the terminal screen.

When X Windows is in use, the plot window supports a variety of interactive features that assist the user in selecting the plot. The interactive options are discussed after the discussion of the command-line plot options.

The following four additional plot options can be entered on the execution line in addition to the standard MCNP execution options:

`NOTEK`	Suppress plotting at the terminal and send all plots to the graphics metafile, PLOTM. This is used for production and batch situations and when the user's terminal has no graphics capability.
`COM=`*`aaaa`*	Use file *`aaaa`* as the source of plot requests. When an EOF is read, control is transferred to the terminal. In a production or batch situation, end the file with an END command to prevent transfer of control. Never end the COM file with a blank line. If COM is absent, the terminal is used as the source of plot requests.

`PLOTM=aaaa` Name the graphics metafile *aaaa*. The default name is PLOTM.ps. This file is a standard postscript file.

`COMOUT=aaaa` Name the plot-commands output file *aaaa*. The default name is COMOUT. MCNP writes the COMOUT file in order to give the user the opportunity to do the same plotting at some later time, using all or part of the old COMOUT file as the COM file in the second run.

When names are defaulted, unique names for the output files, PLOTM.ps and COMOUT, will be chosen by MCNP to avoid overwriting existing files. Unique names are created by changing the last letter of the default name until the next available name is found. For example, if the file PLOTM.ps already exists, MCNP tries the name PLOTN.ps, etc., until it finds an available name.

MCNP can be run in a batch environment without much difficulty, but the user interaction with the plotter is significantly reduced. When not using an interactive graphics terminal, use the NOTEK option on the MCNP execution line or set TERM=0 along with other PLOT commands when first prompted by PLOT. (***Note:*** *For geometry plotting with X Windows, a plot window will appear before the first plot request as the interactive plot window is created. To prevent this, use the NOTEK option.*) Every view plotted will be put in a postscript file called PLOTn where n begins at M and goes to the next letter in the alphabet if PLOTM exists. In the interactive mode, plots can be sent to this graphics metafile with the FILE keyword (see the keyword description in Section B for a complete explanation). The PLOTn.ps file is a postscript file that can be sent to a postscript printer.

A plot request consists of a sequence of commands terminated by pressing the ENTER key. A command consists of a keyword, usually followed by some parameters. Lines can be continued by typing an & (ampersand) before pressing the ENTER key, but each keyword and its parameters must be complete on one line. The & character can be used in the COM file as well as at the plot prompt. Keywords and parameters are blank-delimited. A plot request line cannot have more than 80 characters on a single line. Use the & to enter more complex commands. Commas and equal signs are interpreted as blanks. Keywords can be shortened to any degree as long as they are not ambiguous and are spelled correctly. Parameters following the keywords cannot be abbreviated. Numbers can be entered in free-form format and do not require a decimal point for floating point data. Keywords and parameters remain in effect until you change them. ***Note:*** *If a shortened, ambiguous keyword is used, the entire command line will be rejected and a message to that effect will be printed to the terminal. The commands OPTIONS, HELP and '?' display a list of the keywords to help the user recall the correct keyword.*

Before describing the individual plotting commands, it may help to explain the mechanics of 2-dimensional (2D) plotting. To obtain a 2D slice of a geometry, the user must decide where the slice should be taken and how much of the slice should be viewed on the terminal screen. The slice is actually a 2D plane that may be arbitrarily oriented in space; therefore, the first problem is to decide the plane position and orientation. In an orthogonal 3-dimensional coordinate system, the three axes are perpendicular to each other. An orthogonal axis system is defined with a set of BASIS vectors on the 2D plane used to slice the geometry to determine the plot orientation. The first BASIS vector is the horizontal direction on the screen. The second BASIS vector is the vertical

direction on the screen. The surface normal for the plane being viewed is perpendicular to the two BASIS vectors.

How much of the slice to view is determined next. The center of the view plane is set with the ORIGIN command which serves two purposes: first, for planes not corresponding to simple coordinate planes, it determines the position of the plane being viewed; second, the origin becomes the center of the cross-sectional slice being viewed. For example, for a Y-Z plot, the *x*-coordinate given with the PX command determines the location of the PX plane. The ORIGIN is given as an *x, y*, and *z*-coordinate and is the center of the plot displayed.

Because planes are infinite and only a finite area can be displayed at any given time, you must limit the extent of the cross-sectional plane being displayed with the EXTENT command. For instance, a plane defined with PX=X_1 at an ORIGIN of X_1,Y_1, and Z_1 would produce a Y-Z plane at $X = X_1$, centered at Y_1 and Z_1 using the default BASIS vectors for a PX plane of 0 1 0 and 0 0 1. If the EXTENT entered is Y_2 and Z_2, the plot displayed would have a horizontal extent from $Y_1 - Y_2$ to $Y_1 + Y_2$ and a vertical extent of $Z_1 - Z_2$ to $Z_1 + Z_2$.

The BASIS vectors are arbitrary vectors in space. This may seem confusing to the new user, but the majority of plots are PX, PY, or PZ planes where the BASIS vectors are defaulted. For the majority of geometry plots, these simple planes are sufficient and you do not have to enter BASIS vectors. The flexibility of the BASIS option can also be used to examine the geometry from more obscure views.

All the plot parameters for the MCNP plotter have defaults. To obtain a plot, click on the plot area of the interactive screen or, if in command line mode, press ENTER. The default geometry plot is a PX plane centered at 0,0,0 with an extent of −100 to +100 on Y and −100 to +100 on Z. The *y*-axis will be the horizontal axis of the plot, and the *z*-axis will be the vertical axis. Surface labels are printed. This default is the equivalent of entering the command line:

```
origin 0 0 0  extent 100 100  basis 0 1 0  0 0 1  label 1 0
```

By resetting selected plot parameters, any desired plot can be obtained. Most parameters remain set until changed, either by the same command with new values or by a conflicting command.

Warning: Placing the plot plane exactly on a surface of the geometry is not a good idea. For example, if the input geometry has a PX plane at X=0, that plane coincides with the default plot plane. Several things can result when such alignment occurs. Some portion of the geometry may be displayed in dotted lines, which usually indicates a geometry error. Some portion of the geometry may simply not show up at all. Very infrequently the code may crash with an error. To prevent all of these unpleasantries, move the plot plane a short space away from surfaces.

B. Geometry Plot Commands Grouped by Function

This section contains a detailed description of each of the PLOT keywords and its parameters. Type only enough of the keyword so that it is unique, but it must be spelled correctly. The parameters must be typed exactly as given here.

1. Device–Control Commands

Normally PLOT draws plots on the user's terminal and nowhere else. By using the following commands, the user can specify that plots not be drawn on the terminal and/or that they be sent to a graphics metafile or postscript file for processing later by a graphics utility program that will send the plots to other graphics devices.

`TERM` *n* This command sets the output device type according to *n*:

- 0 terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics file. TERM 0 is equivalent to putting NOTEK on MCNP's execute line.
- 1 Restore visible plotting window on next plot request.

`FILE` *aa* Send (or do not send) plots to the postscript file PLOTM.PS according to the value of the parameter *aa*. The graphics file is not created until the first FILE command is entered. FILE has no effect in the NOTEK or TERM=0 cases. The allowed values of *aa* are:

- blank only the current plot is sent to the graphics metafile.
- ALL the current plot and all subsequent plots are sent to the metafile until another FILE command is entered.
- NONE the current plot is not sent to the metafile nor are any subsequent plots sent until another FILE command is entered.

`VIEWPORT` *aa* Make the viewport rectangular or square according to the value of *aa*. The default is RECT. This option does not affect the appearance of the plot. It only determines whether space is provided beside the plot for a legend and around the plot for scales. The allowed values of *aa* are:

- RECT allows space beside the plot for a legend and around the plot for scales.
- SQUARE the legend area, the legend, and scales are omitted, making it possible to print a sequence of plots on some sort of strip medium so as to produce one long picture free from interruptions by legends. ***Note:*** *use of the SQUARE option disables the interactive-window plotter capability.*

2. General Commands

`&` Continue reading commands for the current plot from the next input line. The & must be the last item on the line.

`INTERACT` Return to the interactive, mouse-driven geometry plot interface. This command is used to return from the terminal-command interface when the PLOT option is invoked from the interactive plotter.

`RETURN` If PLOT was called by MCPLOT, control returns to MCPLOT. Otherwise RETURN has no effect.

`MCPLOT` Call or return to MCPLOT, the tally/cross-section plotter.

`PAUSE n` Use with the `COM=aaaa` option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the ENTER key is pressed.

`END` Terminate execution of PLOT.

3. Inquiry Commands

When one of these commands is encountered, the requested display is made and then PLOT waits for the user to enter another line, which can be just pressing the ENTER key, before resuming. The same thing will happen if PLOT sends any kind of warning or comment to the user as it prepares the data for a plot.

`OPTIONS` or ? or `HELP`
Display a list of the PLOT command keywords and available colors.

`STATUS` Display the current values of the plotting parameters.

4. Plot Commands

Plot commands define the values of the parameters used in drawing the next plot. Parameters entered for one plot remain in effect for subsequent plots until they are overridden, either by the same command with new values or by a conflicting command.

`BASIS X1 Y1 Z1 X2 Y2 Z2`
Orient the plot so that the direction (`X1 Y1 Z1`) points to the right and the direction (`X2 Y2 Z2`) points up. The default values are 0 1 0 0 0 1, causing the *y*-axis to point to the right and the *z*-axis to point up. The two vectors do not have to be normalized, but they should be orthogonal. If the two vectors are not orthogonal, MCPLOT will choose an arbitrary second vector that is orthogonal to the first vector. MCPLOT will ignore the command if parallel or zero-length vectors are entered.

`ORIGIN VX VY VZ`
Position the plot so that the origin, which is in the middle of the plot, is at the point (`VX,VY,VZ`). The default values are 0 0 0. The `BASIS` vectors are relative to this point.

`EXTENT EH EV`
Set the scale of the plot so that the horizontal distance from the plot origin to either side of the plot is `EH` and the vertical distance from the origin to the top or bottom is `EV`. If `EV` is omitted, it will be set equal to `EH`. If `EV` is not equal to `EH`, the plot will be distorted. The default values are 100 and 100 giving a 200x200 viewport.

`PX VX` Plot a cross section of the geometry in a plane perpendicular to the *x*-axis at a distance VX from the geometry origin. This command is a shortcut equivalent of

`BASIS 0 1 0 0 0 1 ORIGIN VX vy vz`, where `vy` and `vz` are the current values of `VY` and `VZ`.

`PY VY` Plot a cross section of the geometry in a plane perpendicular to the *y*-axis at a distance `VY` from the geometry origin.

`PZ VZ` Plot a cross section of the geometry in a plane perpendicular to the *z*-axis at a distance `VZ` from the geometry origin.

`LABEL S C DES`

Put labels of size `S` on the surfaces and labels of size `C` in the cells. Use the quantity indicated by `DES` for the cell labels. `C` and `DES` are optional parameters. The sizes are relative to 0.01 times the height of the view surface. If `S` or `C` is zero, that kind of label will be omitted. If `S` or `C` is not zero, it must be in the range from 0.2 to 100. The defaults are `S=1`, `C=0` and `DES=CEL`. The allowed values of `DES` follow, where "*:p*" can be `:N` for neutrons, `:P` for photons, and `:E` for electrons. Following each `DES` value is a short description of the meaning of the values.

`CEL`	cell names
`IMP:`*p*	importances
`RHO`	atom density
`DEN`	mass density
`VOL`	volume
`FCL:`*p*	forced collision
`MAS`	mass
`PWT`	photon-production weight
`MAT`	material number
`TMPn`	temperature (*n*=index of time)
`WWNn:`*p*	weight window lower bound (*n*=energy or time interval)
`EXT:`*p*	exponential transform
`PDn`	detector contribution (*n*=tally number)
`DXC:`*p*	DXTRAN contribution
`U`	universe
`LAT`	lattice type
`FILL`	filling universe
`NONU`	fission turnoff

`LEVEL` *n* Plot only the n^{th} level of a repeated structure geometry. A negative entry (default) plots the geometry at all levels.

`MBODY` Use macrobody surface numbers or macrobody surface facet numbers as surface labels.

`on`	display only the macrobody surface number. This is the default.
`off`	display the macrobody surface facet numbers.

`MESH` *n* Plot the superimposed weight-window mesh. Only a weight-window mesh read in from a WWINP file can be plotted. *n* can have the following values:

0	no lines
1	cell lines only
2	weight window mesh lines only
3	both cell and weight window mesh lines

To plot the values of the mesh windows, set the cell labels to WWN*n:p*, where "*n*" is the weight-window energy interval and "*:p*" is :N for neutrons, P for photons, or E for electrons (See the LABEL command).

`FMESH` *n* Plot mesh tally *n*. Changes the layout of the plot depending on the type of mesh tally. For rectangular meshes, the horizontal axis is in the direction of the dimension with the most number of bins, and the vertical axis is in the direction of the dimension with the second most number of bins. For cylindrical plots, the horizontal axis is along the axis of the cylinder and the vertical axis is along the theta=0 plane. The center of the plot in both cases is at the center of the mesh. To keep the original layout, use the FMESH button of the interactive plotter. FMESH `off` will turn off the mesh tally plotter.

`SCALES` *n* Put scales and a grid on the plot. Scales and grids are incompatible with `VIEWPORT SQUARE`. *n* can have the following values:

0	neither scales nor a grid. This is the default.
1	scales on the edges.
2	scales on the edges and a grid on the plot.

`COLOR` *n* Turn color on or off, set the resolution, or select physical property for color shading. The parameter *n* can have the following values:

on	turn color on.
off	turn color off.
50≤*n*≤3000	set the color resolution to *n*. A larger value increases resolution and drawing time.
by aa	Select physical property to use for geometry shading. Currently allowed options for 'COLOR BY' are:

mat	material (default)
den	gram density
rho	atomic density
tmp	temperature

gradient	use a continuous gradient of 256 colors to show the cell values
solid	use a solid color to represent a range of cell values

When (`den/rho/temp`) is used, the geometry will be shaded using the color gradient mode. Linear interpolation between the minimum non-zero value and the maximum value is used to select the color. A color bar legend of the shades will be drawn in the right margin. The legend is labeled with the property name and the minimum and maximum values. See Figure B-1 for an example of coloring by density (`den`). Coloring by material (`mat`) does not invoke a color bar legend.

`SHADE` *M1* `= parameter...` *M* *K* `= parameter`
`Parameter` can be a color name or a number from 1-64 representing the color

index. Make the cells containing problem material number *Mi* a particular color. This is only valid when `'MAT'` is used to `COLOR BY` (the default). Use the `LABEL` command to display material numbers. `Parameter` designates the desired color (e.g., green, blue, etc.). ***Note:*** *color names are case-sensitive.* The `OPTIONS` command will list available colors if your display is a color monitor. (The index of a color name is in top-bottom, left-right order.)

5. Zoom Commands

Zoom commands redefine the origin, basis, and extent relative to the current origin, basis and extent. The new origin, basis, and extent will be used for all subsequent plots until they are again redefined, either by zoom commands or by plot commands. The zoom commands are usually used to zoom in on some feature of the plot.

`CENTER DH DV`
Change the origin of the plot by the amount `DH` in the horizontal direction and by the amount `DV` in the vertical direction. This command is usually used to define the center of a portion of the current plot that the user wants to enlarge.

`FACTOR F` Enlarge the plot by the factor `1/F`. `F` must be greater than 10^{-6}.

`THETA TH` Rotate the plot counterclockwise by the angle `TH`, in degrees.

`CURSOR` Present the graphics cursor and prepare to receive cursor input from the user. This command is available only if the terminal has a graphics cursor capability. The user defines a rectangular area to be enlarged by moving the cursor to one corner of the rectangle and entering the cursor trigger, then moving it to the diagonally opposite corner of the rectangle and entering the cursor trigger again. On most terminals the cursor trigger is any key other than the ENTER key followed by ENTER. If the extents were equal before the cursor command was entered, the smaller of the two extents defined by the cursor input is made equal to the larger one. The `CURSOR` command should be the only command on the input line.

`RESTORE` Restore the origin and extent to the values they had before the most recent `CURSOR` command. The `RESTORE` command should be the only command on the input line. It cannot be used to undo the effects of the `CENTER`, `FACTOR`, and `THETA` commands.

`LOCATE` Present the graphics cursor and prepare to receive cursor input from the user. This command is available only if the terminal has a graphics cursor capability. The user moves the cursor to a point in the picture and enters the cursor trigger. The *x,y,z*-coordinates of the point are displayed. The `LOCATE` command should be the only command on the input line.

C. Geometry Debugging and Plot Orientation

Surfaces appearing on a plot as dashed lines usually indicate that adjoining space is improperly defined. Dashed lines caused by a geometry error can indicate space that has been defined in more than one cell or space that has never been defined. These geometry errors need to be corrected.

Dashed lines can also occur because the plot plane corresponds to a bounding planar surface. The plot plane should be moved so it is not coincident with a problem surface. Dashed lines can also indicate a cookie cutter cell or a DXTRAN sphere. These are not errors. The reason for the presence of dashed lines on an MCNP plot should be understood before running a problem.

When checking a geometry model, errors may not appear on the 2D slice chosen, but one or more particles may get lost in tracking. To find the modeling error, use the coordinates and trajectory of the particle when it got lost. Entering the particle coordinates as the ORIGIN and the particle trajectory as the first basis vector will result in a plot displaying the problem space.

The `ORIGIN`, `EXTENT`, and `BASIS` vectors all define a space called the plot *window* (in particular, the window that appears on the terminal screen). The window is a rectangular plane twice the length and width of `EXTENT`, centered about the point defined by `ORIGIN`. The first `BASIS` vector B1 is along the horizontal axis of the plot window and points toward the right side of the window. The second `BASIS` vector B2 is along the vertical axis of the plot window and points toward the top of the window.

The signs are determined by the direction of the vectors; in particular, do the vector components point in the $\pm x$, $\pm y$, or $\pm z$ direction? After signs have been fixed, determine the magnitudes of the vector components. Assume the vector is parallel to the x-axis. It has no y component and no z component so the vector would be 1 0 0. If there is no x component but both y and z, and y and z have equal magnitudes, the vector would be 0 1 1. The vector does not have to be normalized. If the angle between the vector and the axes is known, the user can use the sine and cosine of the angle to determine the magnitude of the components. A rough approximation will probably be sufficient.

D. Interactive Geometry Plotting

The geometry plotter supports interactive point and click plotting for all systems with X11 graphics. Figure B-1 shows an example geometry plot window with the interactive controls outlined. The controls are separated into left, right, top, and bottom menus. The plot area itself is also active. Each menu is discussed in the following paragraphs.

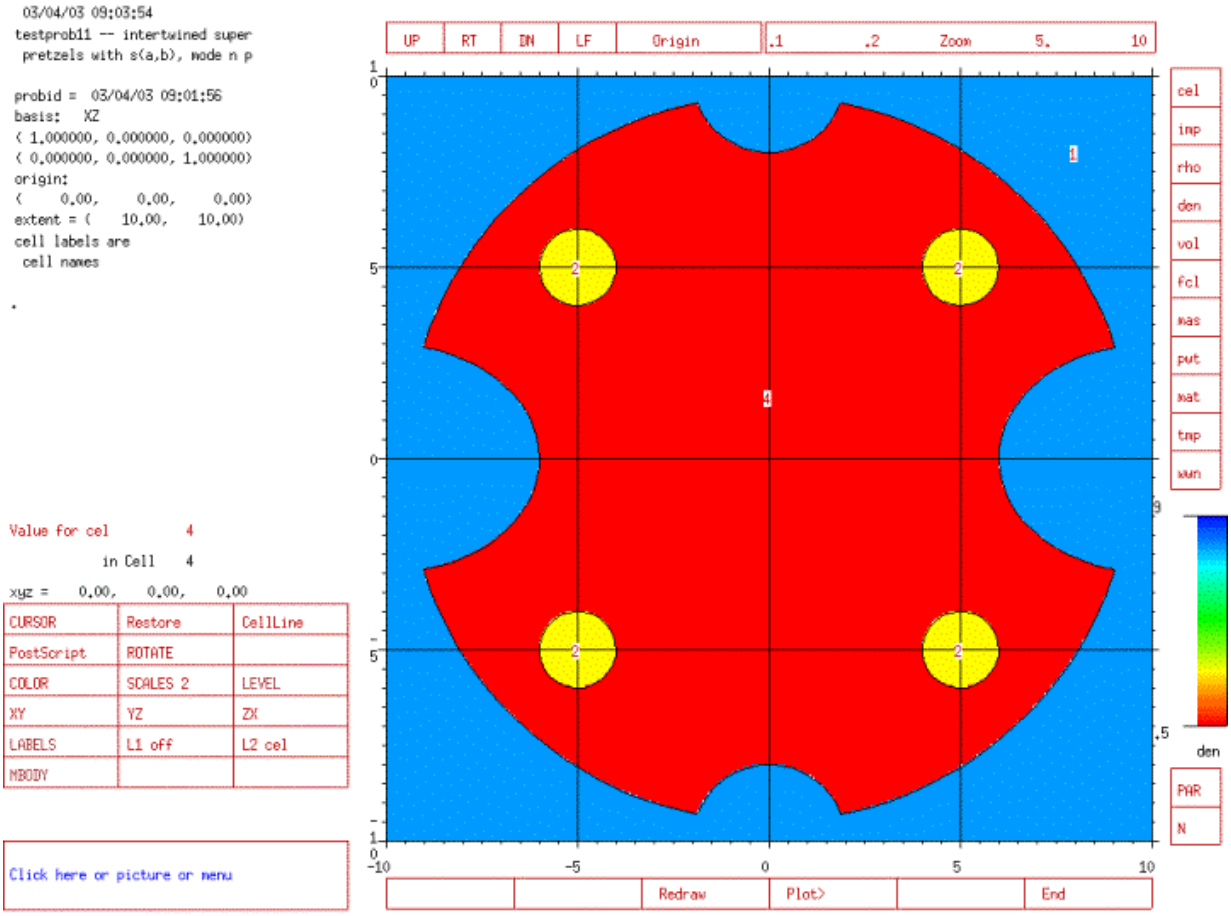

Figure B-1. Geometry plot window showing interactive plotting controls

- Left Menu:

  The left menu is the area from top to bottom left of the geometry plot area. Its controls affect what is plotted and how. In Figure B-1, each control button is outlined in red. In the left menu, there is a 3x6 block of buttons, the Edit button, and the “Click Here...” button. There is also a “hidden” button in the upper left corner that triggers a redraw. If your plot window appears blank when exposed, click in the upper left of the screen to refresh it.

  - “Click here...”: Clicking in this area toggles the acceptance of a text plot command in this box. Up to 29 characters representing one or more complete plot commands can be entered. On acceptance, either more input can be entered or a redraw is done, depending on the command given. ***Note:*** *For extended access to the command-line*

interface, use the PLOT> option in the bottom menu to pass control to the terminal window.

In the 3x6 block of buttons, the function of each button is described below. Blank buttons are unused and reserved for expansion of the interactive plotter capability:

CURSOR	Restore	CellLine
PostScript	ROTATE	
COLOR	SCALES 0	LEVEL
XY	YZ	ZX
LABELS	L1 sur	L2 off
MBODY on	FMESH	

- CURSOR: Clicking here activates the cursor region selector. Click in the plot at an upper corner, then a lower corner of a region. The plot will be redrawn accordingly. This is equivalent to an extent command and an origin command.
- Line Type: (CellLine/No Lines/WW Mesh/WW+Cell) Clicking this button toggles between available line modes. The button label is set to the selected option. The figure shows 'CellLine', the active mode in the example. This button does not force a redraw. The 'WW Mesh' and 'WW+Cell' modes refer to the weight-window mesh and are only available if a weight window mesh is read in from a WWINP file.
- PostScript: Toggles writing of the next picture to the postscript file, PLOTM.ps. It does not trigger a redraw. If postscript is enabled, the plot must be redrawn to write PLOTM.ps. When the postscript-creation is enabled, the button label is "PScript on." Its function is equivalent to the text command FILE with no argument in that only the next plot is written to the file. After the next redraw, the label is reset to "Postscript."
- ROTATE (on/off): Rotates plot 90˚ (interchanges first two basis vectors).
- COLOR (on/off): Toggles between color and no color plotting. This toggle does not trigger a redraw.
- SCALES (0/1/2): Toggles between scale modes (no scales, axes only, axes, and grid). This toggle does not trigger a redraw.
- LEVEL <N>: Toggles between available geometry levels (in repeated-structure geometries only). In the figure, this option is shown in gray because there are no sublevels. The button label identifies the level plotted if levels are present in the input. This toggle does not trigger a redraw.
- XY: Sets the basis to (1,0,0, 0,1,0). Leaves origin alone. This toggle triggers a redraw.
- YZ: Sets the basis to (0,1,0, 0,0,1). Leaves origin alone. This toggle triggers a redraw.
- ZX: Sets the basis to (0,0,1, 1,0,0). Leaves origin alone. This toggle triggers a redraw.
- LABELS: This is currently just a label. It has no function other than identifying the next two buttons as having label operations. It may be used for expansion in the future.
- L1 (sur/off): Sets the status of the surface labeling.
- L2 (<type>/off): Sets the status of the cell labeling to off or to the currently selected cell labels. The cell label type is selected in the right menu.

- MBODY (on/off): Toggles macrobody/macrobody facet labeling. Only active if macrobodies exist in the input. This toggle does not trigger a redraw.
- FMESH <N>: Cycle through mesh tallies. Does not change plot layout. Only present if mesh tallies exist in the input. This toggle does not trigger a redraw.

In addition to the marked buttons, clicking anywhere in the top quarter of the left menu area forces a redraw. On systems without backing-store (i.e., PC, IRIX), the entire window may appear blank if resized or iconified and then restored. Just remember to click in the upper left corner to redraw.

- Right Menu:

  The right menu is used to set cell values for cell labels and to edit quantities and related indices. The set of eleven buttons in the upper portion of the right menu is used to select the type of cell labels and the values to be displayed in the Edit area on plot clicks. After selecting a new label, you must toggle the LABEL2 button off and back on. Then trigger a redraw.

  There are two other buttons in the lower portion of the right menu. The PAR button selects the particle type for cell quantities that have particle-specific values (for example, imp:p). The N button selects a numerical index for cell-quantities that have indexed values (for example, WWN1:n for first-energy-bin weight windows for neutrons).

- Top Menu:

  The top menu contains the shift and zoom functions.

- UP: Shifts origin one full window upwards.
- RT: Shifts origin one full window to the right.
- DN: Shifts origin one full window downwards.
- LF: Shifts origin one full window to the left.
- Origin: Sets the origin to the position of a mouse click in the plot area.
- Zoom: Selects a zoom factor. This is a scale that selects integer scale factors, Nx or 1/Nx, for N=1-10. A second click in the menu for the same scale factor zooms about the current origin. If the second click is in the plot, the origin is reset to that point and the zoom occurs about the new origin. The selected scale factor is displayed before the second click just above the “Click here...” button in the left menu. You can change the zoom factor before the second click by clicking elsewhere on the zoom scale. This is equivalent to a new first click. To undo a zoom by factor Nx that does not move the origin, zoom again by 1/Nx. To effectively cancel a zoom, reselect the factor to 1x or 1/1x after the first click and complete the 1x zoom.

- Bottom Menu

  This menu along the bottom edge of the plot and extending to the right-hand edge, provides

  six buttons. However, only three are currently in use. The three active functions are Redraw, Plot> and End.
  - Redraw: Triggers a redraw of the plot. This can be used after non-redraw options are selected. For example, when the plot settings are as desired, a click on Postscript followed by a click on Redraw writes that plot to the PLOTM.ps file.
  - Plot>: Passes control to the command-line PLOT interface described in Section II.A and B beginning on page B-2. Once in the command-line mode, control can be returned to the interactive plotter with the command INTERACT. This can be useful for extended access to the command line. ***Note:*** *For brief text commands, use the "Click here..." button to type up to 29-character text commands.*
  - The End button is used to exit PLOT.

- Plot Area:

  The plot area is active at all times when the interactive plotter is enabled. It is not active when the command-line interface is in use (Plot> option) except for text commands that need mouse input from the plot window.

  Options that use plot-area interaction include the following:

ZOOM	Second click in plot area selects new origin.
ORIGIN	Click in window sets origin.
LOCATE	(typed command) Clicks in plot area result in display of various values at the location clicked.
CURSOR	Two clicks define a new square view with the largest dimension of the selected rectangle.

  A click in the plot area without any other selected option will cause the cell, location, and variable value for the selected location to be displayed above the left menu. This area is labeled "Value for." The variable displayed is selected using the right menu.

III. THE MCPLOT TALLY AND CROSS-SECTION PLOTTER

MCPLOT plots tally results produced by MCNP and cross-section data used by MCNP. It can draw ordinary 2D *x*-*y* plots ($y(x)$) and contour tally plots or color-filled tally plots of 3-dimensional data, $z(x,y)$. It supports a wide variety of plot options. More than one curve can be plotted on a single *x*-*y* plot. Tally plots can be made from a MCTAL or a RUNTPE file. However, if plotting from a MCTAL file, not all options are available, since not all the information is available in that format.

MCPLOT can also plot cross-section data specified in an INP file: either individual nuclides or the complete material composed of constituent nuclei properly weighted by atomic fraction. The data

plotted reflect adjustments to the cross sections made by MCNP such as energy cutoffs, neutron cross–section temperatures, S(α,β) treatment, summation of photon reactions to provide a total photon cross section, simple physics treatment for photon data, generation of electron stopping powers and other electron data, and more. Cross-section plots cannot be made from a RUNTPE file.

This section covers these general topics in the following order: execute line options, plot conventions and command syntax, plot commands grouped by function, and MCTAL files. MCPLOT options and keywords are shown in upper case but are usually typed by the user in lower case.

Final tally results can be plotted after particle transport has finished. The temporary status of one or more tallies can be displayed during the run as transport is ongoing (*not always possible in parallel computations*). After transport is finished, MCPLOT is invoked by typing a `z` on the MCNP execute line, either as a separate procedure using existing RUNTPE or MCTAL files or as part of a regular uninterrupted MCNP run. There are two ways to request that a plot be produced periodically during the run: 1. Use an MPLOT card in the INP file, or 2. Use the TTY interrupt feature (*not always possible in parallel computations*). See Chapter 3 page 3-151 for an explanation of the MPLOT card. A TTY interrupt, <*ctrl–c*> `m`, causes MCNP to pause at the end of the history that is running when the interrupt occurs and allows plots to be made by calling MCPLOT, which takes plot requests from the terminal.

Limitations of run-time tally plotting: During run-time plotting, no output is sent to the COMOUT file. In addition, the following commands cannot be used: RMCTAL, RUNTPE, and DUMP. The END or RETURN commands are used to exit MCPLOT or return MCNP to transport mode. Cross-section data cannot be displayed after a TTY interrupt or by use of the MPLOT card.

MCPLOT can make tally plots on a machine different from the one on which the problem was run by using the MCTAL file. When the INP file has a PRDMP card with a nonzero third entry, a MCTAL file is created at the end of the run. The MCTAL file contains all the tally data in the last RUNTPE dump and it is a coded ASCII file that can be converted and moved from one kind of machine to another. When the MCTAL file is created, its name can be specified by entering the following in the execute line:

```
mcnp i=inpfile  mctal=filename
```

The default name is a unique name based on MCTAL.

A. Input for MCPLOT and Execution Line Options

To run only MCPLOT and plot tallies after completion of an MCNP calculation, enter the following command:

```
mcnp  z  options
```

where `'z'` invokes MCPLOT. `'Options'` is explained below. Cross-section data cannot be plotted by this method.

The execute line command

mcnp inp=*filename* ixrz *options*

causes MCNP to run the problem specified in *filename* and then the prompt *mcplot* > appears for MCPLOT commands. Both cross-section data and tallies can be plotted. Cross-section data cannot be plotted after a TTY interrupt or by using the MPLOT card.

The execute line command

mcnp inp=*filename* ixz *options*

is the most common way to plot cross-section data. The problem cross sections are read in but no transport occurs. The following commands cannot be used: BAR, CONTOUR, DUMP, FREQ, HIST, PLOT, RETURN, RMCTAL, RUNTPE, WASH and WMCTAL.

The following options can be entered on the execution line:

NOTEK	Suppress plotting at the terminal and send all plots to the graphics file, PLOTM.ps. NOTEK is for production and batch situations and for when the user's terminal has no graphics capability.
COM=*aaaa*	Use file *aaaa* as the source of plot requests. When an EOF is read, control is transferred to the terminal. In a production or batch situation, end the file with an END command to prevent transfer of control. Never end the COM file with a blank line. If COM is absent, the terminal is used as the source of plot requests.
RUNTPE=*aaaa*	Read file *aaaa* as the source of MCNP tally data. The default file name is RUNTPE. If the default RUNTPE file does not exist, the user will be prompted for an RMCTAL or RUNTPE command.The name for the RUNTPE can be specified on the execution line via the runtpe=*runtpe* execute-line option.
PLOTM=*aaaa*	Name the graphics metafile *aaaa*. The default name is PLOTM.ps. This file is a standard postscript file.
COMOUT=*aaaa*	Write all plot requests to file *aaaa*. The default name is COMOUT. MCPLOT writes the COMOUT file in order to give the user the opportunity to do the same plotting at some later time, using all or part of the old COMOUT file as the COM file in the second run.

Unique names for the output files, PLOTM.ps and COMOUT, will be chosen by MCNP to avoid overwriting existing files.

Plot requests are normally entered from the keyboard of a terminal but alternatively can be entered from a file. A plot is requested by entering a sequence of plot commands following a prompt character. The request is terminated by the ENTER key not immediately preceded by an & or by a COPLOT command. Commands consist of keywords, usually followed by some parameters, entered space or comma delimited.

Defaults are available for nearly everything. If MCNP is run with Z as the execute line message, if file RUNTPE is present with more than one energy bin in the first tally, and if the ENTER key is

pressed in response to the MCPLOT prompt, a lin-log histogram plot of tally/MeV vs. energy including error bars and suitable labels will appear on the screen.

B. Plot Conventions and Command Syntax

1. 2D Plot

The origin of coordinates is at the lower left corner of the picture. The horizontal axis is called the *x*-axis. It is the axis of the independent variable such as user bin or cell number or energy. The vertical axis is called the *y*-axis. It is the axis of the dependent variable such as *flux* or *current* or *dose*. Each axis can be either linear or logarithmic.

2. Contour Plot

The origin of coordinates is at the lower left corner of the picture. The horizontal axis is called the *x*-axis. It is the axis of the first of the two independent variables. The vertical axis is called the *y*-axis. It is the axis of the second independent variable. The contours represent the values of the dependent variable. Only linear axes are available. Each contour is drawn in a different color depending on its value with respect to the Z-value extrema.

3. Color-Wash Plot

This plot option is similar to contour plotting, but instead of drawing contours of $z(x,y)$ data, each tally bin is filled with a color selected by the tally value in the bin. The axis conventions are the same as in contour plotting. This option is selected with the command WASH. If two free variables have been selected (with the FREE command), a color-filled plot is drawn. This is a useful option for radiography tallies. A palette of 64 colors ranging from red to yellow to green to blue is used. The color index is selected by linear interpolation between the Z-minimum and the Z-maximum values.

4. Command Syntax

Each command consists of a command keyword, in most cases followed by some parameters. Keywords and parameters are entered blank delimited, no more than 80 characters per line. Commas and equal signs are interpreted as blanks. A plot request can be continued onto another line by typing an & before pressing the ENTER key, but each command (the keyword and its parameters) must be completely on one line. Command keywords, but not parameters, can be abbreviated to any degree not resulting in ambiguity, but must be correctly spelled. The term "current plot" means the plot that is being defined by the commands currently being typed in, which might not be the plot that is showing on the screen. Only those commands marked with an ∗ in the list in Section C below can be used after the first COPLOT command in a plot request because the others all affect the framework of the plot or are for contour or 3-dimensional plots only.

C. Plot Commands Grouped by Function

1. Device–Control Commands

Normally MCPLOT draws plots on the user's terminal and nowhere else. By means of the following commands the user can specify that plots not be drawn on the terminal and/or that they be sent to a graphics metafile or postscript file for processing later by a graphics utility program that will send the plots to other graphics devices.

`TERM` *n* — This command sets the output device type according to *n*:

- 0 — terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphic file. `TERM 0` is equivalent to putting `NOTEK` on MCNP's execute line.
- 1 — Restore visible plotting window on next plot request.

`FILE` *aa* — Send (or do not send) plots to the postscript file PLOTM.PS according to the value of the parameter *aa*. The graphics file is not created until the first FILE command is entered. FILE has no effect in the `NOTEK` or `TERM 0` cases. The allowed values of *aa* are:

- blank — only the current plot is sent to the graphics file.
- `ALL` — the current plot and all subsequent plots are sent to the postscript file (PLOTM.PS) until another `FILE` command is entered.
- `NONE` — the current plot is not sent to the file nor are any subsequent plots until another `FILE` command is entered.

2. General Commands

`* &` — Continue reading commands for the current plot from the next input line. The `&` must be the last item on the line.

`* COPLOT` — Plot a curve according to the commands entered so far and keep the plot open for coplotting one or more additional curves. `COPLOT` is effective for 2D plots only. If `COPLOT` is the last command on a line, it functions as if it were followed by an `&`.

`FREQ` *n* — Specifies the interval between calls to MCPLOT to be every *n* histories. In KCODE calculation, interval is every *n* cycles. If *n* is negative, the interval is in CPU minutes. If *n*=0, MCPLOT is not called while MCNP is running histories. The default is *n*=0. 8 byte integer values allowed for FREQ.

`RETURN` — If MCPLOT was called by MCNP while running histories or by PLOT while doing geometry plotting, control returns to the calling subroutine. Otherwise `RETURN` has no effect.

`PLOT` — Call or return to the PLOT geometry plotter. This cannot be done when plotting from a MCTAL file.

`PAUSE` *n* — Use with the `COM=`*aaaa* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the ENTER key is pressed.

`* END` — Terminate execution of MCPLOT.

* = available with COPLOT

3. Inquiry Commands

* OPTIONS or ? or HELP Display a list of the MCPLOT command keywords.
* STATUS Display the current values of the plotting parameters.
* PRINTAL Display the numbers of the tallies in the current RUNTPE or MCTAL file.
* IPTAL Display the IPTAL array for the current tally. This array (see Appendix E page E-31) tells how many elements are in each dimension of the current 8–dimensional tally.

PRINTPTS Display the *x–y* coordinates of the points in the current plot. PRINTPTS is not available for coplots or contour or color-wash plots.

* = available with COPLOT

4. File Manipulation Commands

* RUNTPE *aa n* Read dump *n* from RUNTPE file *aa*. If the parameter *n* is omitted, the last dump in the file is read.
* DUMP *n* Read dump *n* of the current RUNTPE file.
* WMCTAL *aa* Write the tally data in the current RUNTPE dump to MCTAL file *aa*.

* RMCTAL *aa* Read MCTAL file *aa*.

* = available with COPLOT

5. Parameter–Setting Commands

Parameters entered for one curve or plot remain in effect for subsequent curves and plots until they are either reset to their default values with the RESET command or are overridden, either by the same command with new values, by a conflicting command, or by the FREE command that resets many parameters. There are two exceptions: FACTOR and LABEL are effective for the current curve only. An example of a conflicting command is BAR, which turns off HIST and PLINEAR.

a. General

* TALLY *n* Define tally *n* as the current tally. The parameter *n* specifies one of the Fn cards in the INP file of the problem represented by the current RUNTPE or MCTAL file. The default is the first tally in the problem, which is the lowest numbered neutron tally or, if none, then the lowest numbered photon tally or, if none, then the lowest numbered electron tally.
* PERT *n* Plot a perturbation associated with a tally, where *n* is a number on a PERT *n* card. PERT 0 will reset PERT *n*.

LETHARGY Divide tally bin by lethargy bin width for log energy abscissa. Produces visually accurate area plots for a 2-D LOGLIN energy abscissa (FREE E). A lethargy-normed plot is equivalent to plotting e*f*(e) (see Appendix B, Section III-F).

NONORM Suppress bin normalization. The default in a 2-D plot is to divide the tallies by the bin widths if the independent variable is cosine, energy, or time. However, also see the description of the MCTAL file in Section II.D on page B-25. Bin normalization is not done in contour or color-wash plots.

* FACTOR *a f s*

Multiply the data for axis *a* by the factor *f* and then add the term *s*. *a* is *x, y,* or *z*. *s* is optional. If *s* is omitted, it is set to zero. For the initial curve of a 2D plot, reset the axis limits (XLIMS or YLIMS) to the default values. FACTOR affects *only* the current curve or plot.

* RESET *aa* Reset the parameters of command *aa* to their default values. *aa* can be a parameter–setting command, COPLOT, or ALL. If *aa* is ALL, the parameters of all parameter–setting commands are reset to their default values. After a COPLOT command, only COPLOT, ALL, or any of the parameter-setting commands that are marked with an ∗ in this list may be reset. Resetting COPLOT or ALL while COPLOT is in effect causes the next plot to be an initial plot.

∗ = available with COPLOT

b. Titling Commands (The double quotes are required)

TITLE *n* "*aa*" Use *aa* as line *n* of the main title at the top of the plot. The allowed values of *n* are 1 and 2. The maximum length of *aa* is 40 characters. The default is the comment on the FC card for the current tally, if any. Otherwise it is the name of the current RUNTPE or MCTAL file plus the name of the tally. KCODE plots have their own special default title.

BELOW Put the title below the plot instead of above it.

SUBTITLE *x y* "*aa*"

Write subtitle *aa* at location *x,y*, which can be anywhere on the plot including in the margins between the axes and the limits of the screen.

XTITLE "*aa*" Use *aa* as the title for the *x*-axis. The default is the name of the variable represented by the *x*-axis.

YTITLE "*aa*" Use *aa* as the title for the *y*-axis. The default is the name of the variable represented by the *y*-axis.

* LABEL "*aa*" Use *aa* as the label for the current curve. It is printed in the legend beside a short piece of the kind of line used to plot the curve. The value of LABEL reverts to its default value, blank, after the current curve is plotted. If LABEL is blank, the name of the RUNTPE or MCTAL file being plotted is printed as the label for the curve.

∗ = available with COPLOT

c. Commands that specify what is to be plotted

Tallies in MCNP are binned according to the values of eight different independent variables. Because only one or two of those variables can be used as independent variables in any one plot, one or two of the eight independent variables have to be designated as free variables, and the rest become fixed variables. Fixed values (bin numbers) have to be defined, explicitly or by default, for

all of the fixed variables. The default value for each fixed variable is the total bin, if present; otherwise the first is used instead.

`FREE xy` Use variable *x* (*y* blank) or variables *x* and *y* as the independent variable or variables in the plot. If only *x* is specified, 2D plots are made. If both *x* and *y* are specified, either contour or color-wash plots are made, depending on whether WASH is in effect. See keyword FIXED for the list of the symbols that can be used for *x* and *y*. The default value of *xy* is E, and gives a 2D plot in which the independent variable is energy. The `FREE` command resets XTITLE, YTITLE, XLIMS, YLIMS, HIST, BAR and PLINEAR to their defaults.

`* FIXED q n`

Set *n* as the bin number for fixed variable *q*. The symbols that can be used for *q*, and the kinds of bins they represent are:

`F`	cell, surface, or detector
`D`	total vs. direct or flagged vs. unflagged
`U`	user–defined
`S`	segment
`M`	multiplier
`C`	cosine
`E`	energy
`T`	time

`SET F D U S M C E T`

Define which variables are free and define the bin numbers of the fixed variables. `SET` does the job of the `FREE` and several `FIXED` commands in one compact command. The value of each parameter can be a bin number (the corresponding variable is then a fixed variable) or an ∗ (the corresponding variable is then a free variable). If there is only one ∗, 2D plots are made. If there are two ∗∗, contour or color-wash plots are made. `SET` does the same resetting of parameters that `FREE` does.

`TFC x` Plot the tally fluctuation chart of the current tally. The independent variable is NPS. Allowed values of *x* are († represents data available with plotting from a MCTAL file):

†`M`	mean
†`E`	relative error
†`F`	figure of merit
`L`	201 largest tallies vs. *x* (NONORM for frequency vs. *x*)
`N`	cumulative number fraction of *f(x)* vs. *x*
`P`	probability *f(x)* vs. *x* (NONORM for number frequency vs. *x*)
`S`	SLOPE of the high tallies as a function of NPS
`T`	cumulative tally fraction of *f(x)* vs. *x*
`V`	VOV as a function of NPS
`1-8`	1 to 8 moments of $f(x)*x^{1 \text{ to } 8}$ vs. *x*

(NONORM for $f(x)*\Delta x * x^{1 \text{ to } 8}$ vs. x)

`1c-8c` 1 to 8 cumulative moments of $f(x)*x^{1 \text{ to } 8}$ vs. x

`* KCODE i` The independent variable is the KCODE cycle. The individual estimator plots start with cycle one. The average col/abs/trk-len plots start with the fourth active cycle.

Plot k_{eff} or prompt removal lifetime according to the value of `i`:

`1`	k (collision)
`2`	k (absorption)
`3`	k (track)
`4`	prompt removal lifetime (collision)
`5`	prompt removal lifetime (absorption)
`6`	Shannon entropy of fission source distribution (Can be plotted only from runtpe, not mctal file)
`11-15`	the quantity corresponding to `i`−10, averaged over the cycles so far in the problem.
`16`	average col/abs/trk-len k_{eff} and one estimated standard deviation
`17`	average col/abs/trk-len k_{eff} and one estimated standard deviation by cycles skipped. Cannot plot fewer than 10 active cycles.
`18`	average col/abs/trk-len k_{eff} figure of merit
`19`	average col/abs/trk-len k_{eff} relative error

∗ = available with `COPLOT`

d. Commands for cross-section plotting

`* XS m` Plot a cross section according to the value of `m`:

`Mn`	a material card in the INP file for material `n`. Example: XS M15. The available materials will be listed if a material is requested that does not exist in the INP file.
`z`	a nuclide ZAID. Example: XS 92235.50C. The full ZAID must be provided. The available nuclides will be listed if a nuclide is requested that does not exist in the INP file.
?	Print out a cross-section plotting primer.

`* MT n` Plot reaction `n` of the current material or nuclide ZAID. The default is the total cross section. The available reaction numbers are listed in Appendix G on G–2. If an invalid reaction number is requested, the available reactions in the data file will be listed.

`* PAR p` Plot the data for particle type `p`, where `p` can be N, P, or E of material M*n*. The default is the source particle type for `XS=Mn`. For `XS=z`, the particle type is determined from the data library type. For example, 92000.01g defines `PAR=p`. It must be the first entry on the line.

∗ = available with `COPLOT`

e. Commands that specify the form of 2D plots

`LINLIN` Use linear *x*-axis and linear *y*-axis.

`LINLOG` Use linear *x*-axis and logarithmic *y*-axis. This is the default.

`LOGLIN` Use logarithmic *x*-axis and linear *y*-axis.

`LOGLOG` Use logarithmic *x*-axis and logarithmic *y*-axis.

`XLIMS` *`min max nsteps`*

`YLIMS` *`min max nsteps`*

Define the lower limit, upper limit, and number of subdivisions on the *x*- or *y*-axis. *`nsteps`* is optional for a linear axis and is ineffective for a logarithmic axis. In the absence of any specification by the user, the values of *`min`*, *`max`*, and *`nsteps`* are defined by an algorithm in MCPLOT.

`SCALES` *`n`* Put scales on the plots according to the value of *`n`*:

0 no scales on the edges and no grid.

1 scales on the edges (the default).

2 scales on the edges and a grid on the plot.

`* HIST` Make histogram plots. This is the default if the independent variable is cosine, energy, or time.

`* PLINEAR` Make piecewise–linear plots. This is the default if the independent variable is not cosine, energy, or time.

`* BAR` Make bar plots.

`* NOERRBAR` Suppress error bars. The default is to include error bars.

`* THICK` *`x`* Set the thickness of the plot curves to the value *x*. The legal values lie in the range from 0.01 to 0.10. The default value of `THICK` is 0.02.

`* THIN` Set the thickness of the plot curves to the legal minimum of 0.01.

`LEGEND` *`x y`* Include or omit the legend according to the values of optional parameters *x* and *y*.

no *x* and no *y*:	put the legend in its normal place. (the default).
x=0 and no *y*:	omit the legend.
x and *y* defined:	for 2D plots only, put most of the legend in its usual place but put the part that labels the plot lines at location *x,y*.

* = available with `COPLOT`

f. Commands that specify the form of contour plots.

`CONTOUR cmin cmax cstep %`

Define `cmin`, `cmax`, and `cstep` as the minimum, maximum, and step values for contours. If the optional `%` symbol is included, the first three parameters are interpreted as percentages of the minimum and maximum values of the dependent variable. The default values are 5 95 10 %

`WASH` *`aa`* Set or unset *z*(*x,y*) plotting to use color-wash instead of contours. *`aa`* can be one of two values:

`on` Turn on color-wash plotting for two free variables.

`off` Turn off color-wash plotting (return to contour plotting for two free variables). This is the default. Actually, any value for *aa* other than `on` is equivalent to `off`.

g. Commands for mesh tally plots.

MCNP uses the geometry plotter to display the results of the mesh tally. The default layout depends on the type of mesh tally. For rectangular meshes, the horizontal axis is in the direction of the dimension with the most number of bins, and the vertical axis is in the direction of the dimension with the second most number of bins. For cylindrical plots, the horizontal axis is along the axis of the cylinder and the vertical axis is along the theta=0 plane. The center of the plot in both cases is at the center of the mesh. Different views are obtained by using the MCNP geometry plotter commands. Exiting the mesh tally plotter will return the code to the tally plotter.
Note: there are two ways to change the mesh that is plotted. One way is to use the FMESH button of the interactive plotter command panel. This will change the mesh tally but not the plot attributes (basis, extent, and origin). The second method is to enter the `FMESH n` command in the command box. This will reset the plot layout to the default for that particular mesh tally.

`FMESH n` Plot mesh tally `n`.

`FMRELERR n` Plot the relative errors of mesh tally `n`. If `n` is not provided, will plot the relative error for the current mesh.

`ZLEV` n_1 n_2 n_3 . . . Controls the scale of the mesh tally results. The parameters n_i can have the following values:

`log`	sets the tally data scaling to logarithmic (default)
`lin`	sets the tally data scaling to linear numeric value

If no values are given, sets scale to the default for the particular color mode.
If only one value is given, sets the lower limit of the plot.
If no values are given, sets the lower and upper limits of the plot.
If three or more values are given, sets the values of the color gradients.

`EBIN n` Plot energy bin `n` of the current mesh tally. The total energy bin is the last bin of the tally.

D. MCTAL Files

A MCTAL file contains the tally data of one dump of a RUNTPE file. It can be written by the MCRUN module of MCNP or by the MCPLOT module, by other codes, or even by hand in order to send data to MCPLOT for coplotting with MCNP tally data. Mesh Tally data are not written to the MCTAL file.

As written by MCNP, a MCTAL file has the form shown below, but only as much of it as is essential to contain the information of real substance is necessary. Furthermore, the numerical items do not need to be in the columns implied by the formats as long as they are in the right order, are blank delimited, and have no imbedded blanks. For example, to give MCPLOT a table of something versus energy, the user might write a file as simple as:

```
E    7   1
   .2   .4   .7   1   3   8   12
VALS
   4.00E-5   .022   5.78E-4   .054   3.70E-5   .079   1.22E-5   .122
   7.60E-6   .187   2.20E-6   .245   9.10E-7   .307
```

If more than one independent variable is wanted, other lines such as a T line followed by a list of time values would be needed and the table of tally/error values would need to be expanded. If more than one table of tally/error values is wanted, the file would have to include an NTAL line followed by a list of arbitrarily chosen tally numbers, a TALLY line, and then lines to describe all of the pertinent independent variables would have to be added for each table.

Form of the MCTAL file as written by MCNP

kod, ver, probid, knod, nps, rnr (2A8,A19,15,I11,I15)
kod is the name of the code, MCNP.
ver is the version, 4A.
probid is the date and time when the problem was run and, if it is available, the designator of the machine that was used.
knod is the dump number.
nps is the number of histories that were run.
rnr is the number of pseudorandom numbers that were used.

One blank followed by columns 1–79 of the problem identification line, which is the first line in the problem's INP file. (1x,A79)

NTAL n NPERT m (A4,I6,1X,A5,I6)
n is the number of tallies in the problem.
m is the number of perturbations in the problem.

List of the tally numbers, on as many lines as necessary. (16I5)

The following information is written for each tally in the problem.

TALLY m i j (A5,3I5)
m is the problem name of the tally, one of the numbers in the list after the NTAL line.
i is the particle type: 1=N, 2=P, 3=N+P, 4=E, 5=N+E, 6=P+E, 7=N+P+E, where N=neutron, P=photon, E=electron.
j is the tally type: 0=nondetector, 1=point detector, 2=ring, 3=FIP, 4=FIR, and 5=FIC.

The FC card lines, if any, each starting with 5 blanks (5x,A75)

F n (A2,I8)
n is the number of cell, surface, or detector bins.

List of the cell or surface numbers, on as many lines as necessary. (11I7)
If a cell or surface bin is made up of several cells or surfaces, a zero is written. This list is omitted if the tally is a detector tally.

D n (A2,I8)
n is the number of total vs. direct or flagged vs. unflagged bins. For detectors, n=2 unless there is an ND on the F5 card; for cell and surface tallies, n=1 unless there is an SF or CF card.

U n or UT n or UC n (A2,I8)
n is the number of user bins, including the total bin if there is one. But if there is only one unbounded bin, n=0 instead of 1. If there is a total bin, the character U at the beginning of the line is

followed by the character T. If there is cumulative binning, the character U at the beginning of the line is followed by the character C. These conventions concerning a single unbounded bin and the total bin also apply to the S, M, C, E, and T lines below.

S n or ST n or SC n (A2,I8)
n is the number of segment bins.

M n or MT n or MC n (A2,I8)
n is the number of multiplier bins.

C n f or CT n f or CC n f (A2,I8,I4)
n is the number of cosine bins. f is an integer flag: if f=0 or is absent, the cosine values in the next list are bin boundaries. Otherwise they are the points where the tally values ought to be plotted, and the tally values are not under any circumstances to be divided by the widths of cosine bins. The E and T lines described below have similar flags.

List of cosine values, on as many lines as necessary. 1P6E13.5

E n f or ET n f or EC n f A2,I8,I4
n is the number of energy bins.

List of energy values, on as many lines as necessary. (1P6E13.5)

T n f or TT n f or TC n f (A2,I8,I4)
n is the number of time bins.

List of time values, on as many lines as necessary. (1P6E13.5)

VALS (A4)

List of tally/error data pairs, on as many lines as necessary. (4(1PE13.5,0PF7.4))
The order is what a 9-dimensional Fortran array would have if it were dimensioned (2,NT,NE,...,NF), where NT is the number of time bins, NE is the number of energy bins, ..., and NF is the number of cell, surface, or detector bins. The values here are exactly the same as are printed for each tally in the OUTP file.

TFC n jtf (A3,I5,8I8)
n is the number of sets of tally fluctuation data. jtf is a list of 8 numbers, the bin indexes of the tally fluctuation chart bin.

List of four numbers for each set of tally fluctuation chart data, NPS, tally, error, figure of merit. (I11,1P3E13.5)

This is the end of the information written for each tally.

KCODE nc ikz mk (A5,3I5)
nc is the number of recorded KCODE cycles. ikz is the number of settle cycles. mk is the number of variables provided for each cycle.

List of 3 k_{eff} and 2 prompt removal lifetime values for each recorded KCODE cycle (5E12.5)
if mk=0 or 5; if mk=19, the whole RKPL(19,MRKP) array is given (see Appendix E).

E. Example of Use of COPLOT

```
runtpe a coplot runtpe b
```

Assume all parameter-setting commands have been previously defined. The input above will put two curves on one plot. The first curve will display tally data from RUNTPE `a` and the second curve will display tally data from RUNTPE `b` for the same tally number. Unless reset somehow, MCPLOT will continue to read from RUNTPE `b`. The following command

```
xlims min max    tally 11    coplot rmctal aux    tally 41 &
coplot runtpe a    tally 1
```

changes the upper and lower limit of the *x*-axis, defines Tally 11 as the current tally, plots the first curve from RUNTPE `b`, the second curve from Tally 41 data on MCTAL file `aux`, and the third curve from Tally 1 data on RUNTPE `a`. Future plots will display data from RUNTPE `a` unless reset.

```
tally 24    nonorm    file    coplot    tally 44
```

will send a frame with two curves to a postscript file.

F. Normalization of Energy-Dependent Tally Plots

This section discusses two methods of normalizing an energy-dependent tally for plotting:

- dividing by the width of each energy bin, and
- dividing by the logarithmic width of each energy bin (i.e., dividing by the lethargy width).

This section also discusses how to obtain plots that provide an easy visualization for the tally results by the area under the curve. Examples of both normalizations are provided for a logarithmic energy abscissa.

1. MCNP Tally Values and Energy-Normed Tallies

Assume that an MCNP energy-dependent tally density such as flux or reaction rate has a form of *f(E)* per unit energy. An MCNP tally result T_i in energy bin *i* from *f(E)* is

$$T_i = \int_{E_{l_i}}^{E_{u_i}} f(E)dE \text{ tally units,} \qquad \text{(B.1)}$$

where the energy bin limits are E_{l_i} to E_{u_i}. The T_i's tend to be small for small energy bins and large for larger energy bins. Thus, there is no explicit information about the density *f(E)* in the T_i's unless all energy bins have the same constant width, in which case the correct histogram shape of $f(E)$ is obtained from the T_i's. The average value of *f(E)* over the energy range ΔE_i between E_{l_i} and E_{u_i} is

$$f_i(E) = \frac{\int_{E_{l_i}}^{E_{u_i}} f(E)dE}{\int_{E_{l_i}}^{E_{u_i}} dE} = \frac{T_i}{E_{u_i} - E_{l_i}} \text{(tally units)/(unit energy).} \qquad \text{(B.2)}$$

The $f_i(E)$'s are the bin-wise histogram representations of the tally of *f(E)* because they are the average values of *f(E)* in each energy bin. Note that $f_i(E)$is a constant between E_{l_i} and E_{u_i}.

This $E_{u_i} - E_{l_i}$ norming of T_i, the default for a 2-D MCNP energy-dependent tally spectral plot, is generally agreed to be the proper way to display the $f_i(E)$'s when the abscissa E of a 2-D plot is linear. When a LINLIN (linear abscissa and linear ordinate) plot of $f_i(E)$'s is made with the ordinate starting at zero, the visual area under each histogram represents T_i. This type of visually correct area plot will be termed a **Visually Accurate Area (VAA)** plot. A VAA plot provides correct visual information about the tally by the area under the histogram.

The average energy $\bar{E}_i$ for each $f_i(E)$bin is

$$\bar{E}_i = \frac{\int_{E_{l_i}}^{E_{u_i}} Ef(E)dE}{\int_{E_{l_i}}^{E_{u_i}} f(E)dE} \approx \frac{\int_{E_{l_i}}^{E_{u_i}} E f_i(E)dE}{\int_{E_{l_i}}^{E_{u_i}} f_i(E)dE} = \frac{E_{u_i} + E_{l_i}}{2} \quad , \qquad \text{(B.3)}$$

where the $f_i(E)$histogram approximation to *f(E)* cancels out. $\bar{E}_i$ is used as the average energy for plotting the statistical error bars for tally bin *i*.

2. Definition of Neutron Lethargy

The lethargy U of a neutron with energy E is defined to be

$$U = ln\left(\frac{E_0}{E}\right) = ln(E_0) - ln(E) \quad , \qquad \text{(B.4)}$$

where E_0 is the upper neutron energy for the problem. On the average, neutrons lose a fixed fraction of their energy in each elastic collision with a specific isotope above thermal energies. The lethargy U is used in nuclear reactor analysis to assess the average logarithmic energy loss of these elastically scattered neutrons.

A neutron with energy E_0 has zero lethargy. As the neutron loses energy, its lethargy increases (hence the name "lethargy" because the neutron becomes more lethargic) and is always positive because no energy is greater than E_0. A neutron with zero energy has infinite lethargy.

For eigenvalue problems, MCNP calculates the Energy of the Average neutron Lethargy causing Fission (EALF) (see Note 21 on page 5-106):

$$\text{EALF} = \exp\left[\int ln(E)\Phi(E)\Sigma_f(E)dE / \int \Phi(E)\Sigma_f(E)dE\right] , \qquad \text{(B.5)}$$

where $\Phi(E)$ is the neutron flux and $\Sigma_f(E)$is the fission cross section (the E_0's cancel). MCNP can plot energy-dependent tallies versus a logarithmic energy scale using lethargy for tally bin normalization.

3. Lethargy-Normed Tallies for a Logarithmic Energy Abscissa

When the abscissa E is logarithmic, the T_i norming procedure often preferred involves the differences in the natural logs (ln) of the energy instead of the differences in the energies. It is useful to relate the differences in the logs of the bin energies to the often used neutron lethargy U:

$$ln(E_{u_i}) - ln(E_{l_i}) = U_{l_i} - U_{u_i} , \qquad \text{(B.6)}$$

where U_{l_i} is the lethargy at E_{l_i} and U_{u_i} is the lethargy at E_{u_i} (the $ln(E_0)$ terms cancel: see Eqn. (B.4)).

The tally T_i can be converted to an average bin i lethargy-normed value $F_i(U)$ by

$$F_i(U) = \frac{T_i}{ln(E_{u_i}/E_{l_i})} = \frac{T_i}{U_{l_i} - U_{u_i}} \text{ (tally units)/(unit lethargy).} \qquad \text{(B.7)}$$

The $F_i(U)$'s are the histogram approximation to $F(U)$ per unit lethargy. MCNP plots the $F_i(U)$'s instead of the $f_i(E)$'s for a $ln(E)$ abscissa when the LETHARGY plot command is used. The $F_i(U)$'s are not plotted when the energy abscissa is linear. Only the $f_i(E)$'s and T_i's can be plotted for a linear E abscissa. A LOGLIN (log abscissa and linear ordinate) plot of the $F_i(U)$'s is a VAA plot because the $ln(E)$ abscissa is linear in U and the area under the histogram is visually correct.

4. Relation of Tally Lethargy Norming to Tally Energy Norming

To determine the functional form of $F(U)$ in terms of $f(E)$, equate the U and E density function areas to produce

$$F(U)dU = -f(E)dE . \qquad \text{(B.8)}$$

The negative sign is required because E decreases as U increases. Integrating the left hand side of Eqn. (B.8) from U_{u_i} to U_{l_i} is equal to T_i, as is the integral of the right hand side from E_{u_i} to E_{l_i}.

The differential dU can be written in terms of energy E from Eqn. (B.4) as

$$dU = -d\{ln(E)\} = \frac{-dE}{E} . \qquad \text{(B.9)}$$

Substituting Eqn. (B.9) for dU into Eqn. (B.8) gives

$$F(U) = Ef(E) \ . \tag{B.10}$$

Eqn. (B.10) shows that $F(U)$ can be thought of as the energy E times $f(E)$. Thus, besides producing VAA LOGLIN plots, lethargy-normed plots have the additional virtue of flattening the $1/E$ neutron flux shape that often occurs in neutron spectra. For an $f(E)$ that has a $1/E$ shape everywhere, $F_i(U)$ is a constant for all i (as opposed to the widely varying $f_i(E)$'s), which produces a VAA plot for the $1/E$ shape. Lethargy-normed plots remove many of the decades of $f_i(E)$ change, represent the $1/E$ portions of the spectrum as a constant, and make understanding and comparing the $F_i(U)$ results easier.

5. Average Energy for a Lethargy-Normed Tally

The lethargy-averaged energy $<E_i>$ for energy bin i is defined as

$$<E_i> = \frac{\int_{U_{u_i}}^{U_{l_i}} EF(U)dU}{\int_{U_{u_i}}^{U_{l_i}} F(U)dU} \ . \tag{B.11}$$

For the histogram approximation of $F(U)$ by $F_i(U)$, the $F_i(U)$'s cancel, and changing variables using Eqn. (B.9) gives

$$<E_i> \approx \frac{\int_{U_{u_i}}^{U_{l_i}} E\,dU}{\int_{U_{u_i}}^{U_{l_i}} dU} = \frac{\int_{E_{l_i}}^{E_{u_i}} dE}{\int_{E_{l_i}}^{E_{u_i}} \frac{dE}{E}} = \frac{E_{u_i} - E_{l_i}}{ln\left(\frac{E_{u_i}}{E_{l_i}}\right)} \ . \tag{B.12}$$

In the limit as $E_{u_i} - E_{l_i}$ becomes small, $<E_i> \approx \bar{E}_i$ in Eqn. (B.3) as expected. This average $<E_i>$ is considered to be the centroid energy for a lethargy-normed bin and is used in MCNP to plot statistical error bars, BAR plots, and PLINEAR plots, as well as printing the plotted points using the PRINTPTS command.

6. MCNP LETHARGY Command for Lethargy Normalization

Lethargy-normed plots of energy-dependent tallies with a log energy abscissa are made with the LETHARGY plotting command. This command cannot be used for cross-section plots. For this command to apply, "FREE e" must be active, "LOGLIN" or "LOGLOG" axes must be used, and the "NONORM" command must not be invoked. The LETHARGY command cannot be used after a COPLOT command and can be disabled to return to energy bin-width tally normalization for a log energy abscissa by using RESET LETHARGY. Switching from a logarithmic energy to a linear energy abscissa with LETHARGY in use will automatically change a plot of the $F_i(U)$'s to the $f_i(E)$'s. Switching back to the log energy abscissa will again plot the $F_i(U)$'s.

If an E_0 were specified for a log abscissa plot, a linear lethargy abscissa could be specified starting at the right with a value of zero at E_0 and linearly increasing to the left in steps of about 2.3 per energy decade decrease. MCNP does not label the abscissa as lethargy because of the difficult energy interpretation. The logarithmic energy decades are plotted instead to allow easier interpretation of the areas under the lethargy-normed histogram. For this reason, there is neither a need nor a provision to specify E_0.

7. Requirements for Producing a Visually Accurate Area (VAA) Tally Plot

Consider the characteristics of a function of one variable, such as an MCNP 2-D tally histogram plot. One important quantity for this histogram is the integral over the tally range, which is the total MCNP tally. Another important characteristic is the shape of this histogram that provides information about where the largest regions of the tally have occurred. The area of a tally range under the plotted curve is a measure of the contribution of each range to the total.

The area under this curve is best visualized with both the abscissa and the ordinate having a linear scale. The ordinate usually has a lower value of zero to correctly represent the curve area. A LINLIN plot of the $f_i(E)$'s fits these criteria and therefore is a VAA plot. Often linear scales do not allow complete display of a tally, so logarithmic scales must be used. A logarithmic axis scale typically changes by decades. Each decade change on the abscissa changes a ΔE for a specified length along the abscissa by a decade. The area under the LOGLIN $f_i(E)$ curve is proportional to ΔE, which is not reflected in the visual area representation on the log abscissa plot. A logarithmic ordinate does not visually display the correct tally contribution under the curve because this area in the plot is proportional to the number of ordinate decades. When both axes are logarithmic, the visual interpretation in the plot of the area under the curve is further obscured.

The lethargy variable U is linear in the logarithm of the energy as defined in Eqn. (B.4). U values for decreasing energy E values of E_0, $E_0/10$, and $E_0/100$ are 0, 2.3, and 4.6. Therefore, a LOGLIN plot of the $F_i(U)$'s instead of the $f_i(E)$'s satisfies the VAA plot linear scale criterion for visually examining the area under a curve. The area under each histogram $F_i(U)$ is $F_i(U)*(U_{l_i}-U_{u_i})$, which is exactly the bin i tally T_i as defined in Eqn. (B.7). Similarly, the area under all the $F_i(U)$'s is the sum of the T_i's, which is the total MCNP tally. A LOGLIN plot of the $F_i(U)$'s *is* a VAA plot; a LOGLIN plot of the $f_i(E)$'s is *not* a VAA plot.

8. Comparisons of Energy and Lethargy Tally Normalizations for a Log Energy Abscissa

Energy-normed and lethargy-normed log energy abscissa tally plots for two analytic and two critical uranium assembly problems are discussed to show which are VAA plots. The two analytic $f(E)$ examples will be accurate to three significant figures in the text.

a. A Constant $f(E)$ = 0.100 from 0.0001 to 10 MeV

The first example is the tally of a uniform energy source between 0.0001 and 10 MeV. The expected value of all $f_i(E)$'s is 0.100. Figure B-2 (see figures beginning on page B-36) shows a plot of the five energy-normed $f_i(E)$'s, each with an energy bin width of a decade. The tally T_i in the energy bin from 1 to 10 MeV is (10-1)*0.1 = 0.9. The next lowest energy bin tally is (1 – 0.1)*0.1 = 0.09. The tally bin T_i's are decreasing by a decade per decade decrease in energy,

but the $f_i(E)$'s are a statistically constant 0.1. Visually interpreting this LOGLIN plot of the $f_i(E)$'s by the area under the curve is not useful because the energies are changing by decades along the logarithmic energy abscissa.

Figure B-3 shows a LOGLIN lethargy-normed plot of the corresponding five $F_i(U)$'s. (The "f(u) = ef(e) bin normed" text on the right hand side of the plot is a reminder that this is a lethargy-normed plot.) The shapes of the $f_i(E)$'s in Figure B-2 and the $F_i(U)$'s in Figure B-3 are completely different. $F_i(U)$ for the 1 to 10 MeV tally bin is $0.9/ln(10/1) = 0.391$. The area in the plot of this bin is $ln(10/1)*0.391 = 0.900$, which is the correct T_i for this bin. The tally bin area from 0.1 to 1 MeV is $ln(1/0.1)*0.0391 = 0.0900$. The visual areas of each of the tally bins represent the tally for that bin because of the linear lethargy abscissa obtained by the lethargy normalization. *The LOGLIN lethargy-normed plot in Figure B-3 clearly displays the relative contribution of each of the five tally bins by the area under the histogram. Figure B-3 is a VAA plot.*

Figure B-4 shows the same plot as in Figure B-3, except the ordinate is now logarithmic. The five $F_i(U)$'s are the same in both plots, but the visual area interpretation in Figure B-4 is misleading because the ordinate scale is logarithmic. Nevertheless, Figure B-4 is useful for assessing the behavior of the $F_i(U)$'s that are small and cannot be seen in Figure B-3 with the linear ordinate.

b. $f(E) = 0.087/E$ from 10^{-6} to 0.1 MeV

For a second example, an equal-lethargy 50-bin tally was made of a $1/E$ energy source from 10^{-6} to 0.1 MeV. The lethargy width of each tally bin is $ln(0.1/10^{-6})/50 = 0.23$. All T_i's have an expected value of $0.23/ln(0.1/10^{-6}) = 0.02$ for the equal lethargy energy bins. Figures B-5 and B-6 show LOGLIN and LOGLOG plots of the $f_i(E)$'s. Each tally bin has a relative error of 0.2%. The $f_i(E)$'s have the expected $1/E$ shape of the source. The histograms in both figures decrease with increasing energy because the T_i's are constant and ΔE_i's are continuously increasing. Neither Figure B-5 nor B-6 is a VAA plot because neither shows a meaningful visual under-the-curve area representation of the T_i's for this tally.

The lethargy-normed plot of the $F_i(U)$'s in Figure B-7 is a VAA plot. The $F_i(U)$'s are a statistical constant ($0.02/0.23 = 0.087$) for $f(E) = 1/E$, as predicted by Eqn. (B.10). Figure B-7 shows visually that all equal lethargy widths contribute equally to the total tally, which is correct for the $1/E$ source. The integral of under the curve of Figure B-7 is $0.087*ln(0.1/10^{-6}) = 1$, which is the source strength. Once again, the shapes of the $f_i(E)$'s in Figures B-5 and B-6 and the $F_i(U)$'s in Figure B-7 are completely different.

c. Neutron Fluxes and Fission Rate Spectra for Two Critical Uranium Systems

A third and more realistic example is a comparison of $f_i(E)$and $F_i(U)$ plots for the neutron fluxes and fission rate spectra calculated by MCNP for two critical uranium systems:

1. a water-reflected, water-moderated array of 18 x 20 2.35% Low-Enriched U(LEU)O_2 aluminum clad fuel elements[1]; and
2. the Godiva bare metal 93.7% Highly-Enriched Uranium (HEU) sphere.[2]

The calculations were performed with pre-ENDF/B-VII uranium isotope cross sections (from Los Alamos National Laboratory Group T-16) that are identified by a ".69c." All other isotopes in the

LEU system used ENDF/B-VI ".66c" cross sections with ".60t" S(α,β) data for light water and polyethylene. The calculated k_{eff} for the LEU system is 0.9968 with an estimated standard deviation of 0.0003. The HEU system k_{eff} is 0.9987 with a standard deviation of 0.0003. The calculated EALF for the LEU and HEU systems is 1.0×10^{-7} MeV and 0.82 MeV. The calculated percentages of the incident neutrons causing fission by energy range are listed in Table B.1.

Figures B-8 and B-9 compare the energy-normed and lethargy-normed plots of the neutron flux $f_i(E)$'s and $F_i(U)$'s for the thermal LEU and fast HEU systems. The areas under all curves are one. Only the HEU flux values with relative errors less than 0.1 were plotted, which is the reason this flux curve terminates abruptly. The plots of the $f_i(E)$'s in Figure B-8 do not convey the contributions of the $f_i(E)$flux by the area under the curve because both scales are logarithmic. The $1/E$ flux behavior for the LEU system is evident in the figure over much of the ten decades of the $f_i(E)$'s. Figure B-8 is not a VAA plot.

Figure B-9 is a VAA plot because the visual area under each curve accurately represents the contributions to the total flux by energy range because both axes are linear. The $1/E\, f_i(E)$flux behavior is characterized as the flat $F_i(U)$ range, as predicted by Eqn. (B.10).

Table B.1.
Percentage of Fission Rates by Incident Neutron Energy

System	Spectrum	Less than 0.625 eV	0.625 to 100 keV	Greater than 100 keV
LEU	Thermal	91.4	4.5	4.1
HEU	Fast	0.	5.4	94.6

Figure B-10 shows a LOGLOG plot of the fission rate $f_i(E)$'s versus E for the thermal neutron spectrum LEU and fast high-energy spectrum HEU systems. Each curve is divided by the total tally over all energies so the area under each curve is unity. Figure B-10 shows the thermal and fast fission rate shapes, but does little to convey the fission rate percentages shown in Table B.1. Figure B-10 is *not* a VAA plot.

Figure B-11 shows a LOGLIN plot of the $f_i(E)$'s versus E for just the LEU system. The area under this curve representation of the LEU system also *does not* visually agree with the results in Table B.1: there is no curve area above 6×10^{-7} MeV (0.6 eV). This conclusion about incorrect visual areas is not surprising since the $F(U)$ and $f(E)$ shapes differ so markedly for the first two simple examples. Figure B-11 is *not* a VAA plot.

Figure B-12 shows a LOGLIN VAA plot of the fission rate $F_i(U)$'s versus E for both systems. The area beneath both curves is one. Now the fission rate percentages occurring in each energy range become clear and visually match the results in Table B.1. The LOGLIN lethargy-normed plot in Figure B-12 visually conveys much more information about the fission rate characteristics as a function of energy than the plot of the $f_i(E)$'s in Figures B-10 and B-11.

Comparing the LEU $f_i(E)$'s in Figure B-11 with the LEU $F_i(U)$'s in Figure B-12 shows that the $f_i(E)$thermal fission rate peak in Figure B-11 is skewed toward the lower energies. This shift is caused by the ever-increasing $1/\Delta E_i$ for decreasing energies. The visual area representation of the LEU tally is correct for $F_i(U)$in Figure B-12 and incorrect for $f_i(E)$in Figure B-11.

Figure B-13 shows a LOGLOG plot of the fission rate $F_i(U)$'s versus E. Even though the visual area under this curve is misrepresented by the log ordinate, the behavior of the smaller $F_i(U)$ values versus E becomes clearer.

9. Summary of Energy-Normed and Lethargy-Normed MCNP Tally Plots

Visually Accurate Area (VAA) plots allow an accurate visual assessment of the contributions made to a tally by various ranges. For a LINLIN plot, the energy-normed $f_i(E)$'s are VAA plots. For a LOGLIN plot, the LETHARGY command produces lethargy-normed $F_i(U)$'s that are VAA plots. All other plots, which may provide useful information about the tally, are *not* VAA plots. The energy location in a tally bin of the statistical error bars for energy-normed and lethargy-normed plots is different, as shown by Eqns. (B.3) and (B.12)

It is clear that VAA plots are useful to visually assess by the area under the curve the characteristics of the tally. Equal abscissa bin spacing is not required for VAA plots. The more uniform the abscissa intervals are, however, the easier the area visualization becomes; e.g., it may be hard to estimate the area for a narrow bin that is much higher than other bins. If the abscissa intervals are all the same length, then the shape of a plot is identical to a NONORM plot where the bin T_i's themselves are plotted. The magnitude of the two curves will differ by the bin-width normalization. MCNP can create lethargy-normed plots for $ln(E)$ abscissas for all particle types when the LETHARGY plotting command is used.

THE BOTTOM LINE: Both the LINLIN energy-normed and LOGLIN lethargy-normed plots of energy-dependent tallies allow a direct tally contribution visualization by the area under the histogram.

Figure B-2. A LOGLIN plot of energy-normed $f_i(E)$ versus E for a uniformly sampled energy source between 0.0001 and 10 MeV. The expected value of all $f_i(E)$'s is 0.1. This plot is not a VAA plot.

Figure B-3. A LOGLIN plot of lethargy-normed $F_i(U)$ versus E for a uniformly sampled energy source between 0.0001 and 10 MeV. The area $F_i(U)*\Delta U_i$ of each tally bin is the tally value. This plot is a VAA plot.

Figure B-4. A LOGLOG plot of $F_i(U)$ versus E for a uniformly sampled energy source between 0.0001 and 10 MeV. The smaller tallies not visible at lower energies in Figure B-3 can be seen here. This plot is not a VAA plot.

Figure B-5. A LOGLIN plot of $f_i(E)$ versus E for a $1/E$ energy source between 10^{-6} and 0.1 MeV. Equal lethargy bin spacing (0.23) in energy is used, so all bins contribute the same amount to the total tally for the $1/E$ source. This plot is not a VAA plot.

Figure B-6. A LOGLOG plot of $f_i(E)$ versus E for a $1/E$ energy source between 10^{-6} and 0.1 MeV. The $1/E$ behavior of $f_i(E)$ is evident. This plot is not a VAA plot.

Figure B-7. A LOGLIN plot of $F_i(U) = E*f(E) = E*(0.087/E) = 0.087$ versus E for a $1/E$ energy source between 10^{-6} and 0.1 MeV. The integral of this plot is unity, which is the source strength. This plot is a VAA plot because equal lethargy ranges contribute equally to the total for the $1/E$ source.

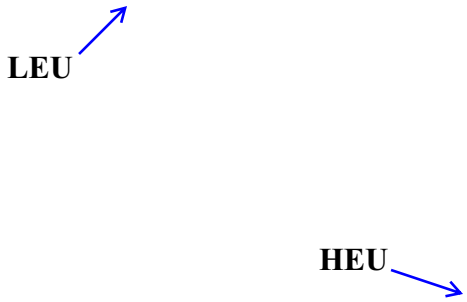

Figure B-8. A LOGLOG plot of the energy-normed neutron flux $f_i(E)$ versus E for the thermal LEU and fast HEU systems. The area under both curves is one. This plot is not a VAA plot.

Figure B-9. A LOGLIN plot of the lethargy-normed neutron flux $F_i(U)$ versus E for the thermal LEU and fast HEU systems. The area under both curves is one. This plot is a VAA plot.

Figure B-10. A LOGLOG plot of the fission rate $f_i(E)$ versus E for the thermal LEU and fast HEU systems. The area under both curves is one. This plot is not a VAA plot.

Figure B-11. A LOGLIN plot of the fission rate $f_i(E)$ versus E for the thermal LEU system. The area under the curve is one. This plot is not a VAA plot because the curve is distorted by the $1/E$ norming.

Figure B-12. A LOGLIN plot of the fission rate $F_i(U)$ versus E for the thermal LEU and fast HEU systems. The area of both curves is one. This plot is a VAA plot.

Figure B-13. A LOGLOG plot of the fission rate $F_i(U)$ versus E for the thermal LEU and fast HEU systems. The area of both curves is one. This plot is not a VAA plot.

IV. REFERENCES

1. V. F. Dean, C. A. Atkinson, and N. R. Smith, "Water Moderated U(2.35)O_2 Fuel Rods in 2.032-cm Square-Pitched Arrays," *International Handbook of Evaluated Criticality Safety Experiments*, LEU-COMP-THERM-001, Nuclear Energy Agency, Organization for Economic Co-Operation and Development (September 2004).
2. R. J. LaBauve, J. Sapir, and C. A. Atkinson, "Bare, Highly Enriched Uranium Sphere (GODIVA)," *International Handbook of Evaluated Criticality Safety Experiments*, HEU-MET-FAST-001, Nuclear Energy Agency, Organization for Economic Co-Operation and Development (September 2004).

APPENDIX I - PTRAC TABLES

Table I.1 presents the format of the PTRAC output file. Table I.2 –Table I.7 provide a detailed description of each variable in the output file. Note that capitalized variables with three or more characters refer to MCNP Fortran variables (except where noted) and are defined in Appendix E.

Table I.1
Format of the PTRAC Output File

		ASCII	Binary
Format	Line	Format	Record
–1	1	(i5)	1
KOD, VER, LODDAT, IDTM	2	(a8,a5,a8,a19)	2
AID	3	(a80)	3
m n_1 V_2^1 V_2^1 … V_{n1}^1 …	4	(1x,10e12.4)	4
.			
. K total lines of PTRAC input data (see Table I.2)			
.			
N_1 N_2 ... N_{20}	4+K	(1x,20i5)	4+K
L_1 L_2 ... L_{N1}	5+K	(1x,30i4)	5+K
L_1^1 L_2^1 … L_{N2+N3}^1			
.			
. M total lines of variable IDs			
.			
********** End of Header – Start NPS and Event Lines **********			
I_1^1 I_2^1 … I_{N1}^1	5+K+M	(1x,5i10,e13.5)	6+K
J_1^1 J_2^1 … $J_{N2,4,6,8,10}^1$	6+K+M	(1x,8i10)	7+K
P_1^1 P_2^1 … $P_{N3,5,7,9,11}^1$	7+K+M	(1x,9e13.5)	
J_1^2 J_2^2 … $J_{N2,4,6,8,10}^2$	8+K+M	(1x,8i10)	8+K
P_1^2 P_2^2 … $P_{N3,5,7,9,11}^2$	9+K+M	(1x,9e13.5)	
.			
. Q total lines of event data for this history (see Table I.3)			
.			
I_1^2 I_2^2 … I_{N1}^2	5+K+M+Q	(1x,5i10,e13.5)	6+K+Q/2
.			
.			

See Table I.3 for all possible values of N_2 – N_{11}

N_1 = Number of variables on the NPS line (I_1 I_2 ...).

N_2 = Number of variables on 1st event line for an “src” event.
N_3 = Number of variables on 2nd event line for an “src” event.

Table I.1
Format of the PTRAC Output File

N_4 = Number of variables on 1st event line for a "bnk" event.
N_5 = Number of variables on 2nd event line for a "bnk" event.
N_6 = Number of variables on 1st event line for a "sur" event.
N_7 = Number of variables on 2nd event line for a "sur" event.
N_8 = Number of variables on 1st event line for a "col" event.
N_9 = Number of variables on 2nd event line for a "col" event.
N_{10} = Number of variables on 1st event line for a "ter" event.
N_{11} = Number of variables on 2nd event line for a "ter" event.

N_{12} = IPT for single particle transport, otherwise 0.
N_{13} = 4 for real*4 output and 8 for real*8 output
N_{14} – N_{20} = not used.

See Table I.4 for definitions of variable IDs:

$L_1\ L_2\ \ldots\ L_{N1}$ = List of variable IDs for the NPS line.

$L_1\ L_2^1\ \ldots\ L_{N2+N3}^1$ = List of variable IDs for an "src" event.

$L_1^2\ L_2^2\ \ldots\ L_{N4+N5}^2$ = List of variable IDs for a "bnk" event.

$L_1^3\ L_2^3\ \ldots\ L_{N6+N7}^3$ = List of variable IDs for a "sur" event.

$L_1^4\ L_2^4\ \ldots\ L_{N8+N9}^4$ = List of variable IDs for a "col" event.

$L_1^5\ L_2^5\ \ldots\ L_{N10+N11}^5$ = List of variable IDs for a "ter" event.

See Table I.4 for corresponding variable IDs:

I_1 = NPS.
I_2 = Event type of the 1st event for this history (see Table I.5).
I_3 = Cell number if cell filtered, otherwise omitted.
I_4 = Surface number if surface filtered, otherwise omitted.
I_5 = Tally number if tally filtered, otherwise omitted.
I_6 = TFC bin tally if tally filtered, otherwise omitted.

Table I.2
PTRAC Input Format

$m\ n_1 V_1^1\ V_2^1 \ldots\ V_{n1}^1 \quad n_2 V_1^2\ V_2^2 \ldots\ V_{n2}^2 \ldots \quad n_{13} V_1^{13}\ V_2^{13} \ldots\ V_{n13}^{13}$

m = Number of PTRAC keywords = 13

n_i = Number of entries for i^{th} keyword or 0 for no entries.

$V_1\ V_2 \ldots\ V_{ni}$ = 1st entry, 2nd entry, ... for the i^{th} keyword (see below).

Index	Keyword	Index	Keyword	Index	Keyword	Index	Keyword
1	BUFFER	5	FILTER	9	SURFACE	13	WRITE
2	CELL	6	MAX	10	TALLY		
3	EVENT	7	MENP	11	TYPE		
4	FILE	8	NPS	12	VALUE		

Table I.3
Event Line Variable IDs (See Table I.4)*

	Type 1 ($N_{12} \neq 0$ WRITE = pos		Type 2 $N_{12} = 0$ WRITE=pos		Type 3 ($N_{12} \neq 0$ WRITE = all		Type 4 $N_{12} = 0$ WRITE=all	
Index	N_2=5 N_3=3	$N_{4,6,8,10}$=6 $N_{5,7,9,11}$=3	N_2=6 N_3=3	$N_{4,6,8,10}$=7 $N_{5,7,9,11}$=3	N_2=6 N_3=9	$N_{4,6,8,10}$=7 $N_{5,7,9,11}$=9	N_2=7 N_3=9	$N_{4,6,8,10}$=8 $N_{5,7,9,11}$=9
J_1	7	7	7	7	7	7	7	7
J_2	8	8	8	8	8	8	8	8
J_3	9	10,12,10,14	9	10,12,10,14	9	10,12,10,14	9	10,12,10,14
J_4	17	11,13,11,15	16	11,13,11,15	17	11,13,11,15	16	11,13,11,15
J_5	18	17	17	16	18	17	17	16
J6		18	18	17	19	18	18	17
J_7				18		19	19	18
J_8								19
P_1	20	20	20	20	20	20	20	20
P_2	21	21	21	21	21	21	21	21
P_3	22	22	22	22	22	22	22	22
P_4					23	23	23	23
P_5					24	24	24	24
P_6					25	25	25	25
P_7					26	26	26	26
P_8					27	27	27	27
P_9					28	28	28	28

* For a “bnk” event (N_4, N_5), interpret J_1 ... J_4 = 7,8,10,11
For a “sur” event (N_6, N_7), interpret J_1 ... J_4 = 7,8,12,13
For a “col” event (N_8, N_9), interpret J_1 ... J_4 = 7,8,10,11
For a “ter” event (N_{10}, N_{11}), interpret J_1 ... J_4 = 7,8,14,15

Table I.4
Description of Variable IDs

Variable ID	MCNP Name	Description
NPS LINE		
1	NPS	See Appendix E
2	—	Event type of 1st event (see Table I.5)
3	NCL(ICL)	See Appendix E
4	NSF(JSU)	See Appendix E
5	JPTAL(1,ITAL)	See Appendix E
6	TAL(JPTAL(7,ITAL))	See Appendix E
EVENT LINE		
7	—	Event type of next event (see Table I.5)
8	NODE	See Appendix E
9	NSR	See Appendix E
10	NXS(2,IEX)	See Appendix E
11	NTYN	Reaction type (see Table I.7)
12	NSF(JSU)	Reaction type (see Table I.7)
13	—	Angle with surface normal (degrees)
14	NTER	Termination type (see Table I.7)
15	—	Branch number for this history
16	IPT	See Appendix E
17	NCL(ICL)	See Appendix E
18	MAT(ICL)	See Appendix E
19	NCP	See Appendix E
20	XXX	See Appendix E
21	YYY	See Appendix E
22	ZZZ	See Appendix E
23	UUU	See Appendix E
24	VVV	See Appendix E
25	WWW	See Appendix E
26	ERG	See Appendix E
27	WGT	See Appendix E
28	TME	See Appendix E

Table I.5
Event Type Description

Location	Variable ID	Event Type src	bnk**	sur	col	ter	Flag*
J_1		1000	±(2000+l)	3000	4000	5000	9000

*When J_1 = 9000, this event is the last event for this history.

**When J_1 < 0, the next event has been rejected and is included for creation information only. The value L is given in Table I.6.

Table I.6
Bank Event Descriptions

L Value	Description	MCNP Subroutine	NXS and NTYN Provided
1	DXTRAN Track	DXTRAN	Y
2	Energy Split	ERGIMP	N
3	Weight Window Surface Split	WTWNDO	N
4	Weight Window Collision Split	WTWNDO	Y
5	Forced Collision-Uncollided Part	FORCOL	N
6	Importance Split	SURFAC	N
7	Neutron from Neutron (n,xn) (n,f)	COLIDN	Y
8	Photon from Neutron	ACEGAM	Y
9	Photon from Double Fluorescence	COLIDP	Y
10	Photon from Annihilation	COLIDP ELECTR	N
11	Electron from Photoelectric	EMAKER	Y
12	Electron from Compton	EMAKER	Y
13	Electron from Pair Production	EMAKER	Y
14	Auger Electron from Photon/X-ray	EMAKER	Y
15	Positron from Pair Production	EMAKER	N
16	Bremsstrahlung from Electron	TTBR BREMS	N
17	Knock-on Electron	KNOCK	N
18	X-rays from Electron	KXRAY	N
19	Photon from Neutron - Multigroup	MGCOLN	Y
20	Neutron (n,f) - Multigroup	MGCOLN	Y
21	Neutron (n,xn) k- Multigroup	MGCOLN	Y
22	Photon from Photon - Multigroup	MGCOLN	Y
23	Adjoint Weight Split - Multigroup	MGACOL	N
24	Weight window time split	WTWDO	Y
25	Neutron from photonuclear	COLIDN	Y
26	DXTRAN annnihilation photon from pulse height tally variance reduction	DXTRAN	Y

Table I.7
NTER and NTYN Variable Descriptions

NTER	Description	NTYN	Description
1	Escape	NEUTRON	
2	Energy cutoff	1	Inelastic S(α,β)
3	Time cutoff	2	Elastic S(α,β)
4	Weight window	-99	Elastic scatter
5	Cell importance	>5	Inelastic scatter (see UKAEA Nuclear Data File)
6	Weight cutoff		
7	Energy importance		
8	DXTRAN		
9	Forced collision	PHOTON	
10	Exponential transform		
		1	Incoherent scatter
NEUTRON		2	Coherent scatter
		3	Fluorescence
11	Downscattering	4	Double fluorescence
12	Capture	5	Pair production
13	Loss to (n,xs)		
14	Loss to fission		
PHOTON			
11	Compton scatter		
12	Capture		
13	Pair production		
ELECTRON			
11	Scattering		
12	Bremsstrahlung		

APPENDIX J - MESH-BASED WWINP, WWOUT, AND WWONE FILE FORMAT

The mesh-based weight window input file WWINP and the mesh-based weight window output files WWOUT and WWONE are ASCII files with a common format. The files consist of three blocks. Block 1 contains the header information, energy (or time) group numbers, and basic mesh information. Block 2 contains the mesh geometry. Block 3 contains the energy (or time) group boundaries and lower weight window bounds. Table J.1 presents the file format using generic variables. Table J.2 describes the variables and gives the equivalent variables from the WWINP, WWOUT, and WWONE files.

The 3 x 3 array of fine mesh cells is stored by assigning an index number to each cell. The assignment of mesh cells is illustrated in Figure J-1. For each value of z (or θ), all cells are indexed in the x-y plane (or the r-z plane). The cell index number is related to the fine mesh number in each coordinate direction through the following formula:

$$\text{cell index number} = 1 + (i - 1) + nfx\,(j - 1) + nfx \cdot nfy\,(k - 1),$$

where i, j, and k are the fine mesh cell numbers along the $x(r)$, $y(z)$, and $z(\theta)$ directions, respectively, and nfx, nfy, and nfz (by implication) are the total number of fine meshes in the $x(r)$, $y(z)$, and $z(\theta)$ directions, respectively.

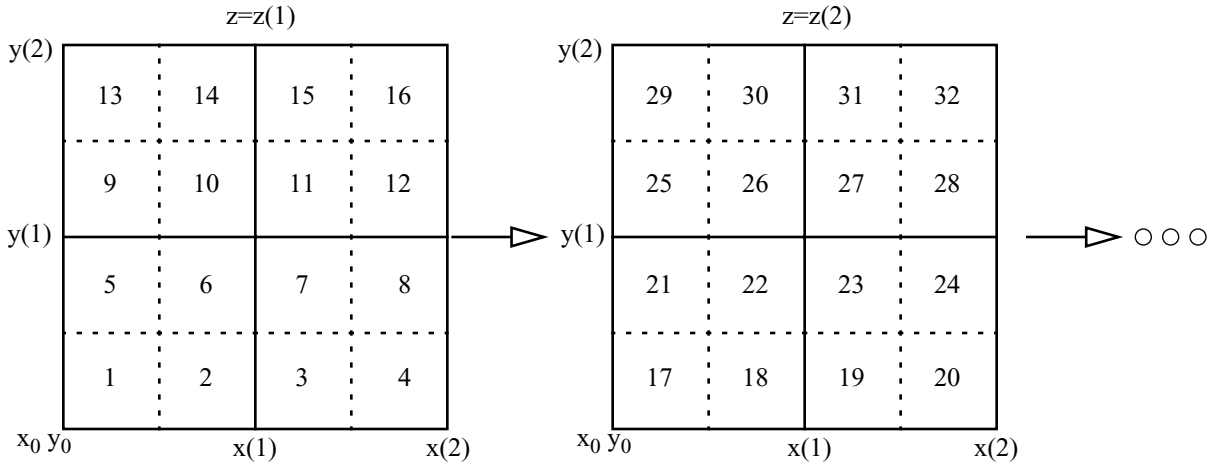

Figure J-1. Superimposed Mesh Cell Indexing

Table J.1
Format of the Mesh-Based WWINP, WWOUT and WWONE File

FORMAT	VARIABLE LIST
	BLOCK 1
4i10	if iv ni nr
7i10	ne(1) … ne(ni)
	nr = 10:
6g13.5	nfx nfy nfz x_0 y_0 z_0
6g13.5	ncx ncy ncz nwg
	nr = 16:
6g13.5	nfx nfy nfz x_0 y_0 z_0
6g13.5	ncx ncy ncz xmax ymax zmax
6g13.5	xr yr zr nwg
	BLOCK 2
	nwg = 1:
6g13.5	x_0 nfmx(1) x(1) rx(1) nfmx(2) x(2)
6g13.5	rx(2) … nfmx(ncx) x(ncx) rx(ncx)
6g13.5	y_0 nfmy(1) y(1) ry(1) nfmy(2) y(2)
6g13.5	ry(2) … nfmy(ncy) y(ncy) ry(ncy)
6g13.5	z_0 nfmz(1) z(1) rz(1) nfmz(2) z(2)
6g13.5	rz(2) … nfmz(ncz) z(ncz) rz(ncz)
	nwg = 2
6g13.5	r_0 nfmr(1) r(1) rr(1) nfmr(2) r(2)
6g13.5	rr(2) … nfmr(ncx) r(ncx) rr(ncx)
6g13.5	z_0 nfmz(1) z(1) rz(1) nfmz(2) z(2)
6g13.5	rz(2) … nfmz(ncy) z(ncy) rz(ncy)
6g13.5	θ_0 nfmθ(1) θ(1) rθ(1) nfmθ(2) θ(2)
6g13.5	rθ(2) … nfmθ(ncz) θ(ncz) rθ(ncz)
	BLOCK 3
	Particle i, i=1,ni
6g13.5	e(i,1) … e(i,ne(i))
	Energy (or time) group j, j=1,ne(i)
6g13.5	w(i,j,1) … w(i,j,nwm)

Table J.2
Explanations of Variables from Table J.1

VARIABLE	WWINP	WWOUT	WWONE
if	File type. Only 1 is supported.		
iv	Unused		
ni	Number of integers on card 2		
nr	Number of parameters from nfx through nwg at the end of Block 1. nr = 10 / 16 for rectangular/ cylindrical mesh		
ne(i)	NWW(i)	NGWW(i)	1 for each i for which NGWW(i) $\neq$ 0
nf[x,y,z]	WWM(1-3)	WWMA(1-3)	
x_0, y_0, z_0	WWM(4-6)	WWMA(4-6)	
nc[x,y,z]	WWM(7-9)	WWMA(7-9)	
[x,y,z]max	WWM(10-12)	WWMA(10-12)	
xr, yr, zr	WWM(13-15)	WWMA(13-15)	
nwg	NWGEOM	NWGEOA	
nfm[x,y,z / r,z,θ](i)	WGM(*)	WGMA(*)	
	Number of fine mesh cells in coarse mesh cell i in x,y,z / r,z,θ directions		
[x,y,z / r,z,θ](i)	WGM(*)	WGMA(*)	
	Upper coordinate of coarse mesh cell i in x,y,z/ r,z,θ directions		
r[x,y,z / r,z,θ](i)	WGM(*)	WGMA(*)	
	Fine mesh ratio in coarse mesh cell i in x,y,z /r,z,θ directions. Currently only 1. is supported.		
r_0, z_0, θ_0	Origin of the radial, axial, and azimuthal directions; must be 0., 0., 0.		
e(i,j)	WWE(*)	EWWG(*)	Default maximum
	j^{th} upper energy (or time) bound for particle type i		
w(i,j,k)	WWF(*)	Weight window generator output	
	Lower weight window bound for particle i, energy (or time) group j, and fine mesh cell k		
nwm	NWWM	NWWMA	

APPENDIX K - XSDIR DATA DIRECTORY FILE

MCNP has two *types* and nine *classes* of data. These data are kept in individual *tables* that are often organized into *libraries*. These tables are located with the XSDIR data directory file. These terms and tables are described in this appendix.

MCNP reads nine *classes* of data from two *types* of data tables. The two types of data tables are:

1. Type 1—standard formatted tables (sequential, 80 characters per record). These portable libraries are used to transmit data from one installation to another. They are bulky and slower to read. Often installations generate Type 2 tables from Type 1 tables using the MAKXSF code (see Appendix C).
2. Type 2—standard unformatted tables (direct-access, binary) locally generated from Type 1 tables. They are not portable except between similar systems such as various UNIX platforms. Type 2 tables are used most because they are more compact and faster to read than Type 1 tables.

Data tables exist for nine *classes* of data: continuous-energy neutron, discrete-reaction neutron, continuous-energy photoatomic interaction, continuous-energy electron interaction, continuous-energy photonuclear interaction, neutron dosimetry, S(α,β) thermal, neutron multigroup, and photoatomic multigroup. A user should think of a data table as an entity that contains evaluation-dependent information about one of the nine *classes* of data for a specific target isotope, isomer, element, or material. For how the data are used in MCNP, a user does not need to know whether a particular table is in Type 1 or Type 2. For a given ZAID, the data contained on Type 1 and Type 2 tables are identical. Problems run with one data type will track problems run with the same data in another format type.

When we refer to data libraries, we are talking about a series of data tables concatenated into one file. All tables on a single library must be of the same *type* but not necessarily of the same *class*. There is no reason, other than convenience, for having data libraries; MCNP could read exclusively from individual data tables not in libraries.

MCNP determines where to find data tables for each ZAID in a problem based on information contained in a system-dependent directory file XSDIR. The directory file is a sequentially formatted ASCII file with 80-character records (lines) containing free-field entries delimited by blanks.

The XSDIR file has three sections. In the first section, the first line is an optional entry of the form:

DATAPATH = *datapath*

where the word DATAPATH (case insensitive) must start in columns 1–5. The = sign is optional. The directory where the data libraries are stored is *datapath*. The XSDIR directory file can be renamed by item 1. The search hierarchy to find XSDIR and/or the data libraries is:

1. XSDIR = cross-section directory file name on the MCNP execution line,
2. DATAPATH = *datapath* in the INP file message block,
3. the current directory,
4. the DATAPATH entry on the first line of the XSDIR file,
5. the UNIX environmental variable setenv DATAPATH *datapath*,
6. the individual data table line in the XSDIR file (see below under Access Route), or
7. the directory specified at MCNP compile time in the BLOCK DATA subroutine.

The second section of the XSDIR file is the atomic weight ratios. This section starts with the words "ATOMIC WEIGHT RATIOS" (case insensitive) beginning in columns 1–5. The following lines are free-format pairs of ZAID AWR, where ZAID is an integer of the form ZZAAA and AWR is the atomic weight ratio. These atomic weight ratios are used for converting from weight fractions to atom fractions and for getting the average Z in computing electron stopping powers. If the atomic weight ratio is missing for any nuclide requested on an Mn card, it must be provided on the AWTAB card.

The third section of the XSDIR file is the listing of available data tables. This section starts with the word "DIRECTORY" (case insensitive) beginning in columns 1–5. The lines following consist of the seven– to ten–entry description of each table. The ZAID of each table must be the first entry. If a table requires more than one line, the continuation is indicated by a + at the end of the line. A zero indicates the entry is inapplicable. Unneeded entries at the end of the line can be omitted.

The directory file has seven to eleven entries for each table. They are:

1.	Name of the Table	character * 10
2.	Atomic Weight Ratio	real
3.	File Name	character * 8
4.	Access Route	character * 70
5.	File Type	integer
6.	Address	integer
7.	Table Length	integer
8.	Record Length	integer
9.	Number of Entries per Record	integer
10.	Temperature	real
11.	Probability Table Flag	character * 6

1. Name of the Table. This is usually the ZAID: 3 characters for Z, 3 characters for A, a decimal point, 2 characters for evaluation identification, and a tenth character used to identify continuous-energy neutron tables by the letter C, discrete-reaction neutron tables by D, dosimetry tables by Y, S(α,β) thermal tables by T, continuous-energy photoatomic tables by P, continuous-energy photonuclear tables by U, continuous-energy electron tables by E, multigroup neutron tables by M, and multigroup photon tables by G. For the S(α,β) tables, the first 6 characters contain a mnemonic character string, such as LWTR.01T.
2. Atomic Weight Ratio. This is the atomic mass divided by the mass of a neutron. The atomic weight ratio here is used only for neutron kinematics and should be the same as it appears in the cross-section table so that threshold reactions are correct. It is the quantity *A* used in all the neutron interaction equations of Chapter 2. This entry is used only for neutron tables.

3. File Name. The file name is the name of the library that contains the table and is a string of eight characters in a form allowed by the local installation.
4. Access Route. The access route is a string of up to 70 characters that tells how to access the file if it is not already accessible, such as a UNIX directory path. If there is no access route, this entry is zero.
5. File Type. 1 or 2.
6. Address. For Type 1 files the address is the line number in the file where the table starts. For Type 2 files, it is the record number of the first record of the table.
7. Table Length. A data table consists of two blocks of information. The first block is a collection of pointers, counters, and character information. The second block is a solid sequence of numbers. For Type 1 and Type 2 tables, the table length is the length (total number of words) of the second block.
8. Record Length. This entry is unused for Type 1 files and therefore is zero. For Type 2 direct access files it is a processor-dependent attribute. The record length is a multiple of the number of entries per record, the number of 8-bit bytes in the record for most systems. Thus for 512 entries per record, the record length is 4096 for double-precision data on most UNIX workstations, 2048 for single-precision data on most UNIX workstations, etc.
9. Number of Entries per Record. This is unused for Type 1 files and therefore is zero. For Type 2 files it is the number of entries per record. Usually this entry is set to 512.
10. Temperature. This is the temperature in MeV at which a neutron table is processed. This entry is used only for neutron data.
11. Probability Table Flag. The character word “ptable” indicates a continuous-energy neutron nuclide has unresolved resonance range probability tables.

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