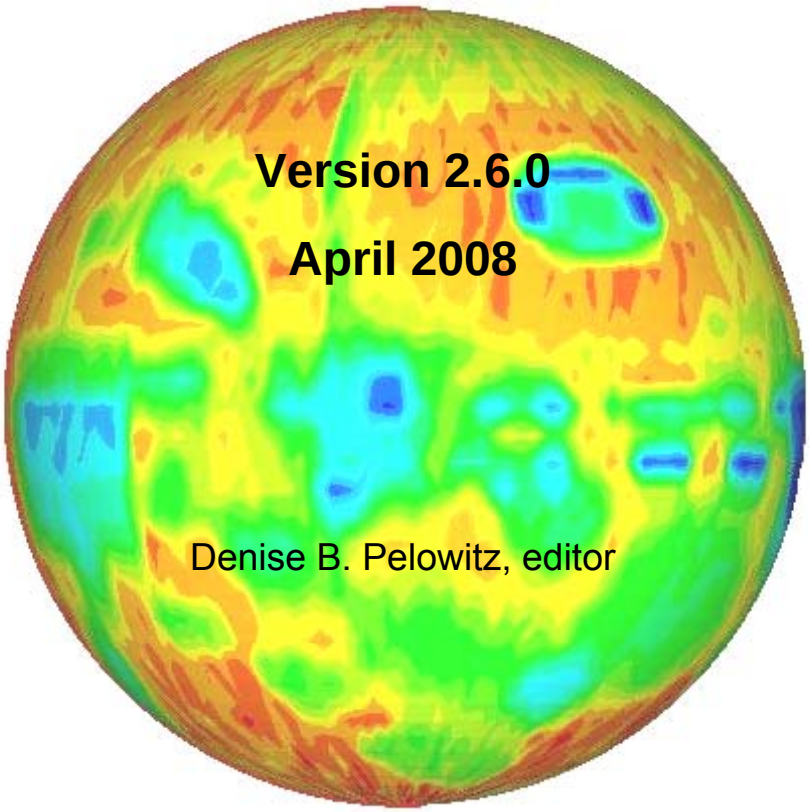
LA-CP-07-1473

MCNPX™ USER'S MANUAL



Version 2.6.0

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Copyright Notice for MCNPX

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1 INTRODUCTION

MCNPX™ is a general purpose Monte Carlo radiation transport code designed to track many particle types over broad ranges of energies. It is the next generation in the series of Monte Carlo transport codes that began at Los Alamos National Laboratory nearly sixty years ago. MCNPX 2.6.0 is the latest Radiation Safety Information Computational Center (RSICC) release of the code, following the 2005 release of MCNPX 2.5.0 [PEL05]. MCNPX 2.5.0 was a superset of MCNP4C [BRI00] and MCNPX 2.4.0 [WAT02b]. MCNPX 2.6.0 includes many new capabilities, particularly in the areas of transmutation, burnup [FEN06a, FEN06b, FEN08], and delayed particle production. Many new tally source and variance-reduction options have been developed. Physics improvements include a new version of the Cascade-Exciton Model (CEM), the addition of the Los Alamos Quark-Gluon String Model (LAQGSM) option, and a substantial upgrade to muon physics. The code is compatible with MCNP5, and references to MCNP™ in this manual refer to the MCNP5 version.

The MCNPX program began in 1994 as an extension of MCNP4B and LAHET 2.8 in support of the Accelerator Production of Tritium Project (APT). The work envisioned a formal extension of MCNP to all particles and all energies; improvement of physics simulation models; extension of neutron, proton, and photonuclear libraries to 150 MeV; and the formulation of new variance-reduction and data-analysis techniques. The program also included cross-section measurements, benchmark experiments, deterministic code development, and improvements in transmutation code and library tools through the CINDER90 project.

Since the initial release of MCNPX, version 2.1, on October 23, 1997, an extensive beta-test team has been formed to test the code versions prior to official release. Approximately 1750 users in approximately 400 institutions worldwide have had an opportunity to try the improvements leading to version 2.6.0 and to provide feedback to the developers. This process is invaluable, and we express our deepest appreciation to the participants in the beta-test program.

Applications for the code among the beta-test team are quite broad and constantly developing. Examples include the following:

- Design of accelerator spallation targets, particularly for neutron scattering facilities
- Investigations for accelerator isotope production and destruction programs, including the transmutation of nuclear waste
- Research into accelerator-driven energy sources

- Accelerator based imaging technology such as neutron and proton radiography
- Detection technology using charged particles via active interrogation
- Design of shielding in accelerator facilities
- Activation of accelerator components and surrounding groundwater and air
- High-energy dosimetry and neutron detection
- Medical physics, especially proton and neutron therapy
- Investigations of cosmic-ray radiation backgrounds and shielding for high altitude aircraft and spacecraft
- Single-event upset in semiconductors from cosmic rays in spacecraft or from the neutron component on the earth's surface
- Analysis of cosmo-chemistry experiments, such as Mars Odyssey
- Charged-particle propulsion concepts for spaceflight
- Investigation of fully coupled neutron and charged-particle transport for lower-energy applications
- Transmutation, activation, and burnup in reactor and other systems
- Nuclear safeguards
- Nuclear criticality safety
- Nuclear material detection
- Design of neutrino experiments

In addition to the activities of the beta-test team, the development of MCNPX is governed by the following documents:

- MCNPX Software Management Plan
- MCNPX Requirements
- MCNPX Design
- MCNPX Functional Specifications

Configuration management of the code is done through the Concurrent Versions System CVS [CED05], which allows us to conveniently track issues and changes. A computer test farm of 20 different software/hardware configurations is maintained to ensure that code development does not adversely affect any previously tested system.

MCNPX documentation is divided into three volumes. Volume 1 (yet to be released) contains details on the interaction physics contained within MCNPX. The document you are reading is Volume 2, the comprehensive MCNPX User's Manual for MCNPX and includes installation instructions, input card descriptions, geometry specifications, and tally plotting details. Volume 3 (yet to be released) is the developer's guide, which provides information of interest to those who wish to modify or enhance capabilities within MCNPX.

The reader must be aware of certain limitations in code usage. These items are listed in Section 2. Section 3 discusses code installation and includes general notes on software management. Sections 4 and 5 provide the input file overview and detailed input card descriptions. Section 6 contains basic geometry, cross-section, and tally plotting instructions. Several appendices provide greater detail regarding various code aspects. For example, Appendix B contains detailed plotting information, Appendix E contains several practical application examples, and Appendix G contains information about available nuclear data libraries.

Workshops in MCNPX are also held on a regular basis (`http://mcnpx.lanl.gov`).

2 WARNINGS AND LIMITATIONS

All computer simulation codes must be validated for specific uses, and the needs of one project may not overlap completely with the needs of other projects. It is the responsibility of the user to ensure that his or her needs are adequately identified, and that benchmarking activities are performed to ascertain how accurately the code will perform. The benchmarking done for code developments for the MCNPX sponsors may or may not be adequate for the needs of the user's particular program. We make our benchmarking efforts public as they are completed, but the user must also develop a rigorous benchmarking program for his/her own application.

The following warnings and known bugs apply to the energies and particles beyond MCNP:

1. Perturbation methods used in MCNP have not been extended yet to the non-tabular models present in MCNPX. MCNPX gives a fatal error if it is run for problems that invoke the perturbation capabilities above the MCNP energy range or beyond the MCNP particle set.
2. KCODE criticality calculations work only with available actinide nuclear data libraries and have not been extended to the model energy regions of the code.
3. Charged-particle reaction products are not generated for some neutron reactions below 20 MeV in the LA150N library. In calculating total particle-production cross sections, the library processing routines include only those reactions for which complete angular and energy information is given for secondary products. Most 150-MeV evaluations are built "on top" of existing ENDF and JENDL evaluations which typically go to 20 MeV. Although the 150-MeV evaluations do include the detailed secondary information in the 20–150-MeV range, the <20-MeV data typically do not. Therefore secondary production is generally ignored when processing interactions in that energy range. Table 4-1 lists the actual secondary particle-production thresholds in LA150N. Fixing this situation is nontrivial, and involves a re-evaluation of the low-energy data. Improved libraries will be issued, but on an isotope-by-isotope basis.
4. No explicit generation of "delta-ray" knock-on electrons as trackable particles is done for heavy charged particles. Delta rays are produced for electrons.
5. Beware of the results of an `F6:P` tally in small cells when running a photon or photon/electron problem. Photon heating numbers include the energy deposited by electrons generated during photon collisions, but assume that the electron energy is deposited locally. In a cell where the majority of the electrons lose all of their energy before exiting that cell, this is a good approximation. However, if the

cell is thin and/or a large number of electrons are created near the cell boundary, these electrons could carry significant energy into the neighboring cell. For this situation, the `F6:P` tally for the cell in which the electrons were created would be too large. The user is encouraged to consider use of the `F6:E` tally instead, which provides an accurate tally of electron energy deposition within a cell.

6. The version of FLUKA contained in the code is kept for legacy purposes. We recommend using the LAQGSM v. 3.01 [MAS06a, MAS06b] model for very high energy calculations.
7. Specifying different densities for the same material produces a warning. MCNPX performs a material density correction for charged-particle energy deposition that is not a strict linear function. MCNPX searches through all cells, finds the first one with the material of interest, and uses the associated material density to determine the correction factor for all cells using that material. For MCNP applications the effect is typically small; therefore this is an adequate procedure. For MCNPX applications that utilize more charged particles and a greatly expanded energy range, this formerly "small" correction becomes increasingly important, and the usual way of handling it is not sufficient. A suggested practice in such instances is to specify a unique material identifier for each density.
8. "Next-event estimators," i.e., point and ring detectors, DXTRAN, and radiography tallies, use an assumption of isotropic scatter for contributions from collisions within the model regime. These estimators require the angular distribution data for particles produced in an interaction to predict the "next event." Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region.
9. A numerical problem occurs in the straggling routines with densities less than about 1e-9 g/cm^3 for heavier charged particles and with densities less than about 1e-15 g/cm^3 for electrons. Users should avoid such low densities.

3 INSTALLATION AND EXECUTION

This section describes how to build MCNPX on a computer system. The system will need a FORTRAN-90 (F90) compiler, a C compiler, and GNU MAKE 3.79 or higher (`http://www.gnu.org`).

The code distribution, available from the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory (`http://rsicc.ornl.gov`) and OECD/NEA (`http://www.nea.fr/html/databank/welcome.html`), contains full source code for the MCNPX 2.6.0 system and test templates for each of the supported architectures.

3.1 F90 AUTOCONFIGURATION

MCNPX has a unique autoconfiguration build system that allows a variety of compilation options to be executed easily on a large number of platforms. MCNPX supports Linux (PGF or Intel compiler), Windows [Compaq Visual FORTRAN (CVF) or Intel compiler], Mac OS X (IBM or Intel compiler), and a variety of UNIX platforms (e.g., Sun Solaris, HP HPUX, IBM AIX, and SGI IRIX).

Test problems and their solution templates are available for all supported systems. The 76 test problems comprise an early version of the MCNP5 42-problem test set supplemented by 34 problems that test specific MCNPX features. The test problems on all systems can be run and compared against the solution templates with a single, simple autoconfiguration command.

3.2 64-BIT-INTEGER SUPPORT

MCNPX has been restructured to enable 64-bit integers. MCNP and MCNPX always have provided 64-bit floating-point real numbers, either by use of compiler directives on supercomputers or by double precision on "cheap" computers (most systems). However, the integers have been 4 byte (32 bit) on all but a few supercomputers; 4-byte integers limit the number of particle histories that can be run in an MCNPX job to about 2 billion. They also limit the number of cross sections and tallies in a problem because these use integer pointers.

With the 64-bit-integer capability, up to 10^{18} histories can be run, memory access problems can be avoided, and the quantity of cross sections and tallies that can be specified is essentially limitless.

The default configuration for MCNPX is still 4-byte integers. The executable versions provided on the MCNPX Beta Test page (`http://mcnpx.lanl.gov`) are all 4-byte-integer versions. Use the following CONFIGURE options to build the 64-bit-integer version:

```
--with-FFLAGS=-i8 --with-NOCHEAP
```

The `--with-NOCHEAP` directive is not available on all systems. If it is not recognized, then add the compile directive `--with-FFLAGS=-i8` and remove `-DCHEAP=1` from `src/mcnpx/Makefile.h`.

Some compilers (e.g., CVF F90) do not recognize the "`-i8`" flag and, in such cases, its equivalent should be substituted for the `FFLAGS` CONFIGURE option. Use of 64-bit integers requires either (a) the use of Type-1 (ASCII) data files, or (b) the re-creation of Type-2 (binary) data files using the 64-bit-integer version of MAKXS. Data-table formats are discussed in Appendix F.

3.3 UNIX BUILD SYSTEM

3.3.1 In the Beginning

Remember that your `PATH` environment variable governs the search order for finding utilities. If necessary, you can type the following command to determine the value of your `PATH` environment variable:

```
ECHO $PATH
```

Consider setting your `PATH` environment variable to a strategic search order so that the utilities that are found first are the ones you intend to use. Setting of environment variables is done differently depending upon what UNIX shell you use. Please consult the appropriate manuals for your shell. Most systems have more than one shell available. Any system can have more than one version of any utility. You must know your utilities.

If you work on a UNIX or Linux operating system you can use the following inquiry commands to learn if you have more than one MAKE utility installed:

```
which make
which gmake
```

Many systems come with a MAKE utility that is provided by the vendor. On UNIX and Linux, you must use the GNU MAKE utility and it must be version 3.79 or later. Sometimes the GNU MAKE utility is installed in an executable file called GMAKE. Sometimes system administrators create symbolic links called *make* that, when resolved, invoke the GMAKE utility. You can create your own symbolic links in directories that you own and control so that when you execute the *make* command you will be executing the MAKE utility you intend to use. You can also establish an alias in the shell runtime control file whereby any *make* command you issue actually executes GMAKE. In the examples that follow, you can substitute the *gmake* command everywhere you see the *make* command.

The important point of this discussion is to know your MAKE and use the right one; otherwise, this automated build system can fail.

If no MAKE or GMAKE is found, you either have a `PATH` value problem, or you need some help from your system administrator to install GNU MAKE.

If both MAKE and GMAKE exist, query each of them to see what version you have. This query is accomplished by using the following commands:

```
make -v
gmake -v
```

Some vendor supplied MAKE utilities do not understand the "`-v`" option that requests that the version number be printed. If you see an error or usage message, then your MAKE is one of the vendor-supplied variety. Ensure you have GNU MAKE version 3.79 or later installed and that it is found in your search path first.

3.3.2 Automated Building

The process used when building MCNPX varies greatly depending upon the following factors:

- hardware platform, e.g., SPARC, ALPHA, I386;
- operating system, e.g., Solaris, Linux, HPUX;
- available compilers, e.g., f90/cc, g90/gcc, pgf90/gcc; and
- MCNPX program options, e.g., the default path of cross sections and other data files.

A special AUTOCONF-generated CONFIGURE script distributed with MCNPX will examine your computing environment, adjust the necessary parameters, and then generate all *makefiles* in your chosen build directory so that they match your particular computing environment.

The full structure is now in place to allow a graceful migration to individual feature tests during the autoconfiguration process in the future.

The AUTOCONF-generated CONFIGURE script will search for GNU compilers first before attempting to locate any other compiler present on your computing environment. Please be aware of exactly how many FORTRAN and C compilers exist in your computing environment. It may be necessary to specify which FORTRAN and C compiler should be used. You have that power via options given to the CONFIGURE script. See the `--with-FC` and `--with-CC` options that are described in Table 3-1 in Section 3.3.4.

You may create as many build directories as desired, anywhere you want, named anything you want. Through the use of options supplied to the CONFIGURE script, you can vary the resulting generated *makefiles* to match a desired configuration.

Most software packages that use AUTOCONF have a basic build procedure that looks like the following:

```
gzip -dc PACKAGE.tar.gz | tar xf -
cd PACKAGE
./configure
make install
```

This method of installation works with MCNPX. However, the development team recommends a slightly different method so the original source tree is not cluttered with all the products of compiling and building.

More complex packages (e.g., the GNU C compiler suite, *gcc*) warn that the simple build procedure given above is a dangerous practice, as it clutters the original source tree with generated *makefiles* and compiled objects and makes it difficult to support multiple builds with different options. It is suggested that a different, initially empty directory be the target of the CONFIGURE process. This preferred build procedure looks like the following:

```
gzip -dc PACKAGE.tar.gz | tar xf -
mkdir Build
cd Build
PATH_OF_PACKAGE-SOURCE/configure
make install
```

Please use an empty directory somewhere other than the source distribution's location as the target of the build. It keeps the source tree clean and allows multiple builds with different options. Even if you think that you will never need additional builds, it costs nothing to retain the flexibility for the future.

3.3.3 Build Examples

The following example in Section 3.3.3.1 illustrates the new CONFIGURE and MAKE procedure as it would be implemented by a system manager installing the MCNPX release on a system with several users. Additional installation examples can be found in the `Docs/install.html` file of the source distribution. A complete list of CONFIGURE options can be found in Table 3-1.

3.3.3.1 SYSTEM-WIDE INSTALLATION

For purposes of this first illustration, we will assume that the MCNPX distribution has been unloaded from CD-ROM or fetched from the net and is in the file `/usr/local/src/mcnpx_2.6.0.tar.gz`. The system manager, logged is as root, will unload the distribution into `/usr/local/src/mcnpx_2.6.0`, build the system in `/tmp/mcnpx`, install the MCNPX executable in `/usr/local/bin`, and install the libraries (and eventually the MCNPX cross sections) in `/usr/local/lib`. Naturally, the specific name of the MCNPX distribution archive will vary depending on the version you have acquired.

The following example uses Bourne shell commands to accomplish this task. If you are more familiar with csh shell, you will need to adjust things appropriately. Note that comments about the shell commands start with the '#' character. Also, don't be alarmed by the generous amount of output from the CONFIGURE and MAKE scripts. They work hard so you do not have to. The following command sequence completes the installation process:

```
# go to the installation directory
cd /usr/local/src
# Unpack the distribution. This creates the directory mcnpx_2.6.0
gzip -dc mcnpx_2.6.0.tar.gz | tar xf -
# go to /tmp and make the build directory
cd /tmp
mkdir mcnpx
# go into that working space
cd mcnpx
# execute the configure script - no special option requests for the
# Makefiles
# the default directory prefix is /usr/local
/usr/local/src/mcnpx_2.6.0/configure
# now make the executable mcnpx program and supporting LCS libraries
make all
# run the regression tests for your architecture
make tests
# install the executables and libraries in /usr/local
make install
```

```
# clean up. The build products are no longer needed.
cd /tmp
rm -rf mcnpx
```

3.3.3.2 SYSTEM-WIDE INSTALLATION WITH EXISTING DIRECTORIES

The previous example typically might be used when a new installation of MCNPX is performed on a system that has no pre-existing MCNPX with which to be compatible. If a user already has MCNPX, then it may be desired to use the existing locations for the data files and cross sections. Either of two CONFIGURE options can be used to customize the locations where MCNPX and its data will be installed and where MCNPX will find those files.

When the user wants to use the normal MCNPX directory layout of

```
.../bin
```

for executables and

```
.../lib
```

for data files, but he does not wish to use the default directory `/usr/local`, then the previous example can be adjusted with additional options. In the previous example, the CONFIGURE script could be given the option

```
/usr/local/src/mcnpx_2.6.0/configure --prefix=/usr/mcnpx
```

Then the MAKE install process would install the MCNPX binary in `/usr/mcnpx/bin` and the data files in `/usr/mcnpx/lib`. The code will use `/usr/mcnpx/lib` as its default location for finding the data files.

When the user has an existing directory layout that does not follow the MCNPX default, then the datapath itself can be customized as follows:

```
/usr/local/src/mcnpx_2.6.0/configure --libdir=/usr/mcnpx
```

This will leave the default executable location as `/usr/local/bin` and set the location for the data files to `/usr/mcnpx`.

Finally, both the `--PREFIX` and the `--LIBDIR` options can be used together with the `--LIBDIR` options taking precedence over the library directory implied by the `--PREFIX`.

These options should remove the need to edit paths in the source code. In fact, with support for these options, there are no longer any paths in the code to edit.

3.3.4 Directory Structure

In order to accommodate the use of the AUTOCONF utility to generate the *makefiles*, it became necessary to rearrange the source code and regression test directories a bit. We also added a *config* directory to hold AUTOCONF-related code. This directory structure is depicted in Figure 3-1.

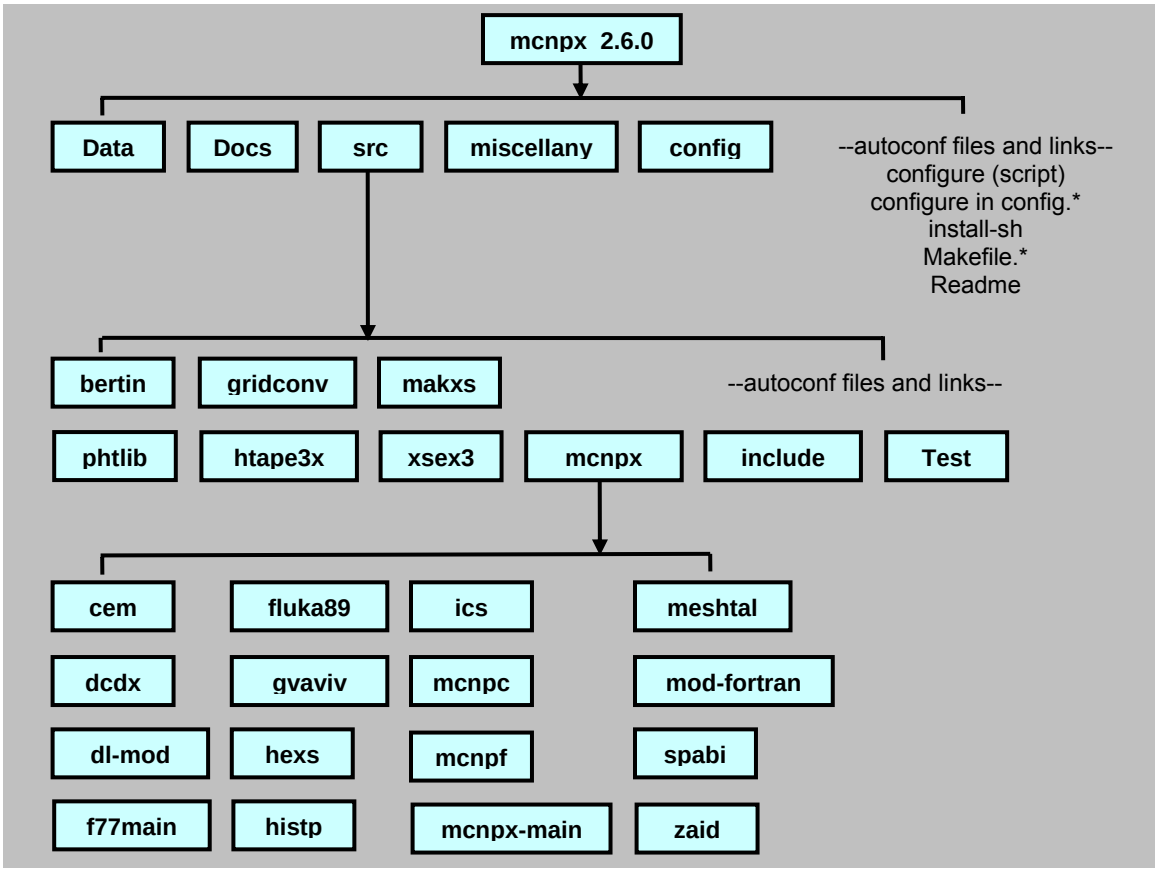


Figure 3-1. Organization Structure

Each of the top two levels contains a collection of AUTOCONF files and links. Removal of any of these files will break the automated CONFIGURE and MAKE capabilities.

First Level:

Data	contains data used with the BERTIN, PHTLIB, and MAKXS targets
Docs	contains files describing this MCNPX distribution
Test	contains the regression test files for the various known platforms in use

src	contains the source code files for MCNPX and several related utilities
miscellany	contains things of interest to developers that don't fit into any other category
config	contains AUTOCONF-related macros, scripts, and initialization files

Second Level:

bertin	builds and executes a program (HCNV) to translate LAHET text input to binary input
phtlib	builds and executes a program (TRX) to translate LAHET text input to binary input
gridconv	converts output files generated by mesh tally and MCTAL files into a variety of different graphics formats
htape3x	reads the history tapes (optionally generated by MCNPX) and performs post-processing on them (See Appendix C.)
makxs	a cross-section-library management tool that converts Type–1 cross sections to Type–2 cross sections and vice versa
xsex3	a utility associated with the new cross-section generation mode for MCNPX that allows tabulation of cross-section sets based on physics models (See Appendix D.)
include	contains include files shared across directories and include files localized in subdirectories
mcnpx	the organizing root directory for the MCNPX program

Third Level:

cem, dcdx, etc.	directories that organize the F90 and C source code files that are related to different aspects of the MCNPX program

Fourth Level: individual F90 and C source code files for a particular aspect of MCNPX

Table 3-1 contains options that are available for use as parameters to the CONFIGURE script for MCNPX 2.6.0.

Table 3-1. CONFIGURE Script Parameters

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with-STATIC`	Linking of the compiled files results in a static archive (`mcnpx.a`).	`STATIC` is the default option; it cannot be used at the same time as `SHARED`.

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with-SHARED`	Linking of the compiled files results in a dynamically linked executable (`mcnpx.so`).	`STATIC` is used. This option is exploratory for future releases of MCNPX.
`--with-DEBUG`	A debug switch appears in the compile step for the generated *makefiles*.	No debug switch appears in the compile step for the generated *makefiles*. This option can be used in combination with other options such as `--with-FC` and `--with-CC`.
`--with-FC=`*value* (Substitute the desired F90 compiler name for the *value* placeholder, e.g., `--with-FC=fort` to use the fort compiler.)	The FORTRAN compiler name *value* will be used to compile the FORTRAN source code. The location of binary directory containing *value* must be in your `$PATH` environment variable.	CONFIGURE will search for a F90 compiler and use the first one it finds. This option can be used in combination with other options such as `--with-DEBUG` and `--with-CC`.
`--with-CC=`*value* (Substitute the desired C compiler name for the *value* placeholder, e.g., `--with-CC=gcc` to use the GNU C compiler.)	The C compiler name *value* will be used to compile C source code. The location of binary directory containing *value* must be in your `$PATH` environment variable.	CONFIGURE will search for a C compiler and use the first one it finds. This option can be used in combination with other options such as `--with-DEBUG` and `--with-FC`.
`--with-LD=`*value* (Substitute the desired link editor name for the *value* placeholder, e.g., `--with-LD=/usr/ccs/bin/ld` to use the Standard Sun linker.)	The link editor *value* will be used to link object code. Unlike the `--with-FC` and `--with-CC` options, whose names are used for more than just finding the executable, *value* can be a full pathname to the location of the desired link-editor program as well as being a single name like "*ld*."	CONFIGURE will search for the linker and use the first one it finds. This is typically needed on systems with both a vendor-supplied compiler set and the GNU tool set. In such cases there may be two versions of `LD` that must be differentiated. This option can be used in combination with other options such as `--with-DEBUG` and `--with-FC`..
`--with-LDFLAGS=`*value* (Append the given library request to the existing `LDFLAGS`. E.g., `--with-LDFLAGS=' -L/usr/local/lib/sparc-sun-solaris2.8/3.2.1 -lgcc'` to link `libgcc.a` into the final executable.)	The parameter *value* is a string that gives the library path after `-L` and library member name after `-l` (omit the characters "`lib`" and the "`.a`"—they are implicit).	CONFIGURE will append the given value to the existing default `LDFLAGS`.

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--PREFIX=`*value* (Substitute a full pathname for the *value* placeholder, e.g., `/home/team/mcnpx`.) (This path should be different from the working directory where the build is taking place.)	The pathname *value* will be used during installation to create `bin` and `lib` data directories for MCNPX's use.	A default value of `/usr/local` is used as the full pathname for the install step. Executables then go to the directory `/usr/local/bin` and data files go to `/usr/local/lib`. (Permissions of the destination may prohibit success of installation.)
`--LIBDIR=`*value* (Substitute a full pathname for the *value* placeholder, e.g., `/home/team/mcnpx`.) (This path should be different from the working directory where the build is taking place.)	The pathname *value* will be used during installation to create a library data directory for MCNPX's use.	A default value of `/usr/local/lib` is used as the full pathname for the install step. (Permissions on the destinations may prohibit success of installation.) This value overrides the library portion of the `--PREFIX` if both are given.

`--with-NO_PAW`
or
`--with-NO_PAW=YES`
	The symbol `NO_PAW` will be defined for compilation and actions are taken in the source to omit `PAW` capabilities when compiling.	If omitted, the default behavior is system dependent. I.e., if the detected hardware/software platform can handle `PAW` it is included.

`--with-NO_PAW=NO`	The symbol `NO_PAW` will not be defined and actions are taken in the source to include `PAW` capabilities with compiling.	If omitted, the default behavior is system dependent. I.e., if the detected hardware/software platform can handle `PAW` it is included.

`--with-PAW`
or
`--with-PAW=YES`
	The symbol `NO_PAW` will not be defined and actions are taken in the source to include `PAW` capabilities with compiling.	If omitted, the default behavior is system dependent. I.e., if the detected hardware/software platform can handle `PAW` it is included.

`--with-PAW=NO`	The symbol `NO_PAW` will be defined for compilation and actions are taken in the source to omit `PAW` capabilities when compiling.	If omitted, the default behavior is system dependent. I.e., if the detected hardware/software platform can handle `PAW` it is included.
`--with-NOCHEAP` If the symbol `CHEAP` is defined it means use `INTEGER4` variables. If the symbol `CHEAP` is not defined it means use `INTEGER8` variables.	If `--with-NOCHEAP` is specified during the CONFIGURE step, the symbol `CHEAP` will *not* be defined for compilation. (This results in `INTEGER8` variables.)	If `--with-NOCHEAP` is omitted during the CONFIGURE step, the symbol `CHEAP` will be defined. The default behavior is to define the symbol `CHEAP` for compilation. (This results in `INTEGER4` variables.)

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with-INTEGER8` Use `INTEGER8` variables and do not define the symbol `CHEAP`. This is equivalent to specifying `--with-NOCHEAP` for the CONFIGURE step.	The symbol `CHEAP` will *not* be defined for compilation. (This results in `INTEGER8` variables.)	If omitted, the default behavior is to define the symbol `CHEAP` for compilation. (This results in `INTEGER4` variables.)
`--with-INTEGER4` Use `INTEGER4` variables and do not define the symbol `CHEAP`. This is the *opposite* of specifying `--with-NOCHEAP` for the CONFIGURE step.	The symbol `CHEAP` will be defined for compilation. (This results in `INTEGER4` variables.)	If omitted, the default behavior is to define the symbol `CHEAP` for compilation. (This results in `INTEGER4` variables.)
`--with_FFLAGS=`*value* There is a separate variable that is used for optimization switches. See `--with-FOPT` in this table. If in doubt, run the CONFIGURE script and examine the system default or system-computed values that appear in the generated `Makefile.h`. You may want to include the defaults in the string you specify for `FFLAGS` with this mechanism when CONFIGURE is run again.	Substitute a quoted or double quoted string for *value* that represents allowable compiler switch settings. These settings will override the system default or system-computed values.	If omitted, the default behavior is system dependent. I.e., the detected hardware/software platform and compilers determine what the default `FFLAGS` should be.
`--with-CFLAGS=`*value* There is a separate variable that is used for optimization switches. See `--with-COPT` in this table. If in doubt, run the CONFIGURE script and examine the system default or system-computed values that appear in the generated `Makefile.h`. You may want to include the defaults in the string you specify for `CFLAGS` with this mechanism when CONFIGURE is run again.	Substitute a quoted or double quoted string for *value* that represents allowable compiler switch settings. These settings will override the system default or system-computed values.	If omitted, the default behavior is system dependent. I.e., the detected hardware/software platform and compilers determine what the default `CFLAGS` should be.

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with_FOPT=`*value* There is a separate variable that is used for non-optimization switches. See `--with-FFLAGS` in this table. If in doubt, run the CONFIGURE script and examine the system default or system-computed values that appear in the generated `Makefile.h`. You may want to include the defaults in the string you specify for `FOPT` with this mechanism. `FOPT` settings are always appended to `FFLAGS` settings when CONFIGURE is run again.	Substitute a quoted or double quoted string for *value* that represents allowable compiler switch settings. These settings will override the system default or system-computed values.	If omitted, the default behavior is system dependent. I.e., the detected hardware/software platform and compilers determine what the default `FOPT` should be.
`--with-COPT=`*value* There is a separate variable that is used for non-optimization switches. See `--with-CFLAGS` in this table. If in doubt, run the CONFIGURE script and examine the system default or system-computed values that appear in the generated `Makefile.h`. You may want to include the defaults in the string you specify for `COPT` with this mechanism. `COPT` settings are always appended to `CFLAGS` settings when CONFIGURE is run again.	Substitute a quoted or double quoted string for *value* that represents allowable compiler switch settings. These settings will override the system default or system-computed values.	If omitted, the default behavior is system dependent. I.e., the detected hardware/software platform and compilers determine what the default `COPT` should be.

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with-PVMLIB`	Defines two symbols (MULTP and PVM) that trigger conditional compilation of parallel code. Use of this option with no given *value* requires the environment variables `PVM_ROOT` and `PVM_ARCH` be set prior to running the CONFIGURE script. `PVM_ROOT` and `PVM_ARCH` are used to generate an include path and a library path. The generated include path is used with `-I` in the compilation step of the build. The generated library path is used with the `-L` and `-l` options in the link step of the build (via the MAKE variable `PARALIB`). Use of a general `PARALIB` MAKE variable allows other parallel options besides PVM to be used in future releases.	If omitted, the default is to omit parallel building.
`--with-PVMLIB=`*value*	Defines two symbols (MULTP and PVM) that trigger conditional compilation of parallel code. This option should be used if you do not want to set the two environment variables `PVM_ROOT` and `PVM_ARCH`. (If you use this option, you *must* also use the `--with-PVMINC=`*value* option.) The *value* given after the `=` *must* be a valid string for the link step of the build. A valid string for the link step takes the form '`-L/some /path/to/pvm/directory -lpvm`' and the string *must* be enclosed within single or double quotation marks. This `value` is assigned to the MAKE variable `PARALIB` for the link step of the build. Use of a general `PARALIB` MAKE variable allows other parallel options besides PVM to be used in future releases.	If omitted, the default is to omit parallel building.

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with-PVMINC=`*value*	Use if you do not want to set the two environment variables `PVM_ROOT` and `PVM_ARCH`. If you use this option, you must also use the `--with-PVMLIB=`*value* option. The `value` given after the equals sign must be a valid path to the PVM include directory. The include path is used with `-I` in the compilation step of the build.	If omitted, the default is to omit parallel building.
`--with-TASKS=`*value* Used only when using the `--with-PVMLIB` option.	Defines a MAKE variable called `TASKS` with the given *value* that is used when running tests.	If omitted, the default behavior is to ignore the MAKE variable `TASKS`.
`--with-MPILIB`	Defines two symbols (MULTP and MPI) that trigger conditional compilation of parallel code. Use of this option with no given *value* requires the environment variables `MPI_ROOT` and `MPI_NAME` be set prior to running the CONFIGURE script. `MPI_ROOT` and `MPI_NAME` are used to generate an include path and a library path. The generated include path is used with `-I` in the compilation step of the build. The generated library path is used with the `-L` and `-l` options in the link step of the build (via the MAKE variable `PARALIB`). Use of a general `PARALIB` MAKE variable allows other parallel options besides MPI to be used in future releases.	If omitted, the default is to omit parallel building.

Option Syntax	Effect on the generated *makefile* if requested	Effect on the generated *makefile* if NOT requested
`--with-MPILIB=`*value*	Defines two symbols (MULTP and MPI) that trigger conditional compilation of parallel code. This option should be used if you do not want to set the two environment variables `MPI_ROOT` and `MPI_NAME`. (If you use this option, you *must* also use the `--with-MPIINC=`*value* option.) The *value* given after the `=` *must* be a valid string for the link step of the build. A valid string for the link step takes the form `'-L/some /path/to/mpi/directory -lmpi'` and the string *must* be enclosed within single or double quotation marks. This *value* is assigned to the MAKE variable `PARALIB` for the link step of the build. Use of a general `PARALIB` MAKE variable allows other parallel options besides MPI to be used in future releases.	If omitted, the default is to omit parallel building.
`--with-MPIINC=`*value*	Use if you do not want to set the two environment variables `MPI_ROOT` and `MPI_NAME`. If you use this option, you must also use the `--with-MPILIB=`*value* option. The *value* given after the equals sign must be a valid path to the MPI include directory. The include path is used with `-I` in the compilation step of the build.	If omitted, the default is to omit parallel building.
`--with-MPICH`	Defines one additional symbol (MPICH) to indicate the use of the public domain version of MPI. This implies that the *value* that appears after the `-l` option of the link step string is an MPICH executable library that triggers conditional compilation of parallel code. See the MAKE variable `PARALIB` description in the `--with-MPILIB` and `--with-MPIINC` options.	If omitted, the `MPILIB` and `MPIINC` options are assumed to be a reference to a vendor-specific implementation of MPI.

3.3.5 Multiprocessing

Parallel versions of MCNPX may be built using either MPI or PVM (Parallel Virtual Machine). (PVM is no longer supported by ORNL and rarely is tested by the development team.) This feature is invoked using one of the following CONFIGURE options:

```
--with-MPILIB[=-L/path/to/mpi/libraries -lmpich]
--with-PVMLIB[=-L/path/to/pvm/libraries -lfpvm3 -lpvm3]
```

Additional information on parallel processing is provided in Appendix A. Build notes for specific hardware/compiler combinations are provided on the MCNPX web site: `http://mcnpx.lanl.gov/documents.html`.

3.3.6 Programmer's Notes

MCNPX can be modified by patches, and as much of the MCNP4C coding as possible has been preserved so that MCNP4C patches can be applied directly to MCNPX. Contact the MCNPX development team for details on creating and applying patch files.

3.4 WINDOWS BUILD SYSTEM

If you wish to modify the MCNPX source or recreate the executables, you will need the CVF compiler (version 6.1 or later) or the Intel compiler (version 8.0 or later). You can use just about any version of the Microsoft C compiler with either one of these. (We use the Microsoft Visual Studio .NET 2003.) Once the FORTRAN and C compilers are installed, follow these steps:

1. Create a folder named `MCNPX` on a drive with enough disk space (~200 Mbytes). Unzip the `v260.tar.gz` file in that folder. We suggest using WinZip 8.0 or later as this is a TAR/GZIP file.
2. Open a "command-prompt" window. Then, using the following commands, create a build directory at the same level as your MCNPX directory, `CD` to that directory, and execute the CONFIGURE batch file:

```
MKDIR MCNPX_BLD
CD MCNPX_BLD
...\MCNPX\v260\configure
```

You must supply the appropriate path to this batch file which is located in the folder created in step #1. There are three options now available with the CONFIGURE command:

I8	Builds the 8-byte integer version
MPI	Builds the MPICH version
CVF	Builds using the CVF compiler

The default (no CONFIGURE option) is to build with the Intel compiler. To build the 8-byte integer MPICH version using the Intel compiler, the command would be the following:

```
...\MCNPX\configure I8 MPI
```

The Intel compiler produces an executable that runs about 25% faster than the CVF executable. After executing the CONFIGURE command, some files specific to a Windows build will be unzipped.

3. Add the MCNPX_BLD\BIN directory to your PATH environment variable. (This is needed to get access to the MAKE executable which is provided in this directory.) This can be done with the following command:

```
SET PATH=%PATH%;C:\MCNPX_BLD\BIN
```

Alternatively, you can permanently edit the PATH environment variable by modifying it via the System Properties. Now you are ready to execute GNU MAKE by typing "make" in the "command-prompt" window. You can CD into any subdirectory and build any subcomponent of MCNPX just as on a UNIX platform. If you wish to run the test suite, CD into SRC\TEST and execute "make".

If you execute a problem and receive a "stack overflow" error, this is NOT an MCNPX bug. A stack limit must be specified upon linking. The included executable has a stack limit of 512 MBytes. This can be increased by editing the Makefile.h file in the MCNPX_BLD\SRC\MCNPX directory (~line 7) and rebuilding MCNPX.

3.5 LIBRARIES AND WHERE TO FIND THEM

Several types of data libraries (0) are used by MCNPX, including the XSDIR pointer file to nuclear data tables for neutron, proton, and photonuclear interactions; cross sections for the Bertini model (BERTIN); gamma emission data for decaying nuclei (PHTLIB); photon and electron interaction libraries; and others. Numerous questions in the beta-test phase of MCNPX have arisen concerning where these libraries should be kept, and this section of the manual has been added for clarification.

The XSDIR file (See Appendix F, Section F.2) tells the code all the information it needs to know regarding where individual isotopic cross-section data can be located. The following logic is used to find the XSDIR file or any library file:

1. Look in the current working directory.
2. Look in the directory specified by the "`datapath`" variable located in the MCNPX execution line.
3. Look in the directory specified by the "`datapath`" variable located in the Message Block at the beginning of the input file (e.g., `datapath=/path/to/the/data/files`).
4. Look in the directory specified by the `DATAPATH` environment variable.
5. Look in the directory specified by the "`datapath`" variable located at the beginning of the XSDIR file.
6. Look in the directory hardwired in the MCNPX source (`/usr/local/lib` for UNIX or `C:\MCNPX\XS` for Windows).

As usual, the XSDIR filename may be set either with the use of a soft link (UNIX systems) or via the MCNPX execution command line:

`mcnpx xsdir=`*`filename`*

All standard evaluated nuclear data libraries used by MCNP can be used by MCNPX 2.6.0 (including the MCPLIB photon and EL electron libraries). Additionally, the LA150 libraries for neutrons, photonuclear, and protons were specifically commissioned for MCNPX. Occasionally we post additional special-purpose libraries for MCNPX on our beta test web site (`http://mcnpx.lanl.gov`).

The LAHET physics modules in MCNPX require three special libraries: BERTIN, containing the elemental cross-section data needed by the Bertini model; PHTLIB, containing nuclear structure data needed to generate de-excitation photons; and BARPOL.dat, containing new high-energy total, reaction, and elastic cross sections.

They are unpacked with the rest of the code, and if "`make install`" is executed, the libraries are placed in the `/lib` directory. The same procedure is used to locate these files as that used to locate the XSDIR file. Therefore, it is recommended that these files are copied into the same subdirectory as the standard MCNPX libraries.

Other libraries used by the code include the following:

- GDR.dat — giant dipole resonance data used by photonuclear routines in CEM
- CINDER.dat — data required for burnup and depletion calculations
- CINDERGL.dat — data required for delayed gamma lines

- FALPHA.tab, FRLDM.tab, PACE2.data, VGSLD.tab — data required for INCL4 physics
- GAMMAN.tbl, LEVEL.tbl, MASS.tbl, SHELL.tbl — data required for CEM03 physics

3.6 EXECUTING MCNPX

3.6.1 Execution Line

The MCNPX execution line has the following form:

`MCNPX KEYWORD=`*`value ...`* `KEYWORD=`*`value execution_option other_options`*

where each `KEYWORD` is an MCNPX default filename to which the user may assign a specific *`value`* (i.e., filename or path); *`execution_option`* is a character or string of characters that informs MCNPX which of five execution module(s) to run; and *`other_options`* provide the user with additional execution control. The execute line message may be up to 240 characters long.

Table 3-2. MCNPX Execution Line Input

Filename Assignment	
Keyword[†]	**Value**[‡]
INP	User-supplied input filename. (DEFAULT=INP)
OUTP	Filename to which results are printed. Created by MCNPX during problem execution. (DEFAULT=OUTP)
RUNTPE	Name of file containing binary restart/start data. Created by MCNPX during initial problem execution and added to by MCNPX during continued problem execution. (DEFAULT=RUNTPE)
XSDIR	Name of cross-section directory file. (DEFAULT=XSDIR)
WWINP	Name of input file containing either cell- or mesh-based lower weight-window bounds.
WWOUT	Name of weight-window generator output file containing either cell- or mesh-based lower weight-window bounds.
WWONE	Name of weight-window generator output file containing cell- or mesh-based time- and/or energy-integrated weight windows.
DUMN1 and DUMN2	See Section 5.8.13, File creation card.
COM	
COMOUT	File to which all plot requests are written.
PLOTM	Name of graphics metafile.
MCTAL	Tally results file (ASCII).

Filename Assignment	
MDATA	Mesh tally data (unformatted binary).
PTRAC	Name of output file containing user-filtered particle events.
NAME	User-supplied input filename. Will automatically generate OUTP, RUNTPE, and MDATA files with the same name as the supplied input filename appended with by "O", "R", and "D" respectively. If the NAME option is used on the execute line, the WWOUT and WWONE filenames end in E and 1, respectively.
SRCTP	Name of file containing fission source data for a KCODE calculation.
WSSA	Name of file to which surface and volume source particles are recorded.
RSSA	Name of file from which surface and volume source particles are read.
† Requires only enough letters of the default name to uniquely identify it. ‡ Filenames are limited to a maximum of 40 characters. Filenames may also include directory paths.	

Execution Options	
Option††	**Description**
I	Execute module IMCN to process the input file.
P	Execute module PLOT to plot geometry.
X	Execute module XACT to process the cross-section data.
R	Execute module MCRUN to perform the particle transport.
Z	Execute module MCPLOT to plot tally results or cross-section data.
†† DEFAULT=IXR	

Other Options	
Option	**Description**
C [*m*]	Continue a run starting with the m^{th} dump. (DEFAULT= last dump)
CN [*m*]	Continue a run, starting with the m^{th} dump and writing the dumps immediately after the fixed part of the RUNTPE, rather than at the end.
DBUG *n*	Write debug information every *n* particles.
NOTEK	Indicates that your terminal has no graphics capability. PLOT output is in PLOTM.PS. Equivalent to TERM=0.
FATAL	Transport particles and calculate volumes even if fatal errors are found.
PRINT	Create the full output file; equivalent to PRINT card in the input file.
TASKS *n*	Invokes multiprocessing on common or distributed memory systems, where *n* is the number of processors to be used. A negative value (-*n*) is allowed only on distributed memory systems to disable load balancing and fault tolerance, increasing system efficiency. This option is used only with PVM multiprocessing.

Note: In some cases, warnings and fatal-error messages will give only the first eight characters of a filename because of format constraints.

Example:

```
MCNPX   NAME=..\..\destination_output_files.   INP=..\input_file
```

In this example, the input file is named *input_file* and is located in the next directory up.

3.6.2 Interrupts

MCNPX allows five types of interactive interrupts while it is running:

<ctrl-c><cr>	MCNPX status (DEFAULT)
<ctrl-c>s	MCNPX status
<ctrl-c>m	Make interactive plots of tallies or the geometry
<ctrl-c>q	Terminate MCNPX gracefully after current history
<ctrl-c>k	Kill MCNPX immediately

Note that when running parallel KCODE problems, <ctrl-c> and quit on a multiple-processor MPI run in Linux do not finish writing the OUTP file before MCNPX exits. This failure appears to be an MPI error in the MPI_FINALIZE call, where the last processor kills all subtasks and the master. Also, the <ctrl-c> interrupt does not function properly when using the MPI executable on Windows systems.

Batch jobs, run in sequential or multiprocessing mode, may be interrupted and stopped with the creation of a file in the directory where the job was started. The name of the file must be "stop*INP*" where *INP* is the name of the original input file. The contents of this file are meaningless. Once this file is created, MCNPX will terminate the job during the next output rendezvous (see 5th entry on PRDMP card, Section 5.8.3) as if a <ctrl-c>q interrupt were issued.

3.6.3 Tips for Correct and Efficient Problems

Provided in this section are checklists 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. A fourth checklist is provided for KCODE calculations. The list can serve as a springboard for further reading in preparation for tackling more difficult problems.

3.6.3.1 PROBLEM SETUP

1. Do not set up all the geometry at one time.

2. Model the geometry and source distribution in enough detail as needed for accuracy.
3. Use simple cells.
4. Use the simplest surfaces, including macrobodies.
5. Put commonly used cards in a separate file and add them to your input file via the READ card.
6. Always plot the geometry to see if it is defined correctly and that it is what was intended.
7. Know and compare calculated mass, cell volumes, and surface areas.
8. Use the VOID card when checking the geometry.
9. Look at print tables 10, 110, and 170 to check the source.
10. Check your source with a mesh tally.
11. Be aware of physics approximations, problem cutoffs, and default cross sections.
12. Cross-section sets matter!
13. Use the most conservative variance-reduction techniques.
14. Do not use too many variance-reduction techniques.
15. Balance user time with computer time.
16. Study all warning messages.
17. Generate the best output (consider the PRINT card).
18. Recheck the INP file (materials, densities, masses, sources, etc.).
19. Remember that garbage into code equals garbage out of code.

3.6.3.2 PREPRODUCTION

1. Do NOT use MCNPX as a black box.
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 reduce the number of unimportant tracks.
13. Check secondary particle production.
14. Do a back-of-the-envelope check of the results.

3.6.3.3 PRODUCTION

1. Save RUNTPE file for expanded output printing, continue-run, and tally plotting.

2. Limit the size of the RUNTPE file with the PRDMP card.
3. Look at figure of merit stability.
4. Make sure answers seem reasonable.
5. Ensure you pass the ten statistical checks.
6. Form valid confidence intervals.
7. Make continue-runs if necessary.
8. Remember, accuracy is only as good as the nuclear data, modeling, MCNPX sampling approximations, etc.
9. Adequately sample all cells.

3.6.3.4 CRITICALITY

1. Run as large a number of histories per cycle as possible.
2. Examine the behavior of k_{eff} with cycle number.
3. Continue calculations if trends are noticed.
4. Use at least 100 cycles after source convergence.

4 INPUT FILES

Input to MCNPX consists of several files that are provided as part of the code package, generated by problem runs, or user-supplied. This section focuses on the user-supplied INP (the default name) file which describes the problem to be run. The INP file contains information about the problem including the geometry specification; the description of materials and selection of cross-section evaluations; the location and characteristics of the source; the type of answers or tallies desired; and any variance-reduction techniques used to improve efficiency. Input cards are summarized by card type in Section 5.9. The user will provide only a small subset of all available input cards in a given problem. The word "card" describes a single line of input up to 80 characters long.

MCNPX input-item storage limitations are summarized in Section 4.4. Modification of these values is accomplished by altering the source code and recompiling.

All features of MCNPX should be used with caution and knowledge. This is especially true of detectors and variance-reduction schemes. Read and understand the relevant sections of the manual before using them.

MCNPX accepts all standard MCNP4C input cards with additional card options that take advantage of the multiparticle capabilities or new physics features of MCNPX. In addition, several new input cards only are available in MCNPX. For example, Section 5.4.6 describes cards added to control the model physics options MCNPX uses when table-based data are not available. Section 5.5.4 describes the `BURN` card.

Accelerator simulation applications require specialized source input to describe an incident particle beam. Usually this takes the form of a directed beam of monoenergetic particles with a different Gaussian profile in both transverse directions. A new source option, described in Section 5.5.1, has been added to MCNPX to fulfill this need. The user should note that beam directions designated along the z-axis will often agree with actual coordinate systems in experimental facilities.

The units of measurement used throughout MCNPX include the following:

- length in centimeters,
- energy in MeV,
- time in shakes (10^{-8} sec),
- temperature in MeV (kT),
- atomic density in atoms/barn-cm,
- mass density in g/cm^3,
- cross sections in barns (10^{-24} cm^2),

- heating numbers in MeV/collision, and
- atomic weight ratio based on a neutron mass of 1.008664967. In these units, Avogadro's number is $0.59703109 \times 10^{-24}$.

4.1 INP FILE

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

4.1.1 Initiate-Run

This form is used to set up a Monte Carlo problem (describe geometry, materials, tallies, etc.) and to run it 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 Card Block	
.	
.	
.	
Blank Line Delimiter	
Surface Card Block	
.	
.	
.	
Blank Line Delimiter	
Data Card Block	
.	
.	
.	
Blank Line Terminator	Optional, but recommended
Anything else	Optional

MCNPX interprets a blank line as the end of the preceding information block. MCNPX will stop reading the input file after encountering the blank line terminator. The space following the blank line terminator can be used at the user's discretion for problem documentation or to retain cards not used in the current run.

4.1.2 Continue-Run

Continue-run allows the user to restart a previously terminated job where it left off. For example, a job run for two hours may be continued for an additional amount of time. The

user can also reconstruct the output of a previous run. A continue-run must contain C or CN in the MCNPX execution line or message block to indicate a continue-run. It will start with the last dump or, alternatively, with the m^{th} dump if either the C *m* or CN *m* option is specified.

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

The restart file (RUNTPE), generated by MCNPX 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 (Section 5.8.3) for a discussion of the selection of the dump frequency. 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 Card Block	
.	
.	
.	
Blank Line Terminator	Optional, but 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, and MPLOT.

If none of the above items is 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 MCNPX execution line are necessary. For example, the command line sequence MCNPX C or MCNPX CN will pick up the job where it stopped and continue until another time limit or particle cutoff is reached or until you stop it interactively. This example assumes that a restart file from the initial run with the default name "RUNTPE" is in your current directory.

The complete continue-run execution line option is C *m* or CN *m*, where *m* specifies from which dump in the restart file to reinitiate the run. If *m* is not specified, the last dump is taken by default. If the initial run producing the restart file was stopped because of particle cutoff (NPS card, Section 5.8.1), the value of *npp* on the NPS card must be increased for a continue-run via a continue-run file. In a continue-run, the *tme* parameter on the CTME card is the number of minutes more to run, not cumulative total time. To run more KCODE cycles, only the fourth entry on the KCODE card, *kct*, must be changed. Like *npp*, *kct* refers to total cycles to be run, including previous ones.

In a continue-run, a negative number entered for *npp* 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 Section 5.8.13.

4.1.3 Card Format

A line in the MCNPX input file is referred to as a "card." This terminology is historical and refers to a time when all input was done with punched cards. Input lines are limited to 80 columns, again a limitation going back to the punched card format. 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 $ (dollar sign) terminates data entry and anything that follows the $ is interpreted as a comment. (One exception is that you cannot use a $ within a mesh tally entry. See Section 5.6.23.) Blank lines are used as delimiters between input blocks and as terminators. Data entries are separated by one or more blanks.

If the first five columns of a card are blank, the entries on the card are interpreted as a continuation of the data from the last named card. The user also can continue data on the following card by ending the line with an & (ampersand) proceeded by at least one blank space. In this case, the data on the continuation card can be in columns 1–80.

4.1.4 Message Block

In computer environments where there are no execution line messages, the optional message block is the only means for giving MCNPX an execution message. Optionally, it is a convenient way to avoid retyping an often-repeated message. Both initiate-run and continue-run input files can contain a message block that replaces or supplements the MCNPX execution line information. If used, the message block is located before the problem title card in the INP file. The message block starts with the string, `MESSAGE:`. The message block ends with a blank line delimiter before the title card. All cards before the blank line delimiter are continuation cards. The syntax and components of the message are the same as for the regular execution line message. Any filename substitution, program module execution option, or keyword entry on the execution line takes precedence over conflicting information in the message block. Renaming of the input file default filename, `INP=`*`filename,`* is *not* a legitimate entry in the message block. The name `INP` can be changed on the execution line only.

4.1.5 Problem Title Card

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 MCNPX 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.

4.1.6 Comment Cards

Comment cards can be used anywhere in the INP file after the problem title card and before the last blank terminator card. (The mesh tally format is an exception. See Section 5.6.23.) These cards must have a `C` anywhere in columns 1–5 followed by at least one blank and can be up to a total of 80 columns long. Comment cards are printed only with the input file listing and not anywhere else in the MCNPX output file. The `FC` input card is available for user comments and is printed as a heading for a tally (as a tally title, for example). The `SC` card is available for user comments and is printed as a heading for a source probability distribution.

4.1.7 Cell, Surface, and Data Cards

Detailed specifications for the cell, surface, and data cards are provided in Section 5. A general description of these card types is provided in this section to orient the user.

The first entry on any cell card is the user-assigned cell number, which must begin in the first five columns of the card. The second entry is a cell material number that

corresponds to a material card number (*m* on the M card) in the data-card input block. If the cell is void, a zero is entered for the material number. For a cell with non-zero material number, the material density follows the material number. The next entries include a list of signed surfaces that provide a complete specification of the geometry of the cell. Optionally, after the geometry description, cell parameters can be entered.

Similarly, the first entry on any surface card is the user-assigned surface number, which must begin in the first five columns of the card. The second entry is typically 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.

The remaining data input for MCNPX follows the second blank card delimiter (or third blank card if there is a message block). Although a horizontal input format for data cards is most commonly used, a vertical format option permitted by MCNPX is particularly useful for some cell parameters and source distributions. Both formats are described in the sections that follow.

4.1.7.1 DATA CARD HORIZONTAL INPUT FORMAT

Like cell and surface cards, 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. An individual entry cannot be split between two cards. There can be only one card of any given type for a given particle designation. (See Section 4.1.8.) Integers must be entered where integer input is required. Other numerical data can be entered in any form acceptable to a FORTRAN E-edit descriptor.

MCNPX allows five shortcuts to facilitate data input in some instances:

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, then 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` value may not be exact, but in the example `1 4I 6`, all interpolates are exact and the entry is equivalent to `1 2 3 4 5 6`.
3. *x*M means *multiply* the previous entry on the card by the value *x*. For example, `1 1 2M 2M 2M 2M 4M 2M 2M` is equivalent to `1 1 2 4 8 16 64 128 256`.
4. *n*J means *jump* over the entry where used and take the default value. As an example, the following two cards are identical in their effect:

```
DD   0.1   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 can't remember it. Another example of this capability is `DBCN  7J  5082`.

5. *n*`LOG` or, equivalently, *n*`ILOG` means insert *n* (base-10) logarithmic interpolates between the entries immediately preceding and following this feature. For example, `0.001 4LOG 100` is equivalent to `0.001 0.01 0.1 1 10 100`.

These features apply to both integer and floating-point quantities. If *n* (an integer) is omitted in the constructs *n*`R`, *n*`I`, *n*`LOG`, *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`, *n*`LOG`, 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. The preceding number cannot be `0.0` for *n*`LOG` or *n*`ILOG`.
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 anything except `I` and may begin the card input list.

Several examples follow:

`1 3M 2R`	is equivalent to	`1 3 3 3`
`1 3M I 4`	is equivalent to	`1 3 3.5 4`
`1 3M 3M`	is equivalent to	`1 3 9`
`1 2R 2I 2.5`	is equivalent to	`1 1 1 1.5 2.0 2.5`
`1 R 2M`	is equivalent to	`1 1 2`
`1 R R`	is equivalent to	`1 1 1`
`1 2I 4 3M`	is equivalent to	`1 2 3 4 12`
`1 2I 4 2I 10`	is equivalent to	`1 2 3 4 6 8 10`
`3J 4R`	is illegal	
`1 4I 3M`	is illegal	
`1 4I J`	is illegal	

4.1.7.2 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 lead to errors when users add or delete cells. In vertical 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 multi-line 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 is ignored if it is present.

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. To indicate that vertical input format is being used, 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 names are entered, all must be entered. If cell names are entered, the cells don't have to be in the same order as they are in the cell cards block. If cell names 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 presently 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 would be needed.

We strongly suggest keeping columns reasonably neat for user 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, LOG, ILOG, 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, are not allowed if cell or surface names are present.

The form of a column input block is

#	S_1	S_2	...	S_m
k_1	d_{11}	d_{12}	...	d_{1m}
k_2	d_{21}	d_{22}	...	d_{2m}
.	.	.	...	.
.	.	.	...	.
.	.	.	...	.
k_n	d_{n1}	d_{n2}	...	d_{nm}

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 MCNPX 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 Js possibly followed by some blanks.
6. If d_{ji} is nonblank, $d_{j,i-1}$ must also be nonblank. A J may be used if necessary to make $d_{j,i-1}$ 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 names. The same is true with surface parameters.
10. If the k_j are present, the d_{ji} must not be multiple special syntax items, such as 9R.

4.1.8 Particle Designators

Several of the input cards require a particle designator to distinguish between input data for tracked particles. Refer to the pertinent card information for instructions. The particle designator consists of a colon followed by the particle symbol or IPT number(s) immediately after the name of the card. These particle designations are presented in Table 4-1. At least one blank must follow the particle designator. For example, IMP:N signifies neutron importances follow; 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.

Table 4-1. MCNPX Particles

IPT*	Name of Particle	Symbol	Mass (MeV)	Low Kinetic Energy Cutoff (MeV)	Mean Lifetime[1] (seconds)
Original MCNP Particles					
1	neutron (n)	n	939.56563	0.0	887.0
-1	anti-neutron (n)	-n	939.56563	0.0	887.0
2	photon (γ)	p	0.0	0.001	Huge
3	electron (e^-)	e	0.511008	0.001	Huge
-3	positron (e^+)	-e	0.511008	0.001	Huge
Leptons					
4	muon$^-$ (μ^-)	| ('pipe' symbol)	105.658389	0.11261	2.19703×10^{-6}
-4	anti-muon$^-$ (μ^+)	-|	105.658389	0.11261	2.19703×10^{-6}
5	tau$^-$ (τ^-)	*	1777.1	1.894	2.92×10^{-13}†
6	electron neutrino (ν_e)	u	0.0	0.0	huge
-6	anti-electron neutrino ($^-\nu_e$)	-u	0.0	0.0	huge
7	muon neutrino (ν_m)	v	0.0	0.0	huge†
8	tau neutrino (ν_t)	w	0.0	0.0	huge†
Baryons					
9	proton (p)	h	938.27231	1.0	huge
-9	anti-proton ($^-$p)	-h	938.27231	1.0	huge
10	lambda^0 (Λ^0)	l	1115.684	1.0	2.632×10^{-10}†
11	sigma$^+$ (Σ^+)	+	1189.37	1.2676	7.99×10^{-11}†
12	sigma$^-$ (Σ^-)	-	1197.436	1.2676	1.479×10^{-10}†
13	cascade^0 (Ξ^0)	x	1314.9	1.0	2.9×10^{-10}†
14	cascade$^-$ (Ξ^-)	y	1321.32	1.4082	1.639×10^{-10}†
15	omega$^-$ (Ω^-)	o	1672.45	1.7825	8.22×10^{-11}†
16	lambda$_c^+$ (Λ_c^+)	c	2285.0	2.4353	2.06×10^{-13}†
17	cascade$_c^+$ (Ξ_c^+)	!	2465.1	2.6273	3.5×10^{-13}†
18	cascade$_c^0$ (Ξ_c^0)	?	2470.3	1.0	9.8×10^{-14}†
19	lambda$_b^0$ (Λ_b^0)	r	5641	1.0	1.07×10^{-12}†

[1] Particle Data Group (PDG), *Particle Physics Booklet*, July 2002, extracted from K. Hagiwara et al., "Review of Particle Physics," *Physical Review* **D 66**, 010001 (2002).

IPT*	Name of Particle	Symbol	Mass (MeV)	Low Kinetic Energy Cutoff (MeV)	Mean Lifetime[1] (seconds)
Mesons					
20	pion$^+$ (π^+)	/	139.56995	0.14875	2.603×10^{-8}
-20	pion$^-$ (π^-)	-/	139.56995	0.14875	2.603×10^{-8}
21	neutral pion (π^0)	z	134.9764	0.0	8.4×10^{-17}
22	kaon$^+$ (K^+)	k	493.677	0.52614	1.2371×10^{-8}
-22	kaon$^-$ (K^-)	-k	493.677	0.52614	1.2371×10^{-8}
23	K_0 short	%	497.672	0.000001	0.8926×10^{-10}
24	K_0 long	^	497.672	0.000001	5.17×10^{-8}
25	D^+	g	1869.3	1.9923	1.05×10^{-12}†
26	D^0	@	1864.5	1.0	4.15×10^{-13}†
27	D_s^+	f	1968.5	2.098	4.67×10^{-13}†
28	B^+	j	5278.7	5.626	1.54×10^{-12}†
29	B^0	b	5279.0	1.0	1.5×10^{-12}†
30	B_s^0	q	5375.	1.0	1.34×10^{-12}†
Light Ions					
31	deuteron	d	1875.627	2.0	huge
32	triton	t	2808.951	3.0	12.3 years
33	helium-3	s	2808.421	3.0	huge
34	helium-4 (α)	a	3727.418	4.0	huge
Heavy Ion**					
35	heavy ions‡	#	varies	5.0	huge

* An antiparticle is designated by including a "-" sign before the IPT number of the symbol. If no "-" sign is included when designating particle type with the PAR keyword on the SDEF card, the default particle type will be the first one listed in Table 4-1 for the IPT number or symbol.

† -decayed on production

‡ The "#" symbol represents all possible heavy ion types. That is, any ion that is not one of the four light ions available in MCNPX.

** A list of heavy ions available for transport is provided in Appendix K.

4.1.9 Default Values

Many MCNPX input parameters have default values that are summarized in Section 5.9. Therefore, you do not always have to specify explicitly every input parameter every time if the defaults match your needs. If an input card is left out, the default values for all parameters on the card are used. However, if you want to change a particular default

parameter on a card where that parameter is preceded by others, you have to specify the others or use the *n*J jump feature to jump over the parameters for which you still want the defaults. For example, the input CUT:P 3J -0.10 is a convenient way to use the defaults for the first three parameters on the photon cutoff card but change the fourth.

4.2 INPUT ERROR MESSAGES

MCNPX makes over 400 checks of the input file for user errors. If the user violates a basic constraint of the input specification, a fatal error message is printed, both at the terminal and in the OUTP file, and MCNPX 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 MCNPX execution line instructs MCNPX to ignore fatal errors and run particles, but the user should be extremely cautious when doing this.

Most MCNPX error messages are warnings that are not fatal. The user should not ignore these messages but should understand their significance before making important calculations.

In addition to FATAL and WARNING messages, MCNPX issues BAD TROUBLE messages immediately before any impending catastrophe, such as a divide by zero, which would otherwise cause the program to "crash." MCNPX 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.

4.3 GEOMETRY ERRORS

There is one important kind of input error that MCNPX will not detect while processing data from the INP file. MCNPX 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 you can and should do to check your geometry before starting a long computer run.

Use the geometry-plotting feature of MCNPX to look at the system from several directions and at various scales. Be sure that what you see is what you intend. Any gaps or overlaps in the geometry will probably show up as red 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, there are any cookie-cutter cells in the source, or there are DXTRAN spheres in the problem.

Set up and run a short problem in which your system is flooded with particle tracks from an external source. The changes required in the INP file to perform this test follow:

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. To do this, you can use the command

   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 your 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.

4.4 STORAGE LIMITATIONS

Table 4-2 summarizes some of the more important limitations that have to be considered when setting up a problem. It may be necessary to modify MCNPX to change one or more of these restrictions for a particular problem.

Table 4-2. Storage Limitations

Entries in the description of a cell	2000 after processing*
Total number of tallies	NTALMX = 100
Detectors	MXDT = 20
Neutron DXTRAN spheres	MXDX = 5
Photon DXTRAN spheres	MXDX = 5
`ESPLT` card entries	20*
Entries on `IDUM` card	50*
Entries on `RDUM` card	50*

*Set as a dimension in an array

5 INPUT CARDS

MCNPX input cards other than those that define cells (Section 5.2.1) and surfaces (Section 5.2.2) typically are entered after the blank card delimiter following the cell-card and surface-card blocks. The mnemonic that specifies the type of data card must begin within the first five columns of the 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.

Note that when *values* are assigned to keywords, the equals sign (=) is optional.

5.1 AUXILIARY INPUT FILE AND ENCRYPTION (READ CARD)

Form: READ KEYWORD=*value(s)* ...

Table 5-1. Auxiliary Input and Encryption (READ)

Keyword	Value
FILE=*filename*	Causes input from the file *filename* to be inserted after the READ card in the MCNPX input deck.
NOECHO	Suppresses printing of the input cards following the READ card.
ECHO	Resumes echoing of the input after a NOECHO keyword was given in a previous READ card. Echoing also will resume when the next READ card is encountered without the NOECHO keyword. (DEFAULT)
DECODE=*password*	Allows reading of an encrypted file. When DECODE is invoked, the encrypted input file is not echoed, and many default print tables are turned off (and cannot be turned back on) to protect the data in the encrypted file.
ENCODE=*password*	Allows the writing of an encrypted file.

The new MCNPX READ card enables (1) the reading of parts of the input file from other (auxiliary) files, (2) the suppression of the printing of the auxiliary input files to shorten output files and protect proprietary information, and (3) the encryption of auxiliary input files to protect proprietary information. Unlike most MCNPX input cards, there may be as many READ cards and auxiliary input files as desired. The

READ card may appear anywhere after the title card of an MCNPX input file but not in the middle of a card continuation. In MCNPX 2.6.0 a READ card cannot appear in the auxiliary file.

The encryption capability can be used to protect proprietary designs of tools and other systems modeled with MCNPX. The encryption capability is localized in subroutine ENCRYPT. The MCNPX scheme is very simple; therefore, it protects nothing. To protect input, the subroutine should be modified to a more sophisticated scheme known only to those producing the data and only executable MCNPX versions should be provided to users of the encrypted files.

Example 1:

```
READ   FILE=filename   NOECHO
```

Because the echoing of the input cards also is resumed when an "end of file" is encountered, the above example causes the input from the auxiliary file, *filename,* to be suppressed. After the file *filename* is read, input transfers back to the input file that contains the READ card and printing is no longer suppressed.

Example 2:

```
READ   DECODE password   FILE=filename
```

This example causes the reading of the encrypted file, *filename*.

Example 3:

```
READ   ENCODE password   FILE=filename
```

This example causes an encrypted file, *filename*, to be written.

5.2 GEOMETRY SPECIFICATION

The geometry of MCNPX treats an arbitrary three-dimensional configuration of user-defined materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori. (See Table 5-4.) The cells are defined by the intersections, unions, and complements of the regions bounded by the surfaces. Surfaces are defined by supplying coefficients to the analytic surface equations or, for certain types of surfaces, known points on the surfaces. MCNPX also provides a "macrobody" capability, where basic shapes such as spheres, boxes, cylinders, etc., may be combined using Boolean operators.

Each surface divides all space into two regions, one with positive sense with respect to the surface and the other with negative sense. Define $S=f(x,y,z)=0$ as the equation of a surface in the problem. For any set of points (x,y,z), if $S=0$ the points are on the surface.

If S is negative, the points are said to have a negative sense with respect to that surface and, conversely, a positive sense if S is positive.

The geometry of each cell is described on a cell card by a list of operators and signed surfaces that bound the cell. (If the sense is positive, the + sign can be omitted.) This geometry description defines the cell to be the intersection, union, and/or complement of the listed regions. The intersection operator in MCNPX is implicit; it is simply the blank space between two signed surface numbers on the cell card. The union operator, signified by a colon (:), allows concave corners in cells and also cells that are completely disjoint. Because the intersection and union operators are binary Boolean operators, their use follows Boolean algebra methodology; unions and intersections can be used in combination in any cell description. Spaces on either side of the union operator are irrelevant, but a space without the colon signifies an intersection.

The complement operator, signified by the # symbol, provides no new capability over the intersection and union operators. It is just a shorthand cell-specifying method that implicitly uses the intersection and union operators. The complement operator can be thought of as standing for *not in*. The notation #*n*, where *n* is a previously defined cell number, means that the description of the current cell is the complement of the description of cell *n*. That is, 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. The notation #(...), where (...) is usually just a list of surfaces describing another cell, means to complement the portion of the cell description in parentheses.

The default order of operations is complement first, intersection second, and unions third. There is no right-to-left ordering. Parentheses can be used to clarify operations and in some cases are required to force a certain order of operations. Innermost parentheses are cleared first. Spaces are optional on either side of a parenthesis. A parenthesis is equivalent to a space and signifies an intersection. Parentheses and operator symbols also function as delimiters; where they are present, blank delimiters are not necessary.

5.2.1 Cell Cards

Form 1: *j m d geom params*
Form 2: *j* LIKE *n* BUT *list*

Table 5-2. Cell Cards

Input Parameter	Description
j	Cell number assigned by the user. Restriction: 1≤*j*≤99999 Restriction: If the cell is affected by a transformation, 1≤*j*≤999 (See Sections 5.2.3.5 and 5.2.3.7.)
m	Material number if the cell is not a void. If *m*>0, the cell contains material *m*, which is specified on the M card located in the data-card section of the INP file. If *m*=0, the cell is a void. Restriction: 1≤*m*≤99999
d	Cell material density. If *d*>0, interpret the value as the atomic density in units of 10^{24} atoms/cm^3 (i.e., atoms/b-cm). If *d*<0, interpret the value as the mass density in units of g/cm^3. This parameter is absent if the cell is a void.
geom	Specification of the geometry of the cell. This specification consists of signed surface numbers and Boolean operators that specify how the regions bounded by the surfaces are to be combined. Boolean operators include the following: "<space>" indicates intersection, ":" indicates union; and "#" indicates complement.
params	Optional specification of cell parameters by entries in the KEYWORD=*value* form. Allowed keywords include IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, TMP, U, TRCL, LAT, and FILL.
n	Name of another cell. Restriction: Cell card for cell *n* must appear in the INP file before the cell card for cell *j*.
list	Set of KEYWORD=*value* specifications that define the attributes that differ between cells *n* and *j*. Allowed keywords include MAT (material number) and RHO (density) as well as the cell parameter keywords IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, TMP, U, TRCL, LAT, and FILL.

Note: Cell parameters may be defined on cell cards instead of in the data-card section of the INP file. 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. It is permitted for some cell parameters to be specified on cell cards, while other subsets are specified in the data section. The format for cell parameters defined on cell cards is KEYWORD=*value(s)*, where the allowed keywords are IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, and TMP, with particle designators where necessary. Similarly, the cell-parameter cards associated with the repeated structures capability, U, TRCL, LAT, and FILL, may be placed either on the cell cards or in the data-card section of the INP file.

Note: The LIKE *n* BUT feature uses keywords for the cell material number and density. The mnemonics are MAT and RHO, respectively. These two keywords are only allowed following the LIKE *n* BUT construct, and may not appear in a normal cell description. Any other keyword name that appears after the BUT is a cell parameter and, therefore, must appear on cell cards only, not on any cards in the data block of the INP file.

Note: TMP and WWN data can be entered on cell cards in two ways. The KEYWORD=*value* form (TMP1=*value* TMP2=*value* ...) 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 1:

```
3  0    -1    2   -4            $ definition of cell 3
5  0    #3                      $ equivalent to next line
5  0   (+1 : -2 : +4)
```

Cell 3 is defined as the region in space with negative sense with respect to surface 1, positive sense with respect to surface 2, and negative sense with respect to surface 4. Cell 5 is the region of space not including cell 3. In the second line of the example, it is specified using the complement operator; in the third line, the same region is specified using the union operator.

Example 2:

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

This second example 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.

Example 3:

```
10  16  -4.2   1   -2    3   IMP:N=4  IMP:P=8  EXT:N=-0.4X
```

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.

5.2.2 Surface Cards

P, PX, PY, PZ, SO, S, SX, SY, SZ, C/X, C/Y, C/Z, CX, CY, CZ, K/X, K/Y, K/Z, KX, KY, KZ, SQ, GQ, TX, TY, TZ, X, Y, Z, BOX, RPP, SPH, RCC, RHP, HEX, REC, TRC, ELL, WED, ARB

Surfaces can be defined by equations (Section 5.2.2.1), points (Sections 5.2.2.2 and 5.2.2.3), or macrobodies (Section 5.2.2.4). Each of these methods is discussed in the sections that follow.

5.2.2.1 SURFACES DEFINED BY EQUATIONS

Form: *j k a list*

Table 5-3. Surfaces Defined by Equations

Input Parameter	Description
j	Surface number assigned by the user. Restriction: 1≤*j*≤99999 Restriction: If surface defines a cell that is transformed with TRCL or TR, 1≤*j*≤999. See Sections 5.2.3.5 and 5.2.3.7.
*j	Reflecting surface number. A particle track that hits a reflecting surface is reflected specularly.
+*j*	White boundary surface number. A particle hitting a white boundary is reflected with a cosine distribution relative to the surface normal.
k	If *k*>0, specifies transformation number *k* of a TR card. If *k*<0, specifies surface *j* is periodic with surface *k*. If *k* is absent or *k*=0, then no coordinate transformation is specified.
a	Equation mnemonic from Table 5-4 that specifies the type of surface.
list	One to ten numerical entries required to define a surface.

The available surface types, equations, mnemonics, and the order of the card entries are given in Table 5-4. To specify a surface by this method, find the surface in Table 5-4 and determine the coefficients for the equation. The information is entered on the surface card according to the above form.

If periodic boundaries are specified such 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 bound only 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.

Note: Detectors and DXTRAN (next-event estimators) usually should not be used in problems that have reflecting surfaces or white boundaries. Also, tallies in problems with reflecting surfaces will need to be normalized differently.

Table 5-4. MCNPX Surface Cards

Mnemonic	Type	Description	Equation	Card Entries
P	Plane	General	$Ax + By + Cz - D = 0$	A B C D
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	$(x-\bar{x})+(y-\bar{y})^2+(z-\bar{z})^2 - R^2 = 0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ 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 ± 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 ± 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 ± 1
KX		On x-axis	$\sqrt{y^2 + z^2} - t(x-\bar{x}) = 0$	$\bar{x}$ t^2 ± 1
KY		On y-axis	$\sqrt{x^2 + z^2} - t(y-\bar{y}) = 0$	$\bar{y}$ t^2 ± 1
KZ		On z-axis	$\sqrt{x^2 + y^2} - t(z-\bar{z}) = 0$	$\bar{z}$ t^2 ± 1
				± 1 used only for 1 sheet cone

Mnemonic	Type	Description	Equation	Card Entries
SQ	Ellipsoid Hyperboloid Paraboloid	Axis not 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	$(x-\bar{x})^2/B^2 + \left(\sqrt{(y-\bar{y})^2 + (z-\bar{z})^2} - A^2\right)/C^2 - 1 = 0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ A B C
TY			$(y-\bar{y})^2/B^2 + \left(\sqrt{(x-\bar{x})^2 + (z-\bar{z})^2} - A^2\right)/C^2 - 1 = 0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ A B C
TZ			$(z-\bar{z})^2/B^2 + \left(\sqrt{(x-\bar{x})^2 + (y-\bar{y})^2} - A^2\right)/C^2 - 1 = 0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ A B C
X Y Z P	Surfaces defined by points (See Sections 5.2.2.2 and 5.2.2.3)			
BOX RPP SPH RCC RHP or HEX REC TRC ELL WED ARB	Surfaces defined by macrobodies (See Section 5.2.2.4)			

Note: The quadratic equation for a cone describes a cone of two sheets—one sheet is a cone of positive slope, and the other has a negative slope. MCNPX provides the option to select either of the two sheets. The +1 or the −1 entry on the cone surface card causes the one sheet cone treatment to be used. If the sign of the entry is positive, the specified sheet is the one that extends to infinity in the positive direction of the coordinate axis to which the cone axis is parallel. The converse is true for a negative entry. A cell whose description contains a two-sheeted cone may require an additional surface specification to help distinguish between the two sheets. This ambiguity surface helps to eliminate any ambiguities as to which region of space is included in the cell.

Note: 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 5-1a. 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 5-1b) whose origin is at 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 5-1c), and -c < a < 0 produces the inner surface (Figure 5-1d).

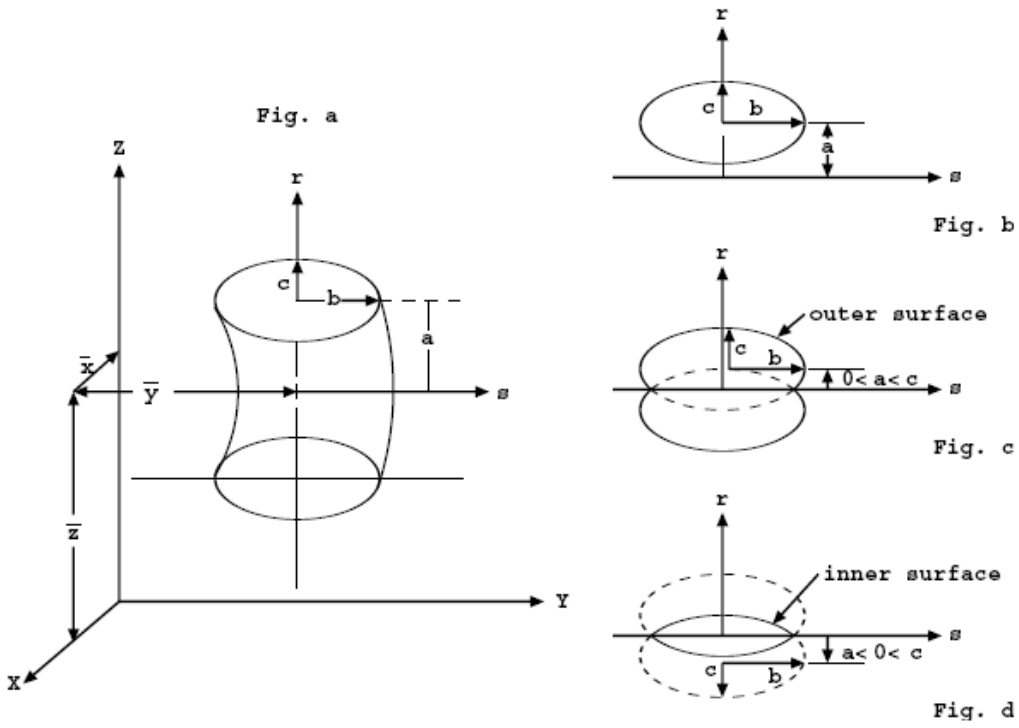


Figure 5-1. Torus

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.

Example 1:

```
1      PY  3
```

Surface 1 describes a plane normal to the y-axis at *y*=3 with positive sense for all points with *y*>3.

Example 2:

```
3      K/Y  0   0   2   0.25   1
```

Surface 3 is 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:

```
11     GQ  1  0.25  0.75   0   -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 degrees 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 TR*n* card (see Section 5.2.3.7) to define the relation between the basic and auxiliary coordinate systems. The input would then be

```
11  7  CX  1
*TR7       6  1  -1.732  0 30  60
```

5.2.2.2 AXISYMMETRIC SURFACES DEFINED BY POINTS

Form: *j n a list*

Table 5-5. Axisymmetric Surfaces

Input Parameter	Description
j	Surface number assigned by user. Restriction: 1≤j≤99999 Restriction: 1≤j≤999 if *j* is the surface number of a repeated structure or if surface *j* defines a cell that is transformed with TRCL. See Section 5.2.3.5.
n	Transformation number on TR card. If *n* is absent, then no coordinate transformation is specified.
a	The letter X, Y, or Z.
list	One to three coordinate pairs.

Surface cards of the 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.

5.2.2.3 GENERAL PLANE DEFINED BY THREE POINTS

Form: $j \quad n \quad \mathrm{P} \quad x_1\ y_1\ z_1 \quad x_2\ y_2\ z_2 \quad x_3\ y_3\ z_3$

Table 5-6. General Plane Defined by Three Points

Input Parameter	Description
j	Surface number assigned by the user. Restriction: $1 \le j \le 99999$ Restriction: $1 \le j \le 999$ if j is the surface number of a repeated structure or if surface j defines a cell that is transformed with TRCL. See Section 5.2.3.5.
n	If $n>0$, specifies transformation number n of a TR card. If $n<0$, specifies surface j is periodic with surface n. If n is absent or $n=0$, then no coordinate transformation is specified.
P	Mnemonic that indicates this is a planar surface. (See Table 5-4.)
x_i, y_i, z_i	Coordinates of three points that 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 5-4. If there are more than four entries, they give the coordinates of three points lying in the desired plane.

5.2.2.4 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 (ITS) codes. The macrobodies can be mixed with the standard cells and surfaces. The macrobody surface is decomposed internally by MCNPX 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 or SSW cards, the surface flagging card, PTRAC, or MCTAL files.

The space inside a macrobody 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.

5.2.2.4.1 BOX—ARBITRARILY ORIENTED ORTHOGONAL BOX

Form: BOX v_x v_y v_z $a1_x$ $a1_y$ $a1_z$ $a2_x$ $a2_y$ $a2_z$ $a3_x$ $a3_y$ $a3_z$

Table 5-7. Macrobody Box (BOX)

Input Parameter	Description
v_x v_y v_z	The x, y, z coordinates of corner.
$a1_x$ $a1_y$ $a1_z$	Vector of 1st side.
$a2_x$ $a2_y$ $a2_z$	Vector of 2nd side.
$a2_x$ $a3_y$ $a3_z$	Vector of 3rd side.

Note: All corners are 90˚.

Example:

```
BOX   -1  -1  -1   2  0  0   0  2  0   0  0  2
```

This input example represents a cube centered at the origin, 2 cm on a side, with sides parallel to the major axes.

5.2.2.4.2 RPP—RECTANGULAR PARALLELEPIPED

Form: RPP x_{min} x_{max} y_{min} y_{max} z_{min} z_{max}

Table 5-8. Macrobody Rectangular Parallelepiped (RPP)

Input Parameter	Description
x_{min} x_{max}	Termini of box sides normal to the x-axis.
y_{min} y_{max}	Termini of box sides normal to the y-axis.
z_{min} z_{max}	Termini of box sides normal to the z-axis.

Note: RPP surfaces will only be normal to the x-, y-, and z-axes.

Example:

```
RPP    -1  1  -1  1  -1  1
```

This specification is equivalent to the BOX example above.

5.2.2.4.3 SPH—SPHERE

Form: SPH v_x v_y v_z r

Table 5-9. Macrobody Sphere (SPH)

Input Parameter	Description
v_x v_y v_z	The x, y, z coordinates of the center of the sphere.
r	Radius of sphere.

5.2.2.4.4 RCC—RIGHT CIRCULAR CYLINDER, CAN

Form: RCC v_x v_y v_z h_x h_y h_z r

Table 5-10. Macrobody Right Circular Cylinder (RCC)

Input Parameter	Description
v_x v_y v_z	The x, y, z coordinates of center of base of right circular cylinder.
h_x h_y h_z	Right circular cylinder axis vector.
r	Radius of right circular cylinder.

Example:

```
RCC    0 -5 0    0 10 0    4
```

This input specification represents a 10-cm-high can about the y-axis with its base plane at y=-5 and a radius of 4 cm.

5.2.2.4.5 RHP OR HEX—RIGHT HEXAGONAL PRISM

Form: RHP v_1 v_2 v_3 h_1 h_2 h_3 r_1 r_2 r_3 s_1 s_2 s_3 t_1 t_2 t_3

Table 5-11. Macrobody Right Hexagonal Prism (HEX or RHP)

Input Parameter	Description
v_1 v_2 v_3	The x, y, z coordinates of the bottom of the hexagonal prism.
h_1 h_2 h_3	Vector from the bottom to the top of the hexagonal prism. For a z-hex with height h, h_1, h_2, and h_3= 0 0 h .
r_1 r_2 r_3	Vector from the axis to the center of the first facet. For a pitch 2p facet normal to y-axis, r_1, r_2, and r_3= 0 p 0 .
s_1 s_2 s_3	Vector to center of the 2nd facet.
t_1 t_2 t_3	Vector to center of the 3rd facet.

Note: Differs from ITS (ACCEPT) format.

Example:

```
RHP    0 0 -4   0 0 8   0 2 0
```

This input specification represents 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.

5.2.2.4.6 REC—RIGHT ELLIPTICAL CYLINDER

Form: REC v_x v_y v_z h_x h_y h_z $v1_x$ $v1_y$ $v1_z$ $v2_x$ $v2_y$ $v2_z$

Table 5-12. Macrobody Right Elliptical Cylinder (REC)

Input Parameter	Description
v_x v_y v_z	The x, y, z coordinates of cylinder bottom.
h_x h_y h_z	Cylinder axis height vector.
$v1_x$ $v1_y$ $v1_z$	Ellipse major axis vector (normal to h_x h_y h_z).
$v2_x$ $v2_y$ $v2_z$	Ellipse minor axis vector (orthogonal to h_x h_y h_z).

Note: If there are 10 entries instead of 12, the 10th entry is the minor axis radius, where the direction is determined from the cross product of $\vec{\mathbf{h}}$ and $\overrightarrow{\mathbf{v1}}$.

Example:

```
REC    0 -5 0   0 10 0   4 0 0   2
```

This input specification represents 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 cm in the x-direction and minor radius 2 cm in the z-direction.

5.2.2.4.7 TRC—TRUNCATED RIGHT ANGLE CONE

Form: TRC v_x v_y v_z h_x h_y h_z r_1 r_2

Table 5-13. Macrobody Truncated Right Angle Cone (TRC)

Input Parameter	Description
v_x v_y v_z	The x, y, z coordinates of cone bottom.
h_x h_y h_z	Cone axis height vector.
r_1	Radius of lower cone base.
r_2	Radius of upper cone base, where $r_1 > r_2$.

Example:

```
TRC    -5 0 0  10 0 0 4  2
```

This input specification represents 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.

5.2.2.4.8 ELL—ELLIPSOID

Form: ELL $v1_x$ $v1_y$ $v1_z$ $v2_x$ $v2_y$ $v2_z$ rm

Table 5-14. Macrobody Ellipsoid (ELL)

Input Parameter	Description
$v1_x$ $v1_y$ $v1_z$	If $rm > 0$, the coordinates of the 1st foci. If $rm < 0$, the coordinates of the center of the ellipsoid.
$v2_x$ $v2_y$ $v2_z$	If $rm > 0$, the coordinates of the 2nd foci. If $rm < 0$, major axis vector with length = major radius.
rm	If $rm > 0$, major radius length. If $rm < 0$, minor radius length.

Examples:

```
ELL    0 0 -2   0 0 2   6
ELL    0 0  0   0 0 3  -2
```

These input specifications represent an ellipsoid at the origin with major axis of length 6 cm in the z-direction and minor axis radius of length 4 cm normal to the z-axis.

5.2.2.4.9 WED—WEDGE

Form: WED v_x v_y v_z $v1_x$ $v1_y$ $v1_z$ $v2_x$ $v2_y$ $v2_z$ $v3_x$ $v3_y$ $v3_z$

Table 5-15. Macrobody Wedge (WED)

Input Parameter	Description
v_x v_y v_z	The x, y, z coordinates of wedge vertex.
$v1_x$ $v1_y$ $v1_z$	Vector of 1st side of triangular base.
$v2_x$ $v2_y$ $v2_z$	Vector of 2nd side of triangular base.
$v3_x$ $v3_y$ $v3_z$	Height vector.

Note: A right-angle wedge has a right triangle for a base defined by *v1* and *v2* and a height *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
```

This input specification represents 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 cm in the x-direction and 3 cm in the y-direction and hypotenuse of length 5 cm.

5.2.2.4.10 ARB—ARBITRARY POLYHEDRON

Form: ARB a_x a_y a_z b_x b_y b_z . . . h_x h_y h_z n_1 n_2 n_3 n_4 n_5 n_6

Table 5-16. Macrobody Arbitrary Polyhedron (ARB)

Input Parameter	Description
a_x a_y a_z b_x b_y b_z c_x c_y c_z d_x d_y d_z e_x e_y e_z f_x f_y f_z g_x g_y g_z h_x h_y h_z	The x-, y-, z-coordinates of the 1st through 8th corners of the polyhedron. There must be eight x, y, z triplets to describe the eight corners of the polyhedron.
n_1 ... n_6	Four-digit numbers describing a side of the polyhedron in terms of its corresponding two corners. (E.g., n_1=1278 is a plane/side bounded by corners 1, 2, 7, & 8 (*a*, *b*, *g*, and *h*).

Note: Thirty entries are required to complete the argument of the card. For polyhedrons of fewer than six sides, zero entries must be supplied.

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
```

This input specification represents a 5-sided polyhedron with corners at x, y, z = (−5,−10,−5) (−5,−10,5) (5,−10,−5) (5,−10,5) (0,12,0), and planar facets constructed from corners 1234, etc. (Note the zero entry for the 6th facet.)

5.2.3 Data Cards Related to Geometry

VOL, AREA, U, FILL, TRCL, LAT, TR

5.2.3.1 VOL CELL VOLUME CARD OR CELL KEYWORD

Form 1 (cell card entry): VOL=*x*

Form 2 (data card): VOL [NO] x_1 x_2 ... x_j

Table 5-17. Cell Volume Card/Keyword (VOL)

Input Parameter	Description
x	Volume of cell.
x_j	Volume of cell *j* where *j*= 1, 2, ..., and the number of entries is equal to the number of cells in the problem.
NO	No volumes or areas are calculated.

Default: MCNPX attempts to calculate the volume of all cells unless "NO" appears on the VOL card. If a value is not entered for a cell on the VOL card, the calculated volume is used.

Use: Use only if required cell volumes are not properly calculated. Provides an alternative way to enter volumes required by tallies. Normally the SD (Section 5.6.15) card would be used.

Note: If the number of entries does not equal the number of cells in the problem, it is a fatal error. Use the jump (*n*J) 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_j entries following NO are optional. If present, x_j entries are the volume values the code will use.

5.2.3.2 AREA SURFACE AREA CARD

Form: AREA x_1 x_2 ... x_i ...

where x_i is the area of surface i where i= 1, 2, ..., and the number of entries equals the total number of surfaces in the problem.

Default: MCNPX attempts to calculate the area of all surfaces. If a value is not entered for a surface on the AREA card, the calculated area, if any, is used.

Use: Use only if required surface areas for F2 tallies are not properly calculated. Provides an alternative way to enter areas required by tallies. Normally the SD (Section 5.6.15) card would be used. A fatal error occurs if an area is required for tallying purposes and is not available either from the MCNPX calculation or from and AREA or SD card.

Repeated Structure 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 repeated structures capability extends the concept of an MCNPX cell. The user can specify that a cell is to be filled with something called a universe. The U card identifies the universe, if any, to which a cell belongs, and the FILL card specifies with which universe a cell is to be filled. A universe is either a lattice (LAT card) 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.

5.2.3.3 U UNIVERSE CARD OR CELL KEYWORD

Form 1 (cell card entry): U=*n*

Form 2 (data card): U n_1 n_2 ... n_j ...

Table 5-18. Universe Card/Keyword (U)

Input Parameter	Description
n	Arbitrary universe number (integer) to which cell is assigned. Note: A negative value for *n* indicates that the cell is not truncated by the boundary of any higher level cell. (I.e., the calculation of distances to surfaces at higher levels may be omitted).
n_j	Universe numbers assigned to each cell of the problem in the same order as the cells appear in the cell card section. Note: When provided in the form of a data card, there must be an entry (which can be 0) for each cell in the problem. The jump feature can be used for cells not assigned a universe number.

Use: Required for repeated structures. A universe may be either a group of standard cells or a single lattice cell. 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. A cell in a universe can be filled by another universe, up to a maximum depth of 10 levels.

Note: Lack of a U card or a zero entry means that the cell does not belong to any universe. Every cell in a problem is either part of the real world (universe level 0) or part of some universe.

Note: 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. Use with EXTREME caution; MCNPX cannot detect errors in this feature because the logic that enables detection is omitted by the presence of the negative universe.

Example:

```
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
```

Cell 1 is filled with cell 2 which is designated universe 1. Cell 2 is filled with cells 3 and 4 (universe 2). It is also a square lattice cell (to be discussed later). Cell 3 is designated universe −2 indicating it is fully enclosed by surface 11. This negative notation can increase computational efficiency.

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
11     s     5    5    0    4
```

5.2.3.4 FILL FILL CARD OR CELL KEYWORD

Form 1 (cell card entry): FILL=*n*

Form 2 (fully specified fill cell card entry): FILL=$i_1{:}i_2\ j_1{:}j_2\ k_1{:}k_2\ \ m_1\ m_2\ \ldots\ m_j\ \ldots$

Form 3 (data card): FILL $n_1\ n_2\ \ldots\ n_j\ \ldots$

Table 5-19. Fill Card/Keyword (FILL)

Input Parameter	Description
n	Arbitrary number (integer) of the universe with which cell is to be filled. If the filled cell is a lattice, every cell of the lattice is filled by the same universe. (DEFAULT=0="real world" universe)
$i_1{:}i_2\ \ j_1{:}j_2\ \ k_1{:}k_2$	Lattice element parameters for the upper and lower bounds in the *i*, *j*, and *k* directions (for fully specified fill).

Input Parameter	Description
n_j	Number of the universe with which each cell is to be filled in the same order as the cells appear in the cell card section. Note: When provided in the form of a data card, there must be an entry for each of the cells in the problem. The jump feature can be used for cells not assigned a universe number.
m_j	Number of the universe with which to fill each existing lattice element (for fully specified fill). Each element in the array corresponds to an element in the lattice. The portion of the lattice covered by the array is filled and the rest of the lattice does not exist.

Use: Required for repeated structures.

Note: The `FILL` entry for a fully specified fill card optionally may 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 and some angles by cosines, all `FILL` and `*FILL` data must be placed on the cell cards of the INP file.

Note: There are two m_j values that can be used in the lattice array that have special meanings. A zero in the level-zero lattice means that the lattice element does not exist. 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. Therefore, using the universe number of a real-world lattice as an m_j value to fill that element with the cell material is not possible.

Example:

```
FILL=0:2 1:2 0:1     4 4 2   $ i=0,1,2 for j=1 & k=0
                     0 4 0   $ i=0,1,2 for j=2 & k=0
                     0 3 3   $ i=0,1,2 for j=1 & k=1
                     4 4 0   $ i=0,1,2 for j=2 & k=1
```

Only eight elements of this lattice exist. Elements (0,1,0), (1,1,0), (1,2,0), (0,2,1) 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.

5.2.3.5 TRCL CELL TRANSFORMATION CARD OR CELL KEYWORD

Form 1 (cell card entry): TRCL=*n*

Form 2 (cell card entry):

TRCL=(*o₁ o₂ o₃ xx′ yx′ zx′ xy′ yy′ zy′ xz′ yz′ zz′ m*)

Table 5-20. Cell Transformation Card/Keyword (TRCL)

Input Parameter	Description
n	Number of the transformation corresponding to a TR card in the data section of the input file. Restriction: 1≤*n*≤999.
o₁ o₂ o₃	Displacement vector of the transformation.
xx′ yx′ zx′ *xy′ yy′ zy′* *xz′ yz′ zz′*	Rotation matrix of the transformation. See Section 5.2.3.7.
m	If *m*=1, then the displacement vector is the location of the origin of the auxiliary coordinate system, defined in the main system. (DEFAULT) If *m*=−1, then the displacement vector is the location of the origin of the main coordinate system, defined in the auxiliary system.

Use: 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. Convenient for many geometries. Use with the LIKE BUT cell description. For regular cell description, it is suggested that the TR on the surface cards be used.

Reminder: Coordinate transformations can be applied only to surfaces with surface numbers <1000.

Note: If the symbol *TRCL is used, the rotation matrix entries are angles in degrees instead of cosines of the angles.

Example:

```
1     0          -1          fill=1   $ rcc can
2     2  -7.8     -2     u=1
3     0           2     u=1
21    like 1 but *trcl=(20 0 0  45 -45 90  135 45 90  90 90 0) &
      fill=2
```

Cell 21 is like cell 1 but is translated to x, y, z = 20, 0, 0 and rotated 45° counter-clockwise with respect to x and y. If the rotational matrix is left incomplete, MCNPX will calculate what it should be, but completeness is the only way to be sure you get what you want and get error messages if you are wrong.

5.2.3.6 LAT LATTICE CARD OR CELL KEYWORD

Form 1 (cell card entry): LAT=*n*

Form 2 (data card): LAT n_1 n_2 ... n_j ...

Table 5-21. Lattice Card/Keyword (LAT)

Input Parameter	Description
n	If *n*=1, the cell describes a rectangular (square) lattice comprised of hexahedra. If *n*=2, the cell describes a hexagonal (triangular) lattice comprised of hexagonal prisms.
n_j	Lattice type assigned to each cell of the problem in the same order as the cells appear in the cell card section Note: When provided in the form of a data card, there must be an entry for each of the cells in the problem. Use jump feature to pass over cells which are not lattice cells.

Use: Used to define an infinite array of hexahedra or hexagonal prisms. A nonzero entry on the LAT card means that the corresponding cell is the (0,0,0) element of a lattice. The order of specification of the surfaces of a lattice cell identifies which lattice element lies beyond each surface. Required for lattices.

Note: Each cell containing a lattice, whether specified using a LAT keyword or a LAT data card, must have an associated FILL keyword.

Note: The cell description of a lattice cell provides the standard MCNPX cell description and the order of the surfaces of the lattice-cell description conveys which lattice element lies beyond each surface. 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. 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), the (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.

Note: The MCNPX geometry plotter can be used to label lattice cells with their indices.

Note: 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. That is, opposite sides have to be identical and parallel.

Example:

```
 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
11     s       5     5    0     4
```

Cell 2 is the base (0,0,0) element of a square lattice described by surface 30, a right parallelepiped with x_{min}=0, x_{max}=10, y_{min}=0, y_{max}=10, and infinite in the z-direction. It is filled with Universe 2 (cells 3 & 4) and it is assigned to universe 1, which fills and is bounded by cell 1 (an RPP with x_{min}=0, x_{max}=50, y_{min}=−10, y_{max}=10, z_{min}=−5 and z_{max}=5. In this case the lattice elements (i,j,k) would be 0:4, −1:0, and 0:0.

5.2.3.7 TR COORDINATE TRANSFORMATION

Form (data card):

TR*n* o_1 o_2 o_3 xx' yx' zx' xy' yy' zy' xz' yz' zz' m

Table 5-22. Coordinate Transformation Card (TR)

Input Parameter	Description
n	Number assigned to the transformation. Restriction: $1 \le n \le 999$
o_1 o_2 o_3	Displacement vector of the transformation. (DEFAULT=0 0 0)
xx' yx' zx' xy' yy' zy' xz' yz' zz'	Rotation matrix of the transformation. (DEFAULT=1 0 0 0 1 0 0 0 1)
m	If m=1 (the default), then the displacement vector is the location of the origin of the auxiliary coordinate system, defined in the main system. If m=−1, then the displacement vector is the location of the origin of the main coordinate system, defined in the auxiliary system.

Default: TR*n* 0 0 0 1 0 0 0 1 0 0 0 1 1

Use: Convenient for many geometries.

Reminder: Coordinate transformations can be applied only to surfaces with surface numbers <1000.

Note: If the symbol *TR is used, the rotation matrix entries are angles in degrees instead of cosines of the angles.

Note: The rotation matrix entries specify the relationship between the directions of the axes of the two coordinate systems. For example, the value of *xx′* is the cosine of the angle (or, if the optional asterisk is used, the angle itself in degrees in the range from 0 to 180) between the x-axis of the main coordinate system and the x′-axis of the auxiliary coordinate system. Similarly, yx′ is the cosine of the angle between the y-axis of the main coordinate system and the x′-axis of the auxiliary system.

The meaning of the rotation matrix entries do not depend on the value of *m*. It is usually not necessary to enter all of the elements of the matrix. The following patterns are acceptable:

1. All nine elements. (Required if one of the systems is right-handed and the other is left-handed.)
2. Two of the three vectors either way in the matrix (6 values). MCNPX 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. MCNPX will fill out the matrix by the Eulerian angles scheme.
4. One vector (3 values). MCNPX will create the other two vectors in some arbitrary way. (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.)
5. None. MCNPX will create the identity matrix. (Appropriate when the transformation is a pure translation.)

A vector consists of the three elements in either a row or a column in the matrix. In all cases, MCNPX 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.

Example:

```
  17   4  RCC    0 0 0    0    12 0    5
*TR4       20 0 0  45 -45 90  135 45 90  90 90 0
```

In this example, surface 17 is transformed via transformation 4 causing it to be displaced to x, y, z = 20, 0, 0 and rotated as in the previously provided example on the TRCL card.

5.3 MATERIAL DATA CARDS

M, MT, MX, TOTNU, NONU, AWTAB, XS, VOID, PIKMT, MGOPT, DRXS

The data cards in this section specify the isotopic composition of the materials in the cells and the cross-section evaluations to be used. (See Appendix G.)

5.3.1 M Material Specification

Form: M*m* *zaid*$_1$ *fraction*$_1$ *zaid*$_2$ *fraction*$_2$ ... [KEYWORD=*value(s)* ...]

Table 5-23. Material Card (M)

Input Parameter	Description
m	Arbitrary material number; same as material number, *m*, on cell card. (Section 5.2.1.) Restriction: 1≤*m*≤99999.
zaid$_i$	Either a full ZZZAAA.*ab*X or partial ZZZAAA element or nuclide identifier for each constituent, where a) ZZZ represents the atomic number; b) AAA, if AAA>0, represents the atomic mass number, and if AAA=000 indicates a naturally occurring element (valid for 1≤ZZZ≤92); c) *ab* is the alphanumeric library identifier; and d) X is the class of data. To represent a metastable isotope, adjust the AAA value using the following convention: AAA′=(AAA+300)+(m×100), where m is the metastable level and m=1,2,3, or 4.
fraction$_i$	Fraction of the *i*th constituent in the material, where if *fraction*>0, then the value is interpreted as an atomic fraction and if *fraction*<0, then the value is interpreted as the weight fraction. Atomic and weight fractions may not both appear on a single M card.
Keyword	**Value**
GAS	Flag for density-effect correction to electron stopping power. If GAS=0, calculation appropriate for material in the condensed (solid or liquid) state is used (DEFAULT), or If GAS=1, calculation appropriate for material in the gaseous state used.
ESTEP=*n1*	Causes the number of electron sub-steps per energy step to be increased to *n1* for the material. If *n1* 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 in the output file. (DEFAULT: internally set)

Input Parameter	Description
HSTEP=*n2*	Causes the number of proton or other charged-particle sub-steps (exclusive of electrons, but including heavy ions) per energy step to be increased to *n2* for the material. If *n2* is smaller than the built-in default found for this material, the entry is ignored. If ESTEP is specified and HSTEP is not, then the ESTEP value is used for HSTEP. Both the default value and the HSTEP value actually used are printed in Table 85 in the output file. (DEFAULT: internally set)
NLIB=*id*	Changes the default neutron table identifier to the string *id*. (DEFAULT: blank string, which selects the first matching entry in XSDIR)
PLIB=*id*	Changes the default photon table identifier to *id*. (DEFAULT: first match in XSDIR)
PNLIB=*id*	Changes the default photonuclear table identifier to *id* (DEFAULT: first match in XSDIR)
ELIB=*id*	Changes the default electron table identifier to *id* (DEFAULT: first match in XSDIR)
HLIB=*id*	Changes the default proton table identifier to *id* (DEFAULT: first match in XSDIR)
COND	Sets conduction state of a material only for the EL03 electron-transport evaluation. If COND<0, material is a nonconductor. If COND=0, material is a nonconductor if there is at least one nonconducting component; otherwise it is a conductor (DEFAULT) If COND>0, material is a conductor if there is at least one conducting component.

Use: Required if you want materials in cells.

Note: For naturally occurring elements, AAA=000. Natural elements not available from among those listed in the XSDIR file must be constructed on an M card by adding together the individual isotopes if they are available. The value of AAA for photons and electrons is always 000, providing no distinction between isotope and element.

Note: The nuclide fractions can be normalized to 1.0 or left unnormalized, in which case the code will perform the normalization.

Note: When a data library *id* is included on an M card, the default table identifier for that material is changed to *id*. Fully specifying a ZAID on that M card overrides the assigned *id* default.

Example 1:

```
M1     NLIB=50D    1001  2    8016.50C  1   6012  1
```

This material consists of three isotopes. Hydrogen (1001) and carbon (6012) are not fully specified and will use the default neutron table that has been defined by the NLIB entry to be 50D, the discrete-reaction library. Oxygen (8016.50C) is fully specified and will use the continuous-energy library. The same default override hierarchy applies to proton, photonuclear, photon, and electron specifications.

Example 2:

To represent the ZZZAAA of the 1st metastable state of ^{110m}Ag, add 300 to the atomic mass number (110+300=410) and to this result add 1×100=100. The adjusted atomic mass number becomes 510. The ZZZAAA for the 1st metastable state of ^{110m}Ag is therefore 47510.

5.3.2 MT *S*(α,β) Material Specification

Form: MT*m* x_1 x_2 ...

Table 5-24. *S*(α,β) Card (MT)

Input Parameter	Description
m	Material identifier, same as *m* on the corresponding material (M) card.
x_i	*S*(α,β) identifier corresponding to a particular component on the M card. The available *S*(α,β) identifiers are listed in Appendix G.

Default: None.

Use: Essential for problems with thermal neutron scattering.

Note: For any material defined on an M card, a particular component of that material (represented by a ZAID number) can be associated through an MT 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 a few electron volts and then the *S*(α,β) treatment will take over. In general, *S*(α,β) effects are most significant below 2 eV.

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
```

5.3.3 MX Mix-and-Match Nuclide Replacement

Form: MX*m*:<*pl*> $zaid_1$ $zaid_2$ ...

Table 5-25. Mix and Match Nuclides (MX)

Input Parameter	Description
m	Material number of an M*m* card that *must* precede the MX*m* card.
<*pl*>	Particle designator (See Table 4-1); allowed values are neutron (N), photonuclear (P), and proton (H).
$zaid_i$	ZZZAAA identifier of replacement nuclide for the i^{th} nuclide on the M card. (See Table 5-23.) The input specification $zaid_i$=MODEL can be used on MX*m*:N and MX*m*:H cards to allow models to be mixed with tabular data. No substitutions are allowed for photoatomic (P) and electron (E) data because those data sets are complete. The input specification $zaid_i$=0 is allowed on MX*m*:P (photonuclear substitution) to specify no photonuclear data for a specific photoatomic reaction.

Use: The MX card enables nuclide substitution for different particle types. (This is an extension of, and replacement for, the MPN card for photonuclear data.) The mix-and-match capability is particularly useful for photonuclear calculations because few photonuclear data tables are available currently. Libraries are used when available and models are used otherwise.

Note: Different nuclides can be substituted for different particle types. For example, natural carbon and calcium can be used for neutrons, whereas ^{12}C and ^{40}Ca can be used for protons and photonuclear reactions.

Note: The MCNPX mix-and-match capability [HEN03] enables mixing and matching of physics models and data tables. It is possible to specify some nuclides with models and other nuclides with data tables (isotope "mixing"). It is also possible to use data tables up to their maximum energy value and then use models above that energy, even when the maximum table energy differs from nuclide to nuclide ("energy matching"). Photonuclear physics is modeled with the new CEM03 model [MAS01, MAS06a] regardless of whether CEM03 is used for other particles.

Example:

```
MODE      n  h  p
M1         1002 1   1003.6 1   6012 1   20040 1   NLIB .24c
MX1:N        j    MODEL       6000     20000
MX1:H     MODEL     1001          j         j
MX1:P      6012        0          j         j
```

In this example, note that models will be used for neutrons on tritium and protons on deuterium. Natural libraries will be used for neutron interactions on carbon and calcium. A model will be used for proton interactions for deuterium, and protons on tritium will substitute the hydrogen cross section. For photonuclear, ^{12}C substitutes for deuterium and the cross section for tritium interactions will be set to 0.0.

For additional examples using the mix and match capability, see Appendix E, Section E.5.

5.3.4 TOTNU Total Fission

Form: `TOTNU [NO]`

Default: If the `TOTNU` card is absent or if a `TOTNU` card is present but has no entry after it, total $\bar{\nu}$, which samples both prompt and delayed fission neutrons, is used for all fissionable nuclides for which prompt and delayed values are available. Thus, the `TOTNU` card is not needed unless only prompt $\bar{\nu}$ is desired.

Use: Needed to specify use of only prompt $\bar{\nu}$. A `TOTNU` card with `NO` as the entry causes prompt $\bar{\nu}$ to be used for all fissionable nuclides for which prompt values are available.

5.3.5 NONU Fission Turnoff

Form 1 (cell card entry): `NONU=`*a*

Form 2 (data card): `NONU [`a_1 a_2 `...]`

Table 5-26. Fission Turnoff Card/Keyword (NONU)

Input Parameter	Description
a	If a=0, then fission in cell treated as capture; gammas produced. If a=1, then fission in cell treated as real; gammas produced. If a=2, then fission in cell treated as capture; gammas not produced.
a_j	If a_j=0, then fission in cell j treated as capture; gammas produced. If a_j=1, then fission in cell j treated as real; gammas produced. If a_j=2, then fission in cell j treated as capture; gammas not produced. Number of entries equals the number of cells unless no entry appears. If no entry (i.e., blank), then fission in all cells is treated like capture.

Default: If the NONU card is absent, fission is treated as real fission.

Use: Needed with SSR for fissioning neutron problems only. When fission is already modeled in the source, such as SSR, it should not be duplicated in transport and should be turned off with NONU. Use a_j value of 2.

Example:

```
NONU
```

5.3.6 AWTAB Atomic Weight

Form: AWTAB $zaid_1$ aw_1 $zaid_2$ aw_2 ...

Table 5-27. Atomic Weight (AWTAB)

Input Parameter	Description
$zaid_i$	Nuclide or element identifier used on the M material card excluding the X for class of data specification. (See Table 5-23.)
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: Discouraged. Occasionally useful when XS card introduces rare isotopes.

Note: 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
```

5.3.7 XS Cross-Section File

Form: XS*n* $zaid_i$ aw_i ...

Table 5-28. Cross-Section File (XS)

Input Parameter	Description
n	Arbitrary cross-section identification number. Restriction: 1≤*n*≤999
$zaid_i$	Nuclide identifier (ZZZAAA.*ab*X) used on the M material card.
aw_i	Atomic weight ratio associated with nuclide *i*.
...	Remaining XSDIR entries for the user-provided cross-section table. See Appendix F for the format of the entries.

Restriction: 1≤*n*≤999

Use: XSDIR file entry for nuclide(s) not in XSDIR file.

Note: The XS card can be used to load cross-section evaluations not listed in the XSDIR file directory. The XS cards can be used in addition to the XSDIR file. Each XS card describes one cross-section table. The entries for the XS 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.

5.3.8 VOID Material Void

Form: VOID [c_1 c_2 ...]

where the c_j values form a list of cells to treat as void.

Default: Use problem materials.

Use: Debugging geometry and calculating volumes.

Note: 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.

Note: Entries on the VOID card selectively sets the material number and density to zero for particular cells.

5.3.9 PIKMT Photon-Production Bias

Form: PIKMT $zaid_1$ $ipik_1$ $mt_{1,1}$ $pmt_{1,1}$ ... $mt_{1,ipik_1}$ $pmt_{1,ipik_1}$
$zaid_n$ $ipik_n$ $mt_{n,1}$ $pmt_{n,1}$ ... $mt_{n,ipik_n}$ $pmt_{n,ipik_n}$

Table 5-29. Photon Production Bias

Input Parameter	Description
$zaid_i$	Element identifier of the i^{th} entry. Full or partial identifiers can be specified; that is, 29000 is equivalent to 29000.50.
$ipik_i$	Controls the biasing for $zaid_i$. If $ipik_i$=0, no photon-production biasing is done for $zaid_i$. That is, photons from $zaid_i$ are produced with the normal sampling technique. If $ipik_i$=−1, no photons are produced from $zaid_i$. If $ipik_i$>0, photon-production is biased for $zaid_i$. The value of $ipik_i$ is the number of partial photon-production reactions to be sampled.
$mt_{i,j}$	Identifiers for the partial photon-production reactions to be sampled. Note: Only used if $ipik_i$>0.
$pmt_{i,j}$	Controls, to a certain extent, the frequency with which the specified mt reactions are sampled. Note: Only used if $ipik_i$>0.

Default: If the PIKMT card is absent, no biasing of neutron-induced photons occurs. If the PIKMT card is present, any ZAID not listed has a default value of $ipik$=−1, and no photons are produced for these unlisted ZAID identifiers.

Use: Only useful for biasing photon production.

Note: Entries on the mt and pmt pairs 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.

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 than otherwise would be the case. No photons are produced from ^{16}O or from any other isotopes in the problem that are not listed on the PIKMT card.

5.3.10 MGOPT Multigroup Adjoint Transport Option

Form: MGOPT *mcal igm iplt isb icw fnw rim*

Table 5-30. Multigroup Adjoint Transport Option

Input Parameter	Description
mcal†	If *mcal*=F, specifies a forward problem. If *mcal*=A, specifies an 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. If *iplt*=0, specifies that IMP values set cell importances. Weight windows, if any, are ignored for cell importance splitting and Russian roulette. (DEFAULT) If *iplt*=1, specifies 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. If *iplt*=2, specifies that weight windows do what they normally do.
isb	Controls adjoint biasing for adjoint problems; valid only for *mcal*=A. If *isb*=0, specifies collisions are biased by infinite-medium fluxes. (DEFAULT) If *isb*=1, specifies collisions are biased by functions derived from weight windows, which must be supplied. If *isb*=2, specifies collisions are not biased.
icw	Name of the reference cell for generated weight windows. If *icw*=0, specifies that weight windows are not generated. (DEFAULT) If *icw*≠0, requires volumes be supplied or calculated for all cells of nonzero importance.

Input Parameter	Description
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*. (DEFAULT=1)
rim	Compression limit for generated weight windows. Before generated weight windows are printed out, the weight windows in each group separately are checked to see that the ratio of the highest to the lowest is less than *rim*. If not, they are compressed. (DEFAULT=1000)

† Note: *mcal* and *igm* must be specified. "J" is not an acceptable value for any of the parameters.

Use: Required for multigroup calculation.

Note: Presently, the standard MCNPX 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
```

Note: 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 fewer 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 keyword on the FT tally card.

Note: An input file for an adjoint problem can have both an IMP card and weight-window cards (*iplt*=0 and *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.

5.3.11 DRXS Discrete-Reaction Cross Section

Form: DRXS [$zaid_1$ $zaid_2$ ... $zaid_i$...]

where *zaid*$_i$ is an identifying number of the form ZZZAAA.*ab*, where ZZZ is the atomic number, AAA the atomic mass number, and *ab* the alphanumeric neutron library identifier.

Default: Continuous-energy cross-section treatment if DRXS is absent.

Use: Discouraged. 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.

Note: 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. If the DRXS card is present but has no entries after the mnemonic, discrete cross sections will be used for every nuclide, if available.

Example:

```
DRXS
```

5.4 PHYSICS (ENERGY & THERMAL TREATMENT SPECIFICATION CARDS)

MODE, PHYS, TMP, THTME, COINC, CUT, ELPT, LCA, LCB, LCC, LEA, LEB, FMULT

5.4.1 MODE Problem Type

Form: MODE <*pl*>$_1$ ... <*pl*>$_i$

where <*pl*>$_i$ is a particle designator.

The MODE card can take any argument listed in the "Symbol" column of Table 4-1, in any order. It must list all particles that will be transported in space-delimited format. If a particle is designated, the anti-particle will also be transported; therefore one should not use +/- indicators with the symbols. For example, MODE N H | E will transport neutrons and anti-neutrons, protons and anti-protons, μ^+ and μ^-, and electrons and positrons.

Note: The symbol "#" represents all possible heavy ion types and, although the "#" is generic to all heavy ions, the identity of different heavy ions are tracked by their appropriate ZZZ (charge) and AAA (mass number). The user cannot choose to transport any *particular* heavy ion, however, the user may specify individual ions as source particles and may request tallies for specific ions.

Note: If heavy ions (#) are specified on the MODE card, any residuals produced from any model physics will be transported even if the source particle is not a heavy ion.

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

5.4.2 PHYS Particle Physics Options

5.4.2.1 NEUTRONS (PHYS:N)

Form: PHYS:N *emax ean iunr dnb tabl fism recl*

Table 5-31. Neutron Physics Options (PHYS:N)

Input Parameter	Description
emax	Upper limit for neutron energy. (DEFAULT=100 MeV)
ean	Analog energy limit. (DEFAULT=0 MeV) If E is the energy of the neutron and E>*ean*, perform Implicit capture. If E is the energy of the neutron and E<*ean*, perform analog capture.
iunr	Controls unresolved resonance range probability table treatment when data tables are available. If *iunr*=0, treatment is on. (DEFAULT) If *iunr*=1, treatment is off.
dnb	Controls delayed neutron production from fission. If *dnb*=−1, then analog production of delayed neutrons from fission using libraries only. (DEFAULT) If *dnb*=−101, then analog production of delayed neutrons from fission using models only. If *dnb*=−1001, then analog production of delayed neutrons from fission using models when libraries are missing. If *dnb*=0, then treat prompt and delayed neutrons as prompt. Note: TOTNU "yes" is now the default in MCNPX. To obtain only prompt neutrons, also set TOTNU to "no." If *dnb*=*n*, where 1≤*n*≤15, produce *n* delayed neutrons per fission using libraries only. If *dnb*=100+*n*, where 1≤*n*≤15, produce *n* delayed neutrons per fission using models only. If *dnb*=1000+*n*, where 1≤*n*≤15, produce *n* delayed neutrons per fission using models when libraries missing.

Input Parameter	Description
tabl	Controls table-based physics cutoff. For *tabl*>0, use physics models for energies (E) above *tabl* and data tables for those energies below *tabl*, if available (otherwise use models). For *tabl*=−1, then mix and match. When tables are available, use them up to their upper limit for each nuclide, then use the physics models above. (DEFAULT) Also see MX card in Section 5.3.3.
fism	Fission multiplicity control. If *fism*=0, use the MCNP treatment, which assumes an integer number of neutrons per fission. For example, if $\bar{\nu}$ =2.7, then the number of neutrons will be two 30% of the time and three 70% of the time. [DEFAULT *unless* FMULT card is present or if spontaneous fission source (PAR=SF) is specified on SDEF card.] If *fism*>0, sample $\bar{\nu}$ from a Gaussian distribution. The full-width at half-maximum (FWHM) values are displayed in print table 38. The following values are allowed: If *fism*=1, correct the sampled $\bar{\nu}$ to preserve the average multiplicity (RECOMMENDED). (DEFAULT if FMULT card is present or if PAR=SF is specified on SDEF card.) If *fism*=2, preserve the multiplicity by increasing the $\bar{\nu}$ threshold. If *fism*=3, sample the Gaussian distribution without correction. If *fism*=4, use the MCNP method in the presence of spontaneous fission or the FMULT card. If *fism*=−1, sample $\bar{\nu}$ from Gaussian distribution with FWHM appropriate for fissioning nuclide. (Same as *fism*=1.)
recl	Light ion recoil and NCIA control. If *recl*=0, then no light ion recoil and no neutron capture ions created. (DEFAULT) For 0<*recl*≤1, *recl* is the number of light ions (protons, deuterons, tritons, ^{3}He, and alphas) per incident neutron to be created at each neutron elastic scatter event with light nuclei H, D, T, ^{3}He, and ^{4}He. For 1<*recl*≤2, the quantity *recl*−1 is the number of light ions per incident neutron to be created at each neutron elastic scatter event with light nuclei H, D, T, ^{3}He, and ^{4}He and the neutron capture ion algorithm (NCIA) is active. For *recl*=3, light ion recoil is not active, but NCIA is on. I.e., create charged ions from neutron capture in the table energy range if the library does not have secondary particle production data for these ions.

Default: `PHYS:N  100  0  0  -1  -1  0  0`

Use: Encouraged.

Note: The parameter *emax* must be higher than the highest energy in the problem or the physics *is wrong*. But setting *emax* too high causes excessively

coarse energy binning of slowing-down tables, which reduces accuracy. For problems with energies above 100 MeV, *emax* should be chosen carefully; the default is appropriate for problems with energies below 100 MeV.

Note: Note: *dnb*>0 is disallowed in KCODE calculations.

Note: Light ion recoil physics accounts for the ionization potential and uses the proper two-body kinematics (with neutron free-gas thermal treatment if appropriate) to bank recoil particles with the proper energy and angle. The input card MODE N H D T S A ... is required to produce light ions H, D, T, S, and A. The card CUT:<*pl*> J 0 for particles H, D, T, S, and A is recommended so that the low-energy recoil ions produced are not killed by energy cutoff.

Note: If activated by the 7th entry on the PHYS:N card, the optional neutron capture ion algorithm (NCIA) performs neutron capture in ^{3}He, ^{6}Li, and ^{10}B to produce protons, tritons, deuterons, and/or alphas according to the following table:

Isotope	Reactions
^{3}He	n(^{3}He,h)t n(^{3}He,d)d
^{6}Li	n(^{6}Li,t)a
^{10}B	n(^{10}B,g)a

If these data are in the nuclear data libraries, then the library physics produces the secondary ions instead of the NCIA. The diagnostic indicating that NCIA has been used appears in print table 100.

Note: The energies of light ions are often very low, especially for thermal neutron captures. To enable transport of these secondaries, use the CUT:<*pl*> card to reduce the low energy cutoff.

Note: Unlike most secondary particle production in the table physics region, NCIA particles are coupled. However, if one light ion is created by the data library and the other by NCIA, the correlation between the two particles is lost. If both particles are produced by the library, no correlation exists, either.

Caution: Because neutron energy deposition is physically mediated in most cases by the secondary particle emission, NCIA may be inconsistent for heating calculations. Neutron heating is done with kerma factors (heating numbers), whereas heating from the charged secondaries is done at collisions. For +F6 tallies and type 3 mesh tallies the charged ion heating is subtracted from the neutron heating and thus is counted only once. For F6:N and F6:H, D, T, A tallies, the heating is counted once

for each particle type. If heating tallies are done in cells where charged ions are produced, energy may be double-counted in F6:<*pl*> tallies.

Note: For induced fission, the average value of $\bar{\nu}$ generally comes from the nuclear data library and is a function of the incident neutron energy. For spontaneous fission sources, the fission multiplicity is sampled from a cumulative distribution when available or sampled from a Gaussian distribution when unavailable. The values of the FWHM and spontaneous fission $\bar{\nu}$ may be overridden using an FMULT card (Section 5.4.7).

Example:

```
PHYS:N    800  10  0  3  -1  -1  1
```

5.4.2.2 PHOTONS (PHYS:P)

Form: PHYS:P *emcpf ides nocoh ispn nodop*

Table 5-32. Photon Physics Options (PHYS:P)

Input Parameter	Description
emcpf	Upper energy limit for detailed photon physics treatment. (DEFAULT=*emax* on PHYS:E or PHYS:N card or 100 MeV if neither card is present.
ides	Controls generation of electrons in MODE E problems or bremsstrahlung photons with the thick-target bremsstrahlung model. If *ides*=0, then generation is on. (DEFAULT) If *ides*=1, then generation is off.
nocoh	Controls coherent (Thomson) scattering. If *nocoh*=0, then coherent scattering is turned on. (DEFAULT) If *nocoh*=1, then coherent scattering is turned off.
ispn	Controls photonuclear particle production. If *ispn*=−1, then photonuclear particle production is analog. If *ispn*=0, then photonuclear particle production is turned off. (DEFAULT) If *ispn*=1, then photonuclear particle production is biased. The bias causes a photonuclear event at each photoatomic event.
nodop	Controls Doppler energy broadening. If *nodop*=0, then Doppler energy broadening is turned on. If *nodop*=1, then Doppler energy broadening is turned off. (DEFAULT)

Input Parameter	Description
dgb	Controls delayed gamma production. If *dgb*=0, do not create any delayed gammas. (DEFAULT) If *dgb*=−101, perform analog sampling of delayed gammas using models based on 25-group emission data. If *dgb*=−102, perform analog sampling of delayed gammas using models based on line-emission data (which is currently available for 979 nuclides) augmented by 25-group data (available for the other 3400 nuclides in the CINDER90 database).

Default: `PHYS:P  100  0  0  0  1  0`

Use: Optional.

Note: Photonuclear physics models enable (γ,n) and other photonuclear reactions when photonuclear data tables are unavailable. When some photonuclear data tables are available, MCNPX will mix and match, using tables when available and physics models when no tables are available. Consider using an `MXN:P` card to override this default behavior.

Note: When Doppler broadening is turned on (*nodop*=0), there is no effect unless photon Doppler broadening momentum profile data are available in the photon library. These data are available in the MCPLIB03 and MCPLIB04 photon libraries with ZAID identifiers .03p and .04p.

Note: The *dgb* parameter enables the calculation of emitted delayed-gamma signatures due to 1) the decay of radioactive fission products created by neutron- or photon-induced fission, or 2) residual nuclides created by neutron library interactions and all model interactions. (Photonuclear library interactions are not yet included.) All possible neutron library reactions[1] are included in this treatment; however, currently the capability is enabled only when analog capture is specified, i.e., the third entry on the `CUT:N` card is set to `0`. Delayed-gamma production is currently integrated over 1E8 seconds and uses 87 sampling bins to generate the delayed gammas.

Note: Multigroup-only emission (*dgb*=−101) is preferred when individual line-amplitude detail is not important. This option will then run significantly faster and the emission spectra will converge more quickly than multigroup plus line emission. Multigroup plus line emission (*dgb*=−102) is useful for studies that require high fidelity, detailed-amplitude emission signatures. This option will run significantly slower and can require the execution of large numbers of histories to suitably converge low probability delayed-gamma emission lines.

[1] See the ENDF-6 Formats Manual for a complete list of neturon library reactions.

Note: Delayed-gamma emission is limited to fixed source (SDEF) problems.

5.4.2.3 ELECTRONS (PHYS:E)

Form: PHYS:E *emax ides iphot ibad istrg bnum xnum rnok enum numb*

Table 5-33. Electron Physics Options (PHYS:E)

Input Parameter	Description
emax	Upper limit for electron energy. (DEFAULT=*emax* on PHYS:N card or 100 MeV if no PHYS:N card)
ides	Controls production of electrons by photons or bremsstrahlung photons with the thick-target bremsstrahlung model. If *ides*=0, then electron production by photons is turned on. (DEFAULT) If *ides*=1, then electron production by photons is turned off.
iphot	Controls production of photons by electrons. If *iphot*=0, then photon production by electrons is turned on. (DEFAULT) If *iphot*=1, then photon production by electrons is turn off.
ibad	Controls bremsstrahlung angular distribution method. If *ibad*=0, perform full bremsstrahlung tabular angular distribution. (DEFAULT) If *ibad*=1, perform simple bremsstrahlung angular distribution approximation. Required for photon contributions to detectors and DXTRAN.
istrg	Controls straggling for electron energy-loss method. If *istrg*=0, use sampled straggling for electron energy loss. (DEFAULT) If *istrg*=1, use expected-value straggling for electron energy loss.
bnum	Controls production of bremsstrahlung photons. If *bnum*=0, bremsstrahlung photons will not be produced. If *bnum*>0, produce *bnum* times the analog number of bremsstrahlung photons. Radiative energy loss uses the bremsstrahlung energy of the first sampled photon. (DEFAULT=1) The specification *bnum*<0 is only applicable for EL03 electron-transport evaluation. Produce |*bnum*| times the number of analog photons. Radiative energy loss uses the average energy of all the bremsstrahlung photons sampled.
xnum	Controls production of electron-induced x-rays. If *xnum*>0, produce *xnum* times the analog number of electron-induced x-rays. (DEFAULT=1) If *xnum*=0, x-ray photons will not be produced by electrons.

Input Parameter	Description
rnok	Controls production of knock-on electrons. If *rnok*>0, produce *rnok* times the analog number of knock-on electrons. (DEFAULT=1) If *rnok*=0, knock-on electrons will not be produced.
enum	Controls production of photon-induced secondary electrons. If *enum*>0, produce *enum* times the analog number of photon-induced secondary electrons. (DEFAULT=1) If *enum*=0, photon-induced secondary electrons will not be produced.
numb	Controls bremsstrahlung production. If *numb*>0, produce *numb* bremsstrahlung on each substep. If *numb*=0, analog bremsstrahlung production. (DEFAULT)

Default: `PHYS:E  100  0  0  0  0  1  1  1  1  0`

Use: Optional.

Note: The parameter *emax* should be set to the highest electron energy encountered in your problem.

Note: The specification *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.

5.4.2.4 PROTONS (PHYS:H)

Form: `PHYS:H  emax  ean  tabl  J  istrg  J  recl`

Table 5-34. Proton Physics Options (PHYS:H)

Input Parameter	Description
emax	Upper proton energy limit. (DEFAULT=*emax* on PHYS:N card or 100 MeV if no PHYS:N card)
ean	Analog energy limit. (DEFAULT=0 MeV) If E is the energy of the proton and E>*ean*, perform implicit capture. If E is the energy of the proton and E<*ean*, perform analog capture.
tabl	Table-based physics cutoff. For *tabl*>0, use physics models for energies (E) above *tabl* and data tables for those below *tabl*, if available (otherwise use models). For *tabl*=−1, then mix and match. When tables are available, use them up to their upper limit for each nuclide, then use the physics models above. (DEFAULT)

Input Parameter	Description
J	Unused placeholder. (Be sure to put the J in the keyword string.)
istrg	Controls charged-particle straggling. If *istrg*=0, then use Vavilov model for charged-particle straggling. (DEFAULT) If *istrg*=1, use continuous slowing-down approximation for charged-particle straggling. If *istrg*=−1, use old Vavilov model (from MCNPX 2.2.4).
J	Unused placeholder. (Be sure to put the J in the keyword string.)
recl	Light ion recoil control. If *recl*=0, then no light ion recoil. (DEFAULT) For 0<*recl*≤1, *recl* is the number of light ions (protons, deuterons, tritons, ^{3}He, and alphas) to be created at each proton elastic scatter event with light nuclei H, D, T, ^{3}He, and ^{4}He.

Default: `PHYS:H  100  0  -1  J  0  J  0`

Use: Optional

Note: The parameter *emax* must be higher than the highest energy in the problem or the physics *is wrong*. But setting *emax* too high causes excessively coarse energy binning of slowing-down tables, which reduces accuracy. For problems with energies above 100 MeV, *emax* should be chosen carefully; the default is appropriate for problems with energies below 100 MeV.

Note: Light ion recoil physics accounts for the ionization potential and uses the proper two-body kinematics (with neutron free-gas thermal treatment if appropriate) to bank recoil particles with the proper energy and angle. The input card `MODE N H D T S A ...` is required to produce light ions `H`, `D`, `T`, `S`, and `A`. The card `CUT:`<*pl*> `J 0` for particles `H`, `D`, `T`, `S`, and `A` is recommended so that the low-energy recoil ions produced are not killed by energy cutoff. Note that protons colliding with hydrogen to produce more protons can produce an overwhelming number of protons. Therefore, caution is required, and *recl*<1 may be needed. This capability is the same for incident neutrons as controlled by the *recl* keyword on the `PHYS:N` card.

Caution: Protons colliding with hydrogen to produce more protons can produce an overwhelming number of protons; and 0<*recl*<1 may be needed.

Example:

```
PHYS:H   800  10  150  J  0  J  2
```

5.4.2.5 OTHER PARTICLES (PHYS:<*PL*>)

Form: PHYS:<*pl*> *emax* J J J *istrg*

Table 5-35. Other Charged-Particle Physics Options (PHYS:<*pl*>)

Input Parameter	Description
<*pl*>	Particles designators other than N, P, E, and H.
emax	Upper energy limit. (DEFAULT=*emax* on PHYS:N card or 100 MeV if no PHYS:N card)
J J J	Unused placeholders. (Be sure to put the Js in the keyword string.)
istrg	Controls charged-particle straggling. If *istrg*=0, use Vavilov model with an energy correction addressing stopping powers. (DEFAULT) If *istrg*=1, use continuous slowing-down ionization model. If *istrg*=−1, use old Vavilov model (from MCNPX 2.2.4).

Default PHYS:<*pl*> 100 3J 0

Use: Optional

Note: The parameter *emax* must be higher than the highest energy in the problem or the physics *is wrong*. But setting *emax* too high causes excessively coarse energy binning of slowing-down tables, which reduces accuracy. For problems with energies above 100 MeV, *emax* should be chosen carefully; the default is appropriate for problems with energies below 100 MeV.

Note: Although heavy ions (#) may be designated, there is no heavy ion recoil for proton elastic scattering events.

Example:

```
PHYS:D    800   3J   1
```

5.4.3 TMP Free-Gas Thermal Temperature Card/Keyword

Form 1 (cell card entry): TMP*n*=*t*

Form 2 (data card): TMP*n* t_1^n t_2^n . . . t_j^n . . .

Table 5-36. Free-Gas Thermal Temperature Card/Keyword (TMP)

Input Parameter	Description
t	Temperature of cell at time n, in MeV.
n	Index of time on the THTME card. Restriction: $n \leq 99$
t_j^n	Temperature of j^{th} cell at time n, in MeV. Number of entries equals number of cells in the problem.

Default: t_j^n =2.53 x 10^{-8} MeV, room temperature, for all cells of the problem.

Use: Optional. Required when THTME card is used. Needed for low-energy neutron transport at other than room temperature. A fatal error occurs if a zero temperature is specified for a non-void cell.

Note: The TMP cards provide MCNPX the time-dependent thermal cell temperatures that are necessary for the free-gas thermal treatment of low-energy neutron transport. This treatment becomes important when the neutron energy is less than about 4 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.

Note: The thermal temperature of a cell is denoted by kT in units of MeV. The following conversion formulas may be used:

***kT* (MeV)**	**Unit of *T***
$8.617 \times 10^{-11}\ T$	degrees K
$8.617 \times 10^{-11}\ (T+273.15)$	degrees C
$4.787 \times 10^{-11}\ T$	degrees R
$4.787 \times 10^{-11}\ (T+459.67)$	degrees F

5.4.4 THTME Thermal Times

Form: THTME t_1 t_2 ... t_i ...

Table 5-37. Thermal Times (THTME)

Input Parameter	Description
t_i	Time in shakes (10^{-8} sec) at which thermal temperatures are specified on the TMP*i* card(s). Number of entries is equal to the total number of thermal times specified. Restriction: $i \leq 99$

Default: Zero; temperature is not time dependent.

Use: Optional. Use with TMP card(s).

Note: The THTME card specifies the times at which the thermal temperatures on the TMP cards are provided. The times must be monotonically increasing. For each entry on the THTME card, there must be a TMP card.

5.4.5 Problem Cutoff Cards

5.4.5.1 CUT:<*PL*> TIME, ENERGY, AND WEIGHT CUTOFFS

Form: CUT*:*<*pl*> *t* *e* wc_1 wc_2 *swtm*

Table 5-38. Time, Energy, and Weight Cutoff Card (CUT*:<pl>*)

Input Parameter	Description
<*pl*>	Particle designator.
t	Time cutoff in shakes, 1 shake=10^{-8} sec.
e	Lower energy cutoff in MeV.
wc_1, wc_2	Weight cutoffs. If weight goes below wc_2 roulette is played to restore weight to wc_1. Setting wc_1=wc_2=0 invokes analog capture.
swtm	Minimum source weight.

Neutron default: *t*=very large, *e*=0.0 MeV, wc_1=-0.50, wc_2=-0.25, *swtm*=minimum source weight if the general source is used

Photon default: *t*=neutron cutoff, *e*=0.001 MeV, wc_1=-0.50, wc_2=-0.25, *swtm*=minimum source weight if the general source is used
If there are pulse-height tallies, wc_1=wc_2=0

Electron default: *t*=neutron cutoff, *e*=0.001 MeV, wc_1=0, wc_2=0, *swtm*=minimum source weight if the general source is used

Default energy cutoff values for all particles are provided in Table 4-1.

Use: Optional, as needed.

Note: If a particle's time becomes greater than *t* as specified for that particle, its transport is stopped and it is killed. Any particle with energy lower than the *e* specified for that particle is killed.

Note: If a neutron's weight WGT falls below wc_2 times the ratio R of the source cell importance to the current cell importance, then with probability WGT/(wc_1*R), the neutron survives and is assigned WGT=wc_1*R. If negative values are entered for the weight cutoffs, the values $|wc_1|*W_s$ and $|wc_2|*W_s$ will be used for wc_1 and wc_2, respectively, where W_s is the minimum starting weight assigned to a source neutron from an MCNPX general source. These negative entries are recommended for most problems. If only wc_1 is specified, then wc_2=0.5*wc_1.

Note: If wc_1 is set to zero, capture is treated explicitly by analog rather than implicitly by reducing the neutrons' weight according to the capture probability. If *ean*=*emax* on the PHYS:N card, analog capture is used regardless of the value of wc_1 except for neutrons leaving a DXTRAN sphere. The CUT:P weight cutoffs are analogous to those on the CUT:N card except that they are used only for energies above the *emcpf* entry on the PHYS:P card.

Note: To generate delayed particles from non-fissioning isotopes, wc_1 must be set to zero on both the photon and neutron CUT:<*pl*> cards so that analog capture is invoked.

Note: If *ean*=*emax* (neutrons or protons) on the PHYS card, analog capture is used regardless of the value of wc_1 except for neutrons leaving a DXTRAN sphere. For photons, the weight cutoffs are used only for energies above the *emcpf* entry on the PHYS:P card. For energies below *emcpf*, analog capture is the only choice with one exception: photons leaving a DXTRAN sphere.

Note: Positron physics is identical to electron physics, except for positron annihilation. Whereas electrons below the energy cutoff are terminated, positrons below the energy cutoff produce annihilation photons. The positrons have a positive charge and may be tallied using the FT card ELC option (Section 5.6.17).

Note: The parameter *swtm* can be used to make the weight cutoffs relative to the minimum starting weight of a source particle for a 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 as well. Then *swtm* is multiplied by the WGT entry on the SDEF card, but is unaffected by any directional or energy biasing.

5.4.5.2 ELPT CELL-BY-CELL ENERGY CUTOFF

Form: ELPT:<*pl*> x_1 x_2 ... x_j ...

Table 5-39. Cell-by-Cell Energy Cutoff Card (ELPT:<*pl*>)

Input Parameter	Description
<*pl*>	Particle designator.
x_j	Lower energy cutoff of cell j. Number of entries equals number of cells in problem.

Default: Cutoff parameters from CUT:<*pl*>

Use: Optional

Note: A separate lower energy cutoff can be specified for each cell in the problem. The higher of either the value on the ELPT:<*pl*> card or the global value *e* on the CUT:<*pl*> card applies.

5.4.6 Physics Models

Five cards (LCA, LCB, LCC, LEA, and LEB) control physics parameters for the Bertini, ISABEL, CEM03, INCL4, and FLUKA options.

These MCNPX input cards provide the user control of physics options. A summary of the cards follows. The options controlling the Bertini and ISABEL physics modules are taken from the User Guide to LCS™ [PRA89]. The user is referred to that document for further information.

All of the input values on the five cards have defaults, which will be taken in the absence of the cards, or with the use of the J input option.

The table that follows, shows how different combinations of physics models are possible using the third and ninth entries, *iexisa* [LCA(3)] and *icem* [LCA(9)], on the LCA card and the seventh entry, *ievap* [LEA(7)], on the LEA card:

	LCA(3)	LCA(9)	LEA(7)
Bertini/Dresner	1	0	0
ISABEL/Dresner	2	0	0
Bertini/ABLA	1	0	2
ISABEL/ABLA	2	0	2
CEM03	---	1	---
INCL4/Dresner	0	2	0
INCL4/ABLA	0	2	2

5.4.6.1 LCA

LCA is used to select the Bertini, ISABEL, CEM03, or INCL4 model, as well as to set certain parameters used in Bertini and ISABEL. CEM03 is a self-contained package with no user-adjustable options presently defined.

Form: LCA *ielas ipreq iexisa ichoic jcoul nexite npidk noact icem*

Table 5-40. LCA Input Description (LCA)

Input Parameter	Description
ielas	Controls elastic scattering. If *ielas*=0, then no nucleon elastic scattering. If *ielas*=1, then elastic scattering for neutrons only. If *ielas*=2, elastic scattering for neutrons and protons. (DEFAULT)
ipreq	Controls pre-equilibrium model. If *ipreq*=0, no pre-equilibrium model will be used. If *ipreq*=1, use pre-equilibrium model after intranuclear cascade. (DEFAULT) If *ipreq*=2 and if *iexisa*=0, select *ipreq*=1 and *ipreq*=3 randomly, with an energy-dependent probability that goes to *ipreq*=3 at low energies and to *ipreq*=1 at high incident energies. If *iexisa*≠0, defaults to *ipreq*=1. If *ipreq*=3 and if *iexisa*=0, use pre-equilibrium model instead of the intranuclear cascade. If *iexisa*≠0, defaults to *ipreq*=1.
iexisa	Controls model choice.† If *iexisa*=0, do not use ISABEL intranuclear cascade (INC) model for any particle. (DEFAULT if *icem*=2, which specifies the INCL4 model) If *iexisa*=1, use Bertini model for nucleons and pions and ISABEL model for other particle types. (DEFAULT) If *iexisa*=2, use ISABEL model for all incident particle types.

Input Parameter	Description
ichoic	Four integers (*ijkl*) that control ISABEL intranuclear cascade model. (DEFAULT=0023) If *i*=0, use partial Pauli blocking. (DEFAULT) If *i*=1, use total Pauli blocking. If *i*=-2, do not use Pauli blocking. (Not recommended) If *j*=0, no interaction between particles already excited above the Fermi sea. (DEFAULT) If *j*>0, *j* is the number of time steps to elapse between such "CAS-CAS" interactions. If *k*=0, use Meyer's density prescription with 8 steps. If *k*=1, use original (isobar) density prescription with 8 steps. If *k*=2, use Krappe's folded-Yukawa prescription for radial density in 16 steps, with a local density approximation to the Thomas-Fermi distribution for the (sharp cutoff) momentum distribution. (DEFAULT) If *k*=3, the choice is the same as *k*=0 but using the larger nuclear radius of the Bertini model. If *k*=4, the choice is the same as *k*=1 but using the larger nuclear radius of the Bertini model. If *k*=5, the choice is the same as *k*=2 but using the larger nuclear radius of the Bertini model. If *l*=1, perform reflection and refraction at the nuclear surface, but no escape cutoff for isobars. If *l*=2, perform reflection and refraction at the nuclear surface, with escape cutoff for isobars. If *l*=3, perform no reflection or refraction, with escape cutoff for isobars. (DEFAULT) If *l*=4, the choice is the same as *l*=1 but using a 25-MeV potential well for pions. If *l*=5, the choice is the same as *l*=2 but using a 25-MeV potential well for pions. If *l*=6, the choice is the same as *l*=3 but using a 25-MeV potential well for pions.
jcoul	Controls Coulomb barrier for incident charged particles. If *jcoul*=1, the Coulomb barrier is on. (DEFAULT) If *jcoul*=0, the Coulomb barrier is off.
nexite	Subtract nuclear recoil energy to get excitation energy. If *nexite*=1, this feature is on. (DEFAULT) If *nexite*=0, this feature is off.
npidk	If *npidk*=0, force π^- to interact by nuclear capture (INC) when cutoff is reached. (DEFAULT) If *npidk*=1, force π^- to terminate by decay at the pion cutoff energy.‡

Input Parameter	Description
noact	Particle transport options. If *noact*=−2, source particles immediately collide; all progeny escape. Used to compute and tally double-differential cross sections and residual nuclei with an F1 or F8 tally in conjunction with the FT RES option. If *noact*=−1, nuclear interactions of source particles only—transport and slowing down are off. Used to compute double-differential cross sections with XSEX code. (See Appendix D.) If *noact*=0, turn off all nonelastic reactions. If *noact*=1, perform normal transport. (DEFAULT) If *noact*=2, attenuation mode—transport primary source particles without nonelastic reactions.
icem	Choose alternative physics model. If *icem*=0, use the Bertini or ISABEL model determined by the *iexisa* parameter. (DEFAULT) If *icem*=1, use the CEM03 model. If *icem*=2, use INCL4 model (Default evaporation model is ABLA; see *ievap* on LEA card.)
ilaq	Choose light ion and nucleon physics modules. If *ilaq*=0, use LAQGSM to handle all heavy ion interactions as well as all light ion interactions above 940 MeV/nucleon. ISABEL will handle light ion interactions below this energy. Use FLUKA for protons and neutrons above the energy cutoff specified by parameters *flenb1* and *flenb2* on the LCB card . (DEFAULT) If *ilaq*=1, use LAQGSM to handle all heavy ion interactions as well as all light ion interactions. LAQGSM also replaces FLUKA for high energy proton and neutron reactions.

† The ISABEL INC model requires a much greater execution time. In addition, incident particle energies must be less than 1 GeV per nucleon for light ions (at higher energies, the LAQGSM model is automatically invoked).

‡ The capture probability for any isotope in a material is proportional to the product of the number fraction and the charge of the isotope. However, capture on ^{1}H leads to decay rather than interaction.

Note: If *noact*=−2 on the LCA card, table physics will be used whenever possible to get the differential data actually used in a given problem. To get the differential data with models only, table data can be turned off by setting the *tabl* parameter on the PHYS:N and/or PHYS:H cards.

Note: Bertini and ISABEL invoke the Dresner evaporation model with Rutherford Appleton Laboratory (RAL) fission by default. The fission model can be switched to the ORNL model using the *ievap* option on the LEA card. The evaporation model can be switched from Dresner to ABLA (with its built-in fission model) by setting *ievap*=2.

Note: Light ions (d, t, ^{3}He, alpha) are handled by ISABEL by default. Specifying *icem*=2 will instead send them to INCL.

Note: CEM03 allows neutrons and protons up to 5 GeV and pions up to 2.5 GeV to initiate nuclear reactions. CEM03 consists of an intranuclear cascade model, followed by a pre-equilibrium model and an evaporation model. Possible fission events are initiated in the equilibrium stage for compound nuclei with a charge number greater than 70. The evaporation/fission/fragmentation is handled mostly by the Generalized Evaporation/Fission Model (GEM2) [FUR00]. Fission fragments undergo an evaporation stage that depends on their excitation energy. After evaporation, a de-excitation of the residual nuclei follows, generating gammas using the PHT data.

Note The antinucleons and kaons are unaffected by the choice of physics models. They always choose ISABEL below the *flenb5* (see LCB card) and FLUKA above the *flenb6*. At energies intermediate to these two, a weighted random choice is made between the two models

5.4.6.2 LCB

Form: LCB *flenb1 flenb2 flenb3 flenb4 flenb5 flenb6 ctofe flim0*

Table 5-41. LCB Input Description (LCB)

Input Parameter	Description
flenb1	Kinetic energy. (DEFAULT=3500 MeV) For nucleons, the Bertini INC model will be used below this value.
flenb2†	Kinetic energy. (DEFAULT=3500 MeV) For nucleons, the FLUKA high-energy generator will be used above this value.
flenb3	Kinetic energy. (DEFAULT=2500 MeV) For pions, the Bertini INC model will be used below this value.
flenb4	Kinetic energy. (DEFAULT=2500 MeV) For pions, the FLUKA high-energy generator will be used above this value.
flenb5	Kinetic energy. (DEFAULT=800 MeV) For nucleons, the ISABEL INC model will be used below this value.
flenb6	Kinetic energy (DEFAULT=800 MeV) For nucleons, an appropriate model will be used above this value. For *iexisa*=2 *flenb6* applies to all particle types. For *iexisa*=1 *flenb6* applies to all particles except nucleons and pions. For *iexisa*=0 *flenb6* is immaterial. See the example following this table for further explanation.

Input Parameter	Description
ctofe	The cutoff kinetic energy (MeV) for particle escape during the INC when using the Bertini model. The cutoff energy prevents low-energy nucleons from escaping the nucleus during the INC; for protons, the actual cutoff is the maximum of *ctofe* and a Coulomb barrier. If *ctofe*≥0, *ctofe* will be used as the cutoff energy. If *ctofe*<0, a random cutoff energy, uniformly distributed from zero to twice the mean binding energy of a nucleon will be sampled for each projectile-target interaction and separately for neutrons and protons. In this case the Coulomb barrier for protons is also randomized. (DEFAULT=−1.0) For the ISABEL INC, the randomized cutoff energy is always used.
flim0	The maximum correction allowed for mass-energy balancing in the cascade stage, used with NOBAL=1 and NOBAL=3. If *flim0*>0, kinetic energies of secondary particles will be reduced by no more than a fraction of *flim0* in attempting to obtain a non-negative excitation of the residual nucleus and a consistent mass-energy balance. A cascade will be resampled if the correction exceeds *flim0*. If *flim0*=0, no correction will be attempted and a cascade will be resampled if a negative excitation is produced. If *flim0*<0, the maximum correction is 0.02 for incident energy above 250 MeV, 0.05 for incident energy below 100 MeV, and is set equal to 5/(incident energy) between those limits. (DEFAULT=−1.0)

† The probability for selecting the interaction model is interpolated linearly between *flenb1* and *flenb2*.

Note: The version of FLUKA used in MCNPX should not be used below 500 MeV/c (momentum).

Note: For nucleons, the Bertini model switches to a scaling procedure above 3.495 GeV, wherein results are scaled from an interaction at 3.495 GeV. Although both models will execute to arbitrarily high energies, a plausible upper limit for the Bertini scaling law is 10 GeV.

Note: LCB controls which physics module is used for particle interactions depending on the kinetic energy of the particle.

Example:

```
LCB   3000  3000  2000  2000  1000  1000
```

For *iexisa*=1, the default, nucleons will switch to the Bertini model from the FLUKA model below 3 GeV, and pions would switch below 2 GeV. Kaons and anti-nucleons would switch to the ISABEL model from the FLUKA model below 1 GeV. (Ions use only the ISABEL model and muons have no nuclear interactions.)

For *iexisa*=2, nucleons and pions would also switch to the ISABEL model below 1 GeV. Note that the upper energy threshold in ISABEL is 1 GeV/nucleon. No interactions are allowed at energies greater than this value.

5.4.6.3 LCC

Form: LCC *stincl v0incl*

Table 5-42. Input Description for INCL4 Options (LCC)

Input Parameter	Description
stincl	Rescaling factor of the cascade duration. (DEFAULT=1.0)
v0incl	Potential depth. (DEFAULT=45 MeV)

Note: The LCC card specifies control parameters for the INCL4 model and the ABLA fission-evaporation model. INCL4 is invoked by setting the ninth LCA card entry, *icem*, to 2, and ABLA is invoked by setting the seventh LEA card entry, *ievap*, to 2.

5.4.6.4 LEA

Form: LEA *ipht icc nobalc nobale ifbrk ilvden ievap nofis*

Table 5-43. LEA Input Description (LEA)

Input Parameters	Description
ipht	Control generation of de-excitation photons. If *ipht*=0, generation of de-excitation photons is off. If *ipht*=1, generation of de-excitation photons is on. (DEFAULT)
icc	Defines the level of physics to be applied for the PHT physics. If *icc*=0, use the continuum model. If *icc*=1, use the Troubetzkoy (E1) model. If *icc*=2, use the intermediate model (hybrid between *icc*=1 and *icc*=2). If *icc*=3, use the spin-dependent model. If *icc*=4, use the full model with experimental branching ratios. (DEFAULT)
nobalc	Controls mass-energy balancing in cascade.† If *nobalc*=0, use mass-energy balancing in the cascade phase. If *nobalc*=1, turn off mass-energy balancing in the cascade phase. (DEFAULT)

Input Parameters	Description
nobale	Controls mass-energy balancing in evaporation. If *nobale*=0, use mass-energy balancing in the evaporation stage. (DEFAULT) If *nobale*=1, turn off mass-energy balancing in the evaporation stage.
ifbrk	Controls Fermi-breakup model nuclide range. If *ifbrk*=1, use Fermi-breakup model for atomic mass number (A)≤13 and for 14≤A≤20 with excitation below 44 MeV. (DEFAULT) If *ifbrk*=0, use Fermi-breakup model only for atomic mass number (A)≤5.
ilvden	Controls level-density model. If *ilvden*=−1, use original HETC level-density formulation. See the LEB card for details on parameter inputs. If *ilvden*=0, use Gilbert-Cameron-Cook-Ignatyuk level-density model [PRA88]. (DEFAULT) If *ilvden*=1, use the Julich level-density parameterization as a function of mass number [CLO83].
ievap	Controls fission-evaporation model. If *ievap*=0, use the RAL fission evaporation model [ATC80]. (DEFAULT) If *ievap*=1, use the ORNL fission evaporation model [BAR81].‡ If *ievap*=2, use the ABLA fission evaporation model.
nofis	Controls fission. If *nofis*=1, allow fission. (DEFAULT) If *nofis*=0, suppress fission.

† Note: A forced energy balance may distort the intent of any intranuclear cascade model. Energy balancing for the INC is controlled by the input parameter *flim0*.

‡ Note: The ORNL model allows fission only for isotopes with atomic number (Z)≥91.

Note: LEA controls evaporation, Fermi-breakup, level-density parameters, and fission models. These are external to the particular intranuclear cascade/pre-equilibrium model chosen (Bertini, ISABEL, or INCL), and may be used with any of these choices (except CEM03).

Note: The Dresner evaporation model can invoke either the RAL or ORNL fission model using the *ievap* parameter.

5.4.6.5 LEB

Form: LEB *yzere* *bzere* *yzero* *bzero*

Table 5-44. LEB Input Descriptions (LEB)

Input Parameter	Description
yzere	The Y0 parameter in the level-density formula for atomic number (Z)≤70. (DEFAULT=1.5. Zero or negative is an error condition.) For target nuclei with Z≤70, the *bzere* and *yzere* parameters are used to compute level densities. The default values are those used in LAHET before installation of the ORNL fission model. For target nuclei with Z≥71, the *bzero* and *yzero* parameters are used to compute level densities for the target nucleus and fission fragments.
bzere	The B0 parameter level-density formula for atomic number (Z)≤70. (DEFAULT=8.0. Zero or negative is an error condition.) (See *yzere* above.)
yzero	The Y0 parameter in the level-density formula for atomic number (Z)≥71 and all fission fragments. (DEFAULT=1.5. Zero or negative is an error condition.) (See *yzere* above.)
bzero	The B0 parameter in the level-density formula for atomic number (Z)≥71 and all fission fragments. (DEFAULT=10.0 for *ievap*=0 and for *ievap*=1. Zero and negative is an error condition.) (See *yzere* above.)

This card controls level-density input options for the original HETC implementation. (*ilvden*=-1 on the LEA card)

5.4.7 FMULT Multiplicity Constants

Form: FMULT *zaid* [KEYWORD=*value(s) ...*]

Table 5-45. Multiplicity Constants (FMULT)

Input Parameter	Description
zaid	*zaid*=nuclide for which data are entered.
Keyword	**Value**
SFNU=*nu* or SFNU=x_1 x_2 ...	The value *nu* is the $\bar{\nu}$ for sampling spontaneous fission multiplicity from a Gaussian distribution with width *w*. The values x_1, x_2, ... provide the cumulative probability distribution of spontaneous fission multiplicity.
WIDTH=*w*	Gaussian width for sampling $\bar{\nu}$ for both spontaneous and induced fission. This value is ignored for spontaneous fission when SFNU is specified as a cumulative probability distribution.

SFYIELD=*y*	Spontaneous fission yield (n/s-g). Used for selecting the spontaneous fission nuclide when more than one is present in a material.
WATT=*a b*	Watt energy spectrum parameters *a* and *b* for spontaneous fission neutron energy sampling.

Use: Enables users to override or add additional fission multiplicity data.

Note: The parameter, *zaid*, must be specified. Defaults exist only for the most common fission nuclei; these defaults are provided in `print table 38` of the MCNPX output [HEN04a, SAN04, HOL84, ENS98, ZUC83, HOL85, HIC56, CRA56, BOL85, DIV56].

Note: Fission widths, Watt fission spectra parameters, and fission yields are not available for the following nuclides, which have no transport cross sections: ^{246}Cf, ^{254}Cf, ^{257}Fm, and ^{252}No. Neither are they available for ^{246}Pu, ^{246}Cm, ^{248}Cm, and ^{250}Cf. To have a spontaneous fission source for these nuclides, a `FMULT` data card is required. For example,

```
FMULT 96246  WIDTH = 1.1  WATT = .2 4  SFYIELD 1
```

Because the multiplicities are provided as a table with 10 bins, the width is ignored for the spontaneous fission source; however, a value is still required for induced fission. For spontaneous fission, the energy distribution is sampled from the two Watt-fission spectra parameters; for induced fission, the energy spectra is chosen from parameters in the nuclear data tables of the transport cross sections. Finally, the spontaneous fission yield must be specified if more than one spontaneous fission source nuclide occurs. The yield is used to determine the relative sampling among spontaneous fission source nuclides. These parameters have no default values; if the `FMULT` card is missing, a fatal error message is issued.

Note; The data that follow are the default values [SAN04] of the multiplicity parameters in MCNPX; these can be modified with the `FMULT` card. The spontaneous fission multiplicity table values are displayed in `print table 38` to three-digits, but are accurate to seven digits in MCNPX.

```
1fission multiplicity data.                                                    print table 38

    zaid  width    watt1    watt2     yield   sfnu

   90232  1.079  .800000  4.00000  6.00E-08  2.140
   92232  1.079  .892204  3.72278  1.30E+00  1.710
   92233  1.041  .854803  4.03210  8.60E-04  1.760
   92234  1.079  .771241  4.92449  5.02E-03  1.810
   92235  1.072  .774713  4.85231  2.99E-04  1.860
   92236  1.079  .735166  5.35746  5.49E-03  1.910
   92238  1.230  .648318  6.81057  1.36E-02  0.048  .297  .722  .950  .993  1.00  1.00  1.00  1.00 1.
   93237  1.079  .833438  4.24147  1.14E-04  2.050
   94236  0.000  .000000  0.00000  0.00E+00  0.080  .293  .670  .905  .980  1.00  1.00  1.00  1.00 1.
   94238  1.115  .847833  4.16933  2.59E+03  0.056  .267  .647  .869  .974  1.00  1.00  1.00  1.00 1.
   94239  1.140  .885247  3.80269  2.18E-02  2.160
```

```
  94240  1.109  .794930  4.68927  1.02E+03  0.063  .295  .628  .881  .980  .998  1.00  1.00  1.00 1.
  94241  1.079  .842472  4.15150  5.00E-02  2.250
  94242  1.069  .819150  4.36668  1.72E+03  0.068  .297  .631  .879  .979  .997  1.00  1.00  1.00 1.
  95241  1.079  .933020  3.46195  1.18E+00  3.220
* 96242  1.053  .887353  3.89176  2.10E+07  0.021  .168  .495  .822  .959  .996  .999  1.00  1.00 1.
  96244  1.036  .902523  3.72033  1.08E+07  0.015  .131  .431  .764  .948  .991  1.00  1.00  1.00 1.
  96246  0.000  .000000  0.00000  0.00E+00  0.015  .091  .354  .699  .917  .993  1.00  1.00  1.00 1.
  96248  0.000  .000000  0.00000  0.00E+00  0.007  .066  .287  .638  .892  .982  .998  1.00  1.00 1.
  97249  1.079  .891281  3.79405  1.00E+05  3.400
  98246  0.000  .000000  0.00000  0.00E+00  0.001  .114  .349  .623  .844  .970  1.00  1.00  1.00 1.
  98250  0.000  .000000  0.00000  0.00E+00  0.004  .040  .208  .502  .801  .946  .993  .997  1.00 1.
  98252  1.207 1.180000  1.03419  2.34E+12  0.002  .028  .153  .427  .733  .918  .984  .998  1.00 1.
  98254  0.000  .000000  0.00000  0.00E+00  0.000  .019  .132  .396  .714  .908  .983  .998  1.00 1.
 100257  0.000  .000000  0.00000  0.00E+00  0.021  .073  .190  .390  .652  .853  .959  .993  1.00 1.
 102252  0.000  .000000  0.00000  0.00E+00  0.057  .115  .207  .351  .534  .717  .863  .959  .997 1.

* = used in problem.
```

All of the available data are presented in `print table 38`. Data actually used are denoted by an *. If any data are overridden by `FMULT` user input, the user data replaces the default data shown in `print table 38`.

Example 1:

```
FMULT  98252  SFYIELD=2.34e12  SFNU=0.002 0.028 0.155 0.428 0.732 0.917
       0.983 0.998 1.0  WIDTH=1.207  WATT=1.18 1.03419
```

Example 2:

```
FMULT  94239  WATT=0.885247 3.8026  WIDTH=1.14 SFYIELD=0.0218 SFNU=2.1
```

Example 3:

```
M123          100257   1.0
AWTAB         100257   257.
MX123:N       29252
```

Nuclear cross-section tables for transporting ^{246}Cf, ^{254}Cf, ^{257}Fm, and ^{252}No are not generally available. To model spontaneous fission from these nuclides, it is necessary to do the transport either with a physics model or by substituting cross sections. Physics models are not recommended at fission energies. To make a nuclide substitution, the `AWTAB` and `MX` cards must be used. The `AWTAB` card provides the atomic weight ratio for ^{257}Fm, which is not provided in the standard MCNPX data libraries. The `MX123:N` card in this example substitutes ^{252}Cf, for which there are neutron cross-section data, for the corresponding nuclide (100257) on the `M123` material card.

5.5 SOURCE SPECIFICATION

SDEF, SI, SP, SB, DS, SC, KCODE, KSRC, BURN, SSW, SSR, SOURCE, SRCDX

Every MCNPX problem has one of four sources: general source (SDEF card), criticality source (KCODE card), surface source (SSR card), or user-supplied source. All can use source distribution functions, specified on SI, SP, SB, and DS cards.

5.5.1 SDEF General Source Definition

Form: SDEF KEYWORD=*value(s) ...*

Table 5-46. General Source Variables (SDEF)

Keyword	Value
CEL	Cell number. [DEFAULT: Determined from XXX, YYY, ZZZ (the position of the particle), and possibly UUU, VVV, WWW (the direction of the flight of the particle)].
SUR	Surface number. [DEFAULT: SUR=0, which indicates a cell (volume) source] Always required when source points lie on the boundary (surface) of a cell.
ERG†	Energy (MeV). (DEFAULT: ERG=14)
TME	Time (shakes). (DEFAULT: TME=0)
DIR	μ, the cosine of the angle between VEC and UUU, VVV, WWW. (Azimuthal angle is always sampled uniformly in 0° to 360°.) (DEFAULT for volume source: μ is sampled uniformly in -1 to 1, i.e., the source is isotropic.) (DEFAULT for surface source: $p(\mu)=2\mu$ in 0 to 1 , i.e., cosine distribution.)
VEC	Reference vector for DIR in vector notation. (DEFAULT for volume source: Required unless source is isotropic.) (DEFAULT for surface source: Vector normal to the surface with sign determined by NRM.)
NRM	Sign of the surface normal. (DEFAULT: NRM=+1)
POS	Reference point for position sampling in vector notation. (DEFAULT POS=0,0,0)
RAD	Radial distance of the position from POS or AXS. (DEFAULT: RAD=0)
EXT	For a volume source is the distance from POS along AXS. For a surface source is the cosine of angle from AXS. (DEFAULT: EXT=0)
AXS	Reference vector for EXT and RAD in vector notation. (DEFAULT: No direction)

Keyword	Value
X	X-coordinate of position. (DEFAULT: X=0)
Y	Y-coordinate of position. (DEFAULT: Y=0)
Z	Z-coordinate of position. (DEFAULT: Z=0)
CCC	Cookie-cutter cell. (DEFAULT: no cookie-cutter cell)
ARA	Area of surface. (Required only for direct contributions to point detectors from plane surface source.) (DEFAULT: none)
WGT	Particle weight (input as explicit value only). (DEFAULT: WGT=1)
TR	Source transformation number. A corresponding TR card is required. (Section 5.2.3.7)
EFF	Rejection efficiency criterion for position sampling (input as explicit value only). (DEFAULT: EFF=0.01)
PAR	Source particle type(s) by symbol or number (e.g., PAR=H or PAR=9). Add negative sign for antiparticle and use a distribution for sampling multiple particle types. To specify a particular heavy ion as a source particle, set PAR to ZZZAAA, where ZZZAAA is the isotope identifier of the ion. Spontaneous Fission (see note below) If PAR=SF, normalize summary and tally information by the number of spontaneous-fission neutrons. If PAR=-SF, normalize summary and tally information by the number of histories (generally, the number of spontaneous fissions). (DEFAULT: If no MODE card, PAR=N.) (DEFAULT: If MODE card in INP file, lowest IPT number or symbol represented on MODE card.)

† 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.

Use: Required for problems using the general source. Optional for problems using the criticality source. An equals sign (=) following a keyword is optional.

Note: The specification of a source variable has one of the following three forms:

1. an explicit value, in which a single, explicit value is given for the specified variable (e.g., CEL=1);

2. a distribution number, *n*, prefixed by a D, in which the specified source variable may have multiple values that will be sampled from distribution SI. (E.g., CEL=D1 indicates that multiple cell numbers will appear on the SI1 card and will be sampled using probabilities entered on the associated SP1 card.); or
3. the name of another variable prefixed by an F, followed by a distribution number prefixed by a D. (E.g., CEL=FPOS=D1 indicates that the cell specification will depend on the position(s) specified on the SI1 card.) None of the position-related keywords (i.e., CEL, SUR, RAD, AXS, EXT, X, Y, Z, and CCC) can be a dependent distribution of POS.

Note: If the source location is on any surface (including "extended" surfaces) used to describe the cell that contains that source, the SUR keyword must be used. A source can lie on an extended surface used to describe any other cell of the problem.

Note: If a source transformation (or distribution of transformations) is specified, the transformation is applied to the particle after its coordinates and direction cosines have been determined. Particle coordinates are modified by both rotation and translation; direction cosines are modified by rotation only. The source transformation capability allows the user to rotate the direction of an accelerator beam or move the entire beam of particles in space.

Note: Sources may be translated to different locations with the TR option. This capability is most useful for setting up the source as an accelerator beam and then using the translation as a distribution to repeat the accelerator source at different locations and orientations. The TR option can be dependent on other source variables. For example, the particle type can depend on the translated source location:

```
SDEF    CEL=FTR=D3   PAR=FTR=D1   TR=D2    ,
```

or the translated source location can be a dependent distribution function of cell:

```
SDEF    CEL=D2       TR=FCEL=D5
```

Note: The source variables POS, RAD, EXT, AXS, X, Y, and Z 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 SI and DS cards.

Volume source information:

A volume distribution can be used in combination with the CEL or CCC keywords 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 MCNPX has no way of checking for this. Cookie-cutter (CCC) rejection can be used instead of or in combination with CEL rejection.

A Cartesian volume distribution is specified with the keywords X, Y, and Z. A degenerate case of the Cartesian distribution, in which the three variables are constants, defines a point source. Other degenerate cases of the Cartesian distribution are a line source and a rectangular plane source.

A spherical volume distribution is specified with the keywords POS and RAD. The keywords X, Y, Z, and AXS *must not* be specified or the distribution will be assumed to be Cartesian or cylindrical. 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 case. If RAD is not specified, the default is zero. This is useful because it specifies a point source at the position POS.

A cylindrical volume distribution is specified with the keywords 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 useful degenerate case is EXT=0, which provides a source with circular symmetry on a plane.

Caution: Never position any kind of degenerate volume distribution on a defined surface of the problem geometry.

Surface source information:

The value of the keyword SUR is nonzero for a distribution on a surface. The shape of the surface can be a spheroid, sphere, cylinder, or plane. If X, Y, and Z are specified, their sampled values determine the position. If X, Y, and Z are not specified, the position is sampled on the surface SUR. With the exception of a spherical surface, the SUR keyword does not automatically provide source points on the listed surface. The user must still use the X, Y, Z, POS, AXS, RAD, and EXT keywords to ensure the source points actually lay on the prescribed surface.

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. There is no provision for easy nonuniform or biased sampling on a spheroidal surface.

If the value of SUR is the name of a spherical surface, the position of the particle is sampled on that surface. A spherical surface source does not have to be on a cell-bounding problem 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°. 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 keyword DIR may be specified without VEC, allowing VEC to default to the outward surface normal.

If the value of SUR is the name of a plane, the position is sampled on that plane. The sampled value of POS must be a point on the plane. 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.

For a cylindrical surface source, the cylindrical surface can be, but does not have to be, a cell-bounding problem surface specified by the keyword SUR. If the cylindrical surface is a problem surface, then the surface number must be specified on the SDEF card with the SUR keyword. The default of VEC is the surface normal. If both DIR and VEC are specified, then particle directions are relative to VEC rather than to the cylindrical surface normal. DIR may be specified without VEC, causing VEC to default to the outward surface normal.

Note: Cookie-cutter rejection is available for both cell and surface sources. If CCC is present, the sampled position is accepted if it is within cell CCC and is resampled if it is not. It is suggested that cookie-cutter cells are bounded by surfaces used for no other purpose in the problem and that the cookie-cutter cell cards appear at the end of the list of cell cards. The efficiency criterion EFF applies to both CCC and CEL rejection. *Caution*: The combination of either CEL or CCC rejection with biased sampling of the position is nearly always an *unfair game*.

Note: When the source is specified in a repeated structure part of the geometry, the CEL parameter on the SDEF card must have a value that is a path from level 0 to level *n*, which is not necessarily the bottom level:

CEL=(c_0<c_1<...<c_n)

where c_i is a cell in the universe that fills cell c_{i-1}, or is zero, or is D*m* for a distribution of cells in the repeated structure case. D*m* is not valid for a lattice. If c_i=0, the cell at that level is searched for. If c_i is one specific element in a lattice, it is indicated as

...<c_i[i j k]<...

A lattice cell without indices results in uniform sampling in all elements if a fully specified FILL card is provided.

Spontaneous fission sources—physics and tally normalization:

Note: Eighteen nuclides are available for a spontaneous fission source (PAR=SF): ^{232}Th, ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{242}Cm, ^{244}Cm, ^{249}Bk, and ^{252}Cf.

If more than one spontaneous-fission nuclide are present in a source cell, the fissioning nuclide will be chosen proportionately to the product of its atom fraction and the spontaneous-fission yield for each nuclide. If no spontaneous-fission nuclide is found in a specified source cell, the code exits with a BAD TROUBLE error, "spontaneous fission impossible."

The number of spontaneous-fission neutrons then is sampled. The spontaneous-fission multiplicity data of Santi [SAN04] and references cited by him are used. The energies are sampled from a Watt spectrum with appropriate spontaneous-fission parameters for the selected nuclide. Only the first spontaneous-fission neutron from each history is printed. If the spontaneous fission samples a multiplicity of zero—that is, no neutrons for a given spontaneous fission—then the history is omitted from the first 50 history lists of print table 110. The number of source particles is the number of spontaneous-fission neutrons, which will be $\bar{\nu}$ times the requested number of source histories on the NPS card.

Fission multiplicity for induced fissions (6th entry on the PHYS:N card) automatically is turned on with the default width (*fism*=-1=nuclide dependent). If *fism*>0 on the PHYS:N card, then that value will be used.

The spontaneous fission source is different from most other SDEF fixed sources. Let

N = *nps* = the number of source-particle histories run in the problem,
W = the average source particle weight, and
$\bar{\nu}$ = the average number of spontaneous fission neutrons per fission.

For most other fixed-source (SDEF) problems,

summary table source tracks = N,
summary table source weight = W, and
summary tables and tallies are normalized by N.

For the spontaneous fission source, SDEF PAR=SF,

summary table source tracks = $\bar{\nu} \cdot \mathrm{N}$,
summary table source weight = W, and
summary tables and tallies are normalized by $\bar{\nu} \cdot \mathrm{N}$, the number of spontaneous fission neutrons.

For the spontaneous fission source, SDEF PAR=-SF,

summary table source tracks = $\bar{\nu} \cdot \mathrm{N}$
summary table source weight = $\bar{\nu} \cdot \mathrm{W}$, and
summary tables and tallies are normalized by N, the number of spontaneous fissions.

Example 1:

```
SDEF
```

This card specifies a 14-MeV isotropic point source at position 0,0,0 at time 0 with weight 1 (all defaults).

Example 2:

```
SDEF   PAR=SF CEL=D1 POS=D2 RAD=FPOS=D3
```

Spontaneous-fission source in which source points will be started from within defined spheres (POS, RAD) and limited to fission cells by CEL. Each sampled source point will be a spontaneous-fission site (PAR=SF) producing the appropriate number of spontaneous-fission neutrons per fission at the appropriate energy with isotropic direction.

Example 3:

```
SDEF   CEL=D3  POS=0 6 0  EXT=D1  RAD=D2  AXS= 0 1 0
SI3    L (1<10[0 0 0]<11) (1<10[1 0 0]<11) (1<10[2 0 0]<11)
         (1<10[0 1 0]<11) (1<10[1 1 0]<11) (1<10[2 1 0]<11)
```

The SDEF card creates a cylindrical volume source oriented along the y-axis with radius specified by the SI2 source information and SP2 source probability cards and extent given by SI1 and SP1. This CEL source specification for repeated-structures geometries is consistent with the repeated-structures tally format. The old-style format (listing cells in the opposite order separated by ":") is still recognized.

Example 4:

```
SDEF   PAR=D1  POS FPAR D2  ERG FPAR D3
SI1   L  H N
SP1      2 1
SB1      1 2
```

```
DS2   L  0 0 0  15 0 0
DS3   L  2 3

SDEF   PAR=FPOS D2  POS=D1  ERG FPOS D3
SI1   L  0 0 0  15 0 0
SP1      2 1
SB1      1 2
DS2   L  h n
DS3   L  2 3
```

The first source definition above defines the source particle type, PAR, as the independent variable; while in the second source definition, the source particles specified by PAR depend on the source positions (POS). Both approaches result in the same source distributions.

Note the following when using a distribution specification for the PAR keyword:

1. The characters L, A, H, S, Q, and T are reserved as SI and DS card options. L=discrete source variables, S=distribution numbers, etc. If the first entry on the SI or DS card is L, A, H, S, Q, or T, it will be interpreted as a distribution option. To list source particles types L, A, H, S, Q, or T, either the corresponding particle numbers (10, 33, 30, 27, or 32) must be used or L, A, H, S, Q, or T must appear as the second or later particle type. Generally, it is best to specify the discrete source variable option; therefore, L will be the first entry, followed by the particle types. A second L will be interpreted correctly as particle type L. For example,

   ```
   SI99  L  -H  N  L  Q  F  T  S
   ```

2. Antiparticles may be designated, as usual, with negative entries:

   ```
   SI77  L  -E  N  -H
   ```

3. Either characters (N, P, E, H, D, S, T, A, etc.) or numbers (1, 2, 3, 9, 31, 32, 33, 34, etc.) may be used. For example,

   ```
   SI98  L  -H  3  -32  N
   ```

4. Spontaneous fission may be used as a particle type. For example,

   ```
   SI87  L  SF  N
   ```

5. Particle types may be listed multiple times to give them different energy distributions, angular distributions, etc., in different parts of the problem. For example:

   ```
   SI23  L  N  n  1  n  N
   ```

6. Heavy ions may be specified using the appropriate ZZZAAA identifier for individual ions. Multiple heavy ions may be specified for the source using a distribution.

Dependent distributions can be used to specify different energies for different heavy ions. Heavy ion particle energy should be input as total energy, **not** energy/nucleon.

7. Tallies are normalized by dividing the total source weight by the number of source histories. Note that weight (WGT on the SDEF card) cannot be a source distribution (either independent or dependent). The weight of particles in the summary tables is controlled by the SI, SP, SB, and DS cards for the particle distribution. For Example 4 above, this normalization procedure is described as follows:

   The total source weight is WGT=1.0 by default. From the SP1 card, the weight of the neutrons that are produced is 0.3333 and the weight of protons that are produced is 0.6667. From the SB1 card, the total number of neutron tracks is $0.6667 \times nps$ for neutrons and $0.333 \times nps$ for protons (where *nps* is the number of source histories actually run). The energy per source particle is normalized to the source particle weight for each source particle type. If the particle type is not a source particle (e.g., photons in the above problem), then the energy per source particle is normalized to the source particle weight of the lowest particle type. In this example, photon source energy would be normalized in the photon creation-and-loss table by 0.3333, which is the weight of the source neutrons produced.

   Example 5:

```
SDEF   DIR=1  VEC=0 0 1  X=D1  Y=D2  Z=0  CCC=99  TR=1
SP1    -41  fx  0
SP2    -41  fy  0
TR1    x0 y0 z0   cosθ -sinθ 0   sinθ cosθ 0   0 0 1
```

   The SDEF card sets up an initial beam of particles traveling along the z-axis (DIR=1, VEC=0 0 1). Information on the x- and y-coordinates of particle position is detailed in the two SP cards. The z-coordinate is left unchanged. The first entry on the SP cards is −41, indicating sampling from a built-in Gaussian distribution. The second SP card entry is the full width half maximum (FWHM) of the Gaussian in either the x-or y-direction. This value must be computed for the x- and y-axes by the user as follows: $f_x = (8\ln 2)^{1/2} a = 2.35482a$ and $f_y = (8\ln 2)^{1/2} b = 2.35482b$. The third entry represents the centroid of the Gaussian in either the x- or y-direction. It is recommended the user input zero for this third entry and handle any transformations of the source with a TR card. The specification of the cookie-cutter cell 99 for source rejection prevents the beam Gaussian from extending infinitely. The TR card performs a rotation of the major axis of the source distribution. Other beam examples appear in Appendix E.

   Example 6:

```
SDEF  POS=0 0 0  RAD=1  EXT=D1  AXS=1 0 0  SUR=5
SDEF  POS=0 0 0  RAD=1  EXT=D1  AXS=1 0 0  SUR=5  DIR=D2
```

```
SDEF  POS=0 0 0  RAD=1  EXT=D1  AXS=1 0 0  DIR=D2
```

The first SDEF card specifies a cylindrical source on surface 5 with default cosine distribution relative to the surface normal. The second SDEF card specifies a cylindrical source on surface 5 with a specified angular distribution that is relative to the cylindrical surface normal. The third SDEF source specification is similar except that a degenerate volume source is used to specify the cylindrical surface source (i.e., omitting the SUR keyword) with a specified angular distribution relative to the surface normal.

Example 7:

```
SDEF    PAR=D1
SI1 L   1  9  3006  26056  92238
SP1     1  1   0.1    0.3    0.5
```

Five different source particles are sampled in this example: neutrons; protons; and the three heavy ions—^{6}Li, ^{56}Fe, and ^{238}U. The relative sampling frequency is given by the probability parameters on the SP1 card.

5.5.1.1 SI SOURCE INFORMATION

Form: SI*n* *option* $i_1 \ldots i_k$

Table 5-47. Source Information Card (SI)

Input Parameter	Description
n	Distribution number from corresponding distribution number on SDEF card. Restriction: $1 \le n \le 999$
option	Determines how the i values are interpreted. If *option* is absent or *option*=H, i values are monotonically increasing histogram bin upper boundaries (scalar only). (DEFAULT) If *option*=L, i values are discrete source variable values (e.g., cell numbers or energies of photon spectrum lines). If *option*=A, i values are points where a probability density is defined. Entries must be monotonically increasing, with the lowest and highest values defining the range of the variable. If *option*=S, i values are distribution numbers.
$i_1 \ldots i_k$	Source variables or distribution numbers

Default: SI*n* H $i_i \ldots i_k$

Note: The S option on the SI card 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. MCNPX can handle this structure to a depth of about 20. 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.

Note: In a multiple-source-particle problem, the "energy per source particle" given in the summary tables is normalized to the source particle weight for each source particle type. If the particle type is not a source particle (listed on the MODE card, but not on SDEF), then the "energy per source particle" is normalized to the source particle weight of the lowest particle type.

5.5.1.2 SP SOURCE PROBABILITY

Form 1: SP*n* *option* $p_1 \ldots p_k$
Form 2: SP*n* *-f a b*

Table 5-48. Source Probability Card (SP)

Input Parameter	Description
n	Distribution number from corresponding distribution number on SDEF and SI cards. Restriction: $1 \le n \le 999$
option	Determines how the *p* values are interpreted. If *option* is absent, it is the same as D for an H or L on the SI card or probability density for an A distribution on the SI card. If *option*=D, *p* values are bin probabilities for an H or L distribution. (DEFAULT) If *option*=C, *p* values are cumulative bin probabilities for an H or L distribution. If *option*=V, *p* values are for cell distributions, probability is proportional to cell volume ($\times p_k$ if p_k are present).
$p_1 \ldots p_k$	Source variable probabilities. Restriction: Must be zero for 1st histogram bin
-f	Designator (negative number) for a built-in function.
a b	Parameters for the built-in function. (Refer to Table 5-49 and Appendix H.)

Default: SP*n* D $p_1 \ldots p_k$

Note: When the H option is used on the SI card, the first numerical entry on the corresponding SP card must be zero.

Note: Probabilities on the SP card need not be normalized.

Note: When the A option is used on the SI card, the numerical entries on the associated SP card are values of the probability density corresponding to the values of the variable on the SI card. The values need not be normalized. This set of SI and SP values creates a curve from which intermediate values are linearly interpolated. The first and last entries on the SP card will typically be zero, but nonzero values are allowed.

Note: When the L option is used on the SI card, the entries on the associated SP card are either probabilities or cumulative probabilities of those discrete values.

Note: 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.

Note: 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.

Table 5-49. Special Source Probability Functions

Keyword	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 or X,Y,Z	-41 a b	Gaussian distribution of time, t, or of position coordinates x, y, z (for beam sources)

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

f = −3 Watt fission energy spectrum: $p(E) = C\exp(-E/a)\sinh(bE)^{1/2}$.

Default: a =0.965 MeV, b =2.29 MeV^{-1}. See Appendix H for additional parameters appropriate to neutron-induced fission in various materials and for spontaneous fission.

f = −4 Gaussian fusion energy spectrum: $p(E) = C\exp\left[-\left((E-b)/a\right)^2\right]$, 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 (FWHM) but is related to it by $FWHM = 2a(\ln 2)^{1/2}$.

Default: a =-0.01 MeV, b =-1 (DT fusion at 10 keV).

f = −5 Evaporation energy spectrum: $p(E) = CE\exp(-E/a)$.

Default: a =1.2895 MeV.

f = −6 Muir velocity Gaussian fusion energy spectrum: $p(E) = C\exp-\left[\left(E^{1/2}-b^{1/2}\right)/a\right]^2$, 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.

Default: a =-0.01 MeV, b =-1 (D-T 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. 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 SUR≠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: $p(t) = c\exp\left[-(1.6651092(t-b)/a)^2\right]$, 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.

Default: a =no default, b =0.

The built-in functions can be used only for the variables shown in Table 5-49. 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.

5.5.1.3 SB SOURCE BIAS

Form 1: SB*n* *option* b_1 ... b_k

Form 2: SB*n* *-f a b*

where *n*, *option*, *f*, *a*, and *b* are the same as for the SP card, except that the only values allowed for *f* are −21 and −31, and the b_1 ... b_k are source-variable-biased probabilities.

Default: SB*n* D b_1 ... b_k

Note: 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.

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 MCNPX.
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.

5.5.1.4 DS DEPENDENT SOURCE DISTRIBUTION

Form 1: DS*n* *option* j_1 ... j_k

Form 2: DS*n* T i_1 j_1 ... i_k j_k

Form 3: DS*n* Q v_1 s_1 ... v_k s_k

Table 5-50. Dependent Source Distribution Card (DS)

Input Parameter	Description
n	Distribution number. Restriction: 1≤*n*≤999
option	Determines how the *j* values are interpreted. If *option* is absent or *option*=H, source variable values in continuous distribution, for scalar variables only. (DEFAULT) If *option*=L, discrete source variable values follow. If *option*=S, distribution numbers follow.
T	Values of the dependent variable (j_i) follow values of the independent variable (i_i), which must be a discrete scalar variable.
i_i	Values of the independent variable.
j_i	Values of the dependent variable.
Q	Distribution numbers (s_i) follow values of the independent variable (v_i), 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 ... j_k

Note: 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. MCNPX 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.

Note: The first form of the DS card has several possibilities. If the SI card of the independent variable has a histogram distribution of m bins (m+1 entries) and the DS card has the blank or H option, the DS card must have m+1 entries to specify m 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.

Note: If the L or S option is used on the DS card, m entries are required to specify m discrete values (for all options on the independent variable except H). (See the note that follows for a histogrammed independent variable.) It is not necessary for the distributions of the independent and dependent variables to be both discrete or both continuous. All combinations work correctly.

Note: If the S option is used on the DS card and the independent variable has a histogram defined by m+1 SI entries, then m numbers must appear on the DS card. Recall that the first bin of a histogram distribution must have an SP value of 0.0. The code will assume that the first independent histogram bin is ignored. A fatal error will result if a dependent source value is assigned to the first histogram bin.

Note: 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.

Note: 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 s_i is sampled for the value of the dependent variable. The value of v_i 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.

5.5.1.5 SC SOURCE COMMENT

Form: SC*n comment*

where *n* is a distribution number such that $1 \le n \le 999$, and *comment* is user-supplied text describing the source.

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 to be part of the comment, not a continuation command.

Default: *comment* absent.

5.5.2 KCODE Criticality Source

Form: KCODE *nsrck rkk ikz kct msrk knrm mrkp kc8*

Table 5-51. Criticality Source Card (KCODE)

Input Parameter	Description
nsrck	Number of source histories per cycle. (DEFAULT=1000)
rkk	Initial guess for k_{eff}. (DEFAULT=1.0)
ikz	Number of cycles to be skipped before beginning tally accumulation. (DEFAULT=30)
kct	Number of cycles to be done. (DEFAULT=*ikz*+100)
msrk	Number of source points for which to allocate storage. (DEFAULT=4500 or 2 × *nsrck*)
knrm	Controls normalization of tallies. If *knrm*=0, normalize tallies by weight. (DEFAULT) If *knrm*=1, normalize tallies by number of histories.
mrkp	Maximum number of cycle values on MCTAL or RUNTPE. (DEFAULT=6500)
kc8	Controls the number of cycles over which summary and tally information are averaged. If *kc8*=0, average over all cycles. If *kc8*=1, average over active cycles only. (DEFAULT)

Defaults: KCODE 1000 1.0 30 (*ikz* + 100) (4500 or 2 × *nsrck*) 0 6500 1

Use: Required for criticality calculations.

Note: The KCODE card specifies the MCNPX criticality source that is used for determining k_{eff}. The criticality source uses total fission $\bar{\nu}$ 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.

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.

5.5.3 KSRC Source Points for KCODE Calculation

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

where x_i, y_i, and z_i are the locations of the 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. MCNPX will start approximately (*nsrck* /number of points) particles at each point. Usually one point in each fissile region is adequate, because MCNPX 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 MCNPX, with a =0.965 MeV, b =2.29 MeV^{-1}.

5.5.4 BURN Depletion/Burnup

Form: BURN KEYWORD=*value(s)* ...

Table 5-52. Depletion/Burnup (BURN)

Keyword	Value
TIME=t_1 t_2...	Incremental time duration t_i for each successive burn step. Time unit is days. (DEFAULT: one time step lasting one day)
PFRAC=f_1 f_2 ...	Fraction f_i of total system power (POWER) applied to burn step t_i. Caution: If only a single PFRAC value (f_1) is provided, but multiple time steps (t_i) are specified, the first time step (t_1) will be assigned a power fraction of f_1; subsequent time steps will have a power fraction of 0. (DEFAULT: f_i=1.0 for all t_i.)
POWER	Total recoverable fission system power (MW). (DEFAULT: POWER=1.0)
MAT=m_1 m_2 ...	Material number m_i of material to be burned. Corresponds identically to material number specified on a material specification card Mm. (DEFAULT: burn all materials) If m<0, then recoverable energy per fission and neutrons per fission are computed and contribute to the power normalization, but the material is not burned. (WARNING: If you have duplicate ZAIDs on an M card of a material to be burned, wrong answers can result. MCNPX will *not* give you a warning in this instance.)
OMIT= m_1 n_1 j_{11} j_{12} ... j_{1n_1} m_2 n_2 j_{21} j_{22} ... j_{2n_2}	For each specified material number, m_i, omit the following n_i isotopes from the transport calculation: j_{i1} j_{i2} … j_{in_i}. Each j_{in_k} must be provided in the form ZZZAAA, where ZZZ is the isotope's atomic number and AAA is its atomic mass number.
AFMIN= af_1 af_2	af_1=Atom fraction below which an isotope will no longer be tracked in the transport calculation. If the atom fraction of an isotope falls below this limit, the atom fraction is set to 0. (DEFAULT: af_1=1.0E-10) af_2=Transmutation chain convergence criteria used in CINDER90. (DEFAULT: af_2=1.0E-10)

Keyword	Value
BOPT=b_1 b_2 b_3	b_1=Q value multiplier. (DEFAULT: b_1=1.0) The parameter b_2 is used to control the ordering and content of the output and is the additive result of two integer values: b_2=I1+I2. The first value, I1, selects among three tiers (see Table 5-53) of fission product content: If I1=0, include only Tier 1 fission products. (DEFAULT) If I1=10, include Tier 2 fission products, which comprise all fission products listed in the XSDIR cross-section directory of MCNPX 2.5.0. If I1=20, include Tier 3 fission products, which comprise fission products in ENDF/B-VII.0 that have CINDER90 yield information. The second value, I2, selects among four ordering options: If I2=1, order output inventory high to low based on mass. (DEFAULT) If I2=2, order output inventory high to low based on total activity. If I2=3, order output inventory high to low based on specific activity. If I2=4, order output inventory based on increasing ZZZAAA. If b_2>0, output will be printed at end of job only. (DEFAULT) If b_2<0 output will be printed at end of each burn step. The parameter b_3 allows the user to disallow the use of high energy physics models if the cross-section energy of interest is less than the benchmarked value. If b_3=-1, a fatal error will occur if models are used. (DEFAULT) If b_3=0, the atom fraction of any data using a model is set to 0. If b_3=1, the problem runs with models.
MATVOL=v_1 v_2 ... v_n	Used to provide the volume of all cells containing a burn material in a repeated structure or lattice geometry. Each v_i entry is the volume of all cells containing burn material m_i. If MATVOL is used, then each m_i entry on the MAT keyword must have a corresponding v_i entry on MATVOL.

Table 5-52. Additional Depletion/Burnup (BURN) (continued)

Keyword

MATMOD=	*nt*	ts_1	nm_1	$mn_{1,1}$	$k_{1,1}$	$z^1_{1,1}$	$c^1_{1,1}$	$z^2_{1,1}$	$c^2_{1,1}$	...	$z^{k_{1,1}}_{1,1}$	$c^{k_{1,1}}_{1,1}$
				$mn_{1,2}$	$k_{1,2}$	$z^1_{1,2}$	$c^1_{1,2}$	$z^2_{1,2}$	$c^2_{1,2}$	...	$z^{k_{1,2}}_{1,2}$	$c^{k_{1,2}}_{1,2}$
					.						.	
					.						.	
					.						.	
				mn_{1,nm_1}	k_{1,nm_1}	z^1_{1,nm_1}	c^1_{1,nm_1}	z^2_{1,nm_1}	c^2_{1,nm_1}	...	$z^{k_{1,nm_1}}_{1,nm_1}$	$c^{k_{1,nm_1}}_{1,nm_1}$
		ts_2	nm_2	$mn_{2,1}$	$k_{2,1}$	$z^1_{2,1}$	$c^1_{2,1}$	$z^2_{2,1}$	$c^2_{2,1}$	...	$z^{k_{2,1}}_{2,1}$	$c^{k_{2,1}}_{2,1}$
		.		$mn_{2,2}$	$k_{2,2}$	$z^1_{2,2}$	$c^1_{2,2}$	$z^2_{2,2}$	$c^2_{2,2}$	...	$z^{k_{2,2}}_{2,2}$	$c^{k_{2,2}}_{2,2}$
		.			.						.	
		.			.						.	
		.			.						.	
		.		mn_{2,nm_2}	k_{2,nm_2}	z^1_{2,nm_2}	c^1_{2,nm_2}	z^2_{2,nm_2}	c^2_{2,nm_2}	...	$z^{k_{2,nm_2}}_{2,nm_2}$	$c^{k_{2,nm_2}}_{2,nm_2}$
		.					.		.			
		.					.		.			
		.					.		.			
		ts_{nt}	nm_{nt}	$mn_{nt,1}$	$k_{nt,1}$	$z^1_{nt,1}$	$c^1_{nt,1}$	$z^2_{nt,1}$	$c^2_{nt,1}$	...	$z^{k_{nt,1}}_{nt,1}$	$c^{k_{nt,1}}_{nt,1}$
				$mn_{nt,2}$	$k_{nt,2}$	$z^1_{nt,2}$	$c^1_{nt,2}$	$z^2_{nt,2}$	$c^2_{nt,2}$	...	$z^{k_{nt,2}}_{nt,2}$	$c^{k_{nt,2}}_{nt,2}$
					.						.	
					.						.	
					.						.	
				$mn_{nt,nm_{nt}}$	$k_{nt,nm_{nt}}$	$z^1_{nt,nm_{nt}}$	$c^1_{nt,nm_{nt}}$	$z^2_{nt,nm_{nt}}$	$c^2_{nt,nm_{nt}}$	...	$z^{k_{nt,nm_{nt}}}_{nt,nm_{nt}}$	$c^{k_{nt,nm_{nt}}}_{nt,nm_{nt}}$

Values

Keyword Input Parameter	Description
nt	Total number of time steps for which concentration changes are specified.

ts_i	Integer identifying the ordinal position of the time step from the TIME keyword (1 for 1st, 2 for 2nd, etc.) at which to change nuclide concentrations of material(s) mn_{i,j_i}, where j_i=1,2,...,nm_i. If ts_i is entered as a positive value, new concentration values will be applied discretely at t_i and $t_{i+1/2}$. If ts_i is entered as a negative value, new concentration values will be applied at t_i and t_{i+1} and linearly interpolated to provide a concentration value at $t_{i+1/2}$. (If ts_i is negative at t_i and the concentrations of any of the altered isotopes at t_{i+1} is equal to the concentration set at t_i, then the concentrations of the altered isotopes will be set to the value at t_i for t_i, $t_{i+1/2}$, and t_{i+1}. At $t_{i+3/2}$, the isotopes will undergo a normal depletion and the concentrations will not be set to the value at t_{i+1}.)
nm_i	Total number of materials at time step ts_i that incur nuclide concentration changes. For each time step identifier ts_i (i=1,2,...,nt) there must be a corresponding nm_i value.
mn_{i,j_i}	Sequential material number for which to change nuclides at time step ts_i for material j_i, where j_i=1,2,...,nm_i. If mn_{i,j_i} is a positive value, concentration must be given as an atom or weight fraction. If mn_{i,j_i} is a negative value, concentration must be given as atom or gram density.
k_{i,j_i}	Number of nuclides of the material mn_{i,j_i} for which concentration values follow. For each material mn_{i,j_i} (j=1,2,...,nm_i) there must be a corresponding k_{i,j_i} value.
$z_{i,j_i}^{k_{i,j_i}}$	Nuclide (in ZZZAAA format) of material mn_{i,j_i} for which a new concentration value immediately follows. There must be k_{i,j_i} pairs of associated nuclide and concentration values.
$c_{i,j_i}^{k_{i,j_i}}$	Concentration value for the nuclide $z_{i,j_i}^{k_{i,j_i}}$ of material mn_{i,j_i}. If $c_{i,j_i}^{k_{i,j_i}}$ is positive, values are interpreted as atom fractions or atom densities. If $c_{i,j_i}^{k_{i,j_i}}$ is negative, values are interpreted as weight fractions or gram densities.

Use: The depletion/burnup capability is limited to criticality (KCODE) problems.

Use: The CINDER.dat library file contains decay, fission yield, and 63-group cross-section data not calculated by MCNPX. This library file must be present and accessible by MCNPX for the burnup capability for to work properly.

Caution: Burning with large time steps that encounter large flux-shape changes during the time step will lead to inaccurate calculations. Use time steps small enough to capture the flux-shape change accurately over time.

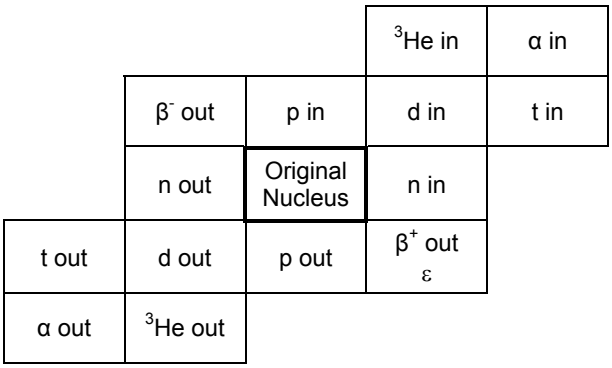
Note: Burnup is given in units of gigawatt days (GWD) per metric tones of uranium (MTU), where MTU is the sum of masses of isotopes containing ≥90 protons.

Note: For negative material numbers, m_i, specified on the MAT keyword, the recoverable energy per fission and neutrons per fission are computed for use in the power normalization procedure and the calculation of fission power fractions. A fatal error results if every material number is negative.

Note: To correctly compute isotopic masses and fluxes for burn materials, the volume of these materials must be either calculated by MCNPX or provided by the user (on the VOL or MATVOL cards). For lattices or repeated structures, MCNPX calculates the volume of each cell, but does not account for multiple occurrences of cell volumes. Therefore, if cells containing a burn material are repeated, then the volume calculated by MCNPX will not represent the total volume of burn material and the user must provide the correct information on the MATVOL card.

Note: Steady-state particle transport in MCNPX includes only those isotopes listed on the material cards, selected from a fission product tier, or produced by the isotope generator algorithm. This algorithm captures only the daughter reactions of the isotopes specified on the materials card; not the entire isotope decay chain. These daughter products are depicted in the chart below, which provides the relative locations of the products of various nuclear processes on the Chart of the Nuclides. To track the buildup of additional decay-chain isotopes in the transport calculation, the isotopes must be listed on the material (M) card. If decay-chain isotopes of interest are not initially present, add them to the material card (M) by providing appropriate isotope identifiers ($zaid_i$) with low atomic/weight fraction values ($fraction_i$) (i.e., 1E-36).

Note: When the information is not specified by MCNPX, CINDER90 uses inherent intrinsic cross-section and decay data to track the time-dependent reactions of 3400 isotopes. MCNPX can only track energy-integrated reaction-rate information for isotopes containing transport cross sections. For isotopes not containing transport cross-section information, MCNPX calculates a 63-group flux that is sent to CINDER90. This flux data then is matched with a 63-group cross-section set inherent within CINDER90 to generate 63-group reaction rates. These resultant reaction rates are then energy integrated to determine the total reactions occurring.



Note: When using the MATMOD keyword, if ts_i is negative at t_i and the concentrations of any of the altered isotopes at t_{i+1} is equal to the concentration set at t_i, then the concentrations of the altered isotopes will be set to the value at t_i for t_i, $t_{i+1/2}$, and t_{i+1}. At $t_{i+3/2}$, the isotopes will undergo a normal depletion and the concentrations will not be set to the value at t_{i+1}.

Note: When using the MATMOD keyword of the BURN card, if a burn material is set to have a concentration change at t_1, then the atom density of that isotope at $t_{1/2}$ is set to the initial value specified at t_0. This is only set for the initial midpoint time step; the rest of the calculation will follow the procedure described for the ts_i parameter.

Table 5-53. Fission Product Content Within Each Burnup Tier

Tier1	Tier 2	Tier 3
		^{69}Ga ^{71}Ga
		^{70}Ge ^{72}Ge ^{73}Ge ^{74}Ge ^{76}Ge
	^{74}As ^{75}As	^{74}As ^{75}As
		^{74}Se ^{76}Se ^{77}Se ^{78}Se ^{79}Se ^{80}Se ^{82}Se
	^{79}Br ^{81}Br	^{79}Br ^{81}Br
	^{78}Kr ^{80}Kr ^{82}Kr ^{83}Kr ^{84}Kr ^{86}Kr	^{78}Kr ^{80}Kr ^{82}Kr ^{83}Kr ^{84}Kr ^{85}Kr ^{86}Kr
	^{85}Rb ^{87}Rb	^{85}Rb ^{86}Rb ^{87}Rb
		^{84}Sr ^{86}Sr ^{87}Sr ^{88}Sr ^{89}Sr ^{90}Sr
	^{88}Y ^{89}Y	^{88}Y ^{89}Y ^{90}Y ^{91}Y
^{93}Zr	^{90}Zr ^{91}Zr ^{92}Zr ^{93}Zr ^{94}Zr ^{96}Zr	^{90}Zr ^{91}Zr ^{92}Zr ^{93}Zr ^{94}Zr ^{95}Zr ^{96}Zr
	^{93}Nb	^{93}Nb ^{94}Nb ^{95}Nb ^{97}Nb

Tier1	Tier 2	Tier 3
^{95}Mo	^{95}Mo	^{92}Mo ^{94}Mo ^{95}Mo ^{96}Mo ^{97}Mo ^{98}Mo ^{99}Mo ^{100}Mo
^{99}Tc	^{99}Tc	^{99}Tc
^{101}Ru	^{101}Ru ^{103}Ru ^{105}Ru	^{96}Ru ^{98}Ru ^{99}Ru ^{100}Ru ^{101}Ru ^{102}Ru ^{103}Ru ^{104}Ru ^{105}Ru ^{106}Ru
		^{103}Rh ^{105}Rh
	^{102}Pd ^{104}Pd ^{105}Pd ^{106}Pd ^{108}Pd ^{110}Pd	^{102}Pd ^{104}Pd ^{105}Pd ^{106}Pd ^{107}Pd ^{108}Pd ^{110}Pd
	^{107}Ag ^{109}Ag	^{107}Ag ^{109}Ag ^{111}Ag
	^{106}Cd ^{108}Cd ^{110}Cd ^{111}Cd ^{112}Cd ^{113}Cd	^{106}Cd ^{108}Cd ^{110}Cd ^{111}Cd ^{112}Cd ^{113}Cd ^{114}Cd ^{116}Cd
		^{113}In ^{115}In
	^{120}Sn	^{112}Sn ^{113}Sn ^{114}Sn ^{115}Sn ^{116}Sn ^{117}Sn ^{118}Sn ^{119}Sn ^{120}Sn ^{122}Sn ^{123}Sn ^{124}Sn ^{125}Sn ^{126}Sn
		^{121}Sb ^{123}Sb ^{124}Sb ^{125}Sb ^{126}Sb
		^{120}Te ^{122}Te ^{123}Te ^{124}Te ^{125}Te ^{126}Te ^{128}Te ^{130}Te ^{132}Te
	^{127}I ^{129}I ^{135}I	^{127}I ^{129}I ^{130}I ^{131}I ^{132}I ^{133}I ^{134}I ^{135}I
^{131}Xe ^{134}Xe	^{124}Xe ^{126}Xe ^{128}Xe ^{129}Xe ^{130}Xe ^{131}Xe ^{132}Xe ^{134}Xe ^{135}Xe ^{136}Xe	^{123}Xe ^{124}Xe ^{126}Xe ^{128}Xe ^{129}Xe ^{130}Xe ^{131}Xe ^{132}Xe ^{133}Xe ^{134}Xe ^{135}Xe ^{136}Xe
^{133}Cs ^{137}Cs	^{133}Cs ^{134}Cs ^{135}Cs ^{136}Cs ^{137}Cs	^{133}Cs ^{134}Cs ^{135}Cs ^{136}Cs ^{137}Cs
^{138}Ba	^{138}Ba	^{130}Ba ^{132}Ba ^{133}Ba ^{134}Ba ^{135}Ba ^{136}Ba ^{137}Ba ^{138}Ba ^{140}Ba
		^{138}La ^{139}La ^{140}La
		^{136}Ce ^{138}Ce ^{139}Ce ^{140}Ce ^{141}Ce ^{142}Ce ^{143}Ce ^{144}Ce
^{141}Pr	^{141}Pr	^{141}Pr ^{142}Pr ^{143}Pr ^{145}Pr
^{143}Nd ^{145}Nd	^{143}Nd ^{145}Nd ^{147}Nd ^{148}Nd ^{150}Nd	^{142}Nd ^{143}Nd ^{144}Nd ^{145}Nd ^{146}Nd ^{147}Nd ^{148}Nd ^{150}Nd
	^{147}Pm ^{149}Pm	^{147}Pm ^{148}Pm ^{149}Pm ^{151}Pm
	^{147}Sm ^{149}Sm ^{150}Sm ^{151}Sm ^{152}Sm	^{144}Sm ^{147}Sm ^{148}Sm ^{149}Sm ^{150}Sm ^{151}Sm ^{152}Sm ^{153}Sm ^{154}Sm
	^{151}Eu ^{152}Eu ^{153}Eu ^{154}Eu ^{155}Eu	^{151}Eu ^{152}Eu ^{153}Eu ^{154}Eu ^{155}Eu ^{156}Eu ^{157}Eu
	^{152}Gd ^{154}Gd ^{155}Gd ^{156}Gd ^{157}Gd ^{158}Gd ^{160}Gd	^{152}Gd ^{153}Gd ^{154}Gd ^{155}Gd ^{156}Gd ^{157}Gd ^{158}Gd ^{160}Gd
		^{159}Tb ^{160}Tb
		^{156}Dy ^{158}Dy ^{160}Dy ^{161}Dy ^{162}Dy ^{163}Dy ^{164}Dy
	^{165}Ho	^{165}Ho
		^{162}Er ^{164}Er ^{166}Er ^{167}Er ^{168}Er ^{170}Er
	^{169}Tm	^{169}Tm

Example 1:

```
BURN    TIME = 100 70  MAT = 1 3 4  POWER=1.0  PFRAC = 1.0 1.0
```

```
        BOPT= 1.0 -12 1
M1      8016.60c   4.5854e-2
        92235.60c  1.4456e-4
        92238.60c  1.9939e-2
        94238.60c  1.1467e-4
        94239.60c  1.0285e-3
        94240.60c  7.9657e-4
        94241.60c  3.3997e-4
        94242.60c  5.6388e-4
M2      2004       -1.0
M3      40000.60c  -1.0
M4      1001.60c   4.7716e-2
        8016.60c   2.3858e-2
        5010.60c   3.6346e-6
        5011.60c   1.6226e-5
MT4     lwtr.01t
```

In this example, materials M1, M3, and M4 are burned. Only material M1 contained fissionable actinides. Four tables are generated: one for the combined burnup of all material numbers on the MAT keyword (1,3,and 4) and one for each of these three materials.

Example 2:

```
BURN   TIME = 15.0 30.0 30.0  MAT = 3 4  POWER = 2.0
       OMIT = 3 3 8017 92234 92239 4 1 92234  BOPT =1.0 -11
```

Materials M3 and M4 are burned for 15, 30, and 30 days at a power level of 2 MW. Excluded from the burn of M3 are three isotopes ^{17}O, ^{234}U, and ^{239}U; excluded from M4 is ^{234}U. Output is produced at the end of each burn step and ordered by decreasing mass, Tier-2 fission products are treated.

5.5.5 SSW Surface Source Write

Form: SSW s_1 s_2 (c_1 ... c_k) s_3 ... s_n KEYWORD=*values*

Table 5-54. Surface Source Write Card

Input Parameter	Description
s_i	Problem surface number, with the appropriate sign to indicate sense of inward or outward particle direction, for which particle-crossing information is to be written to the surface source file WSSA. Macrobody facets are allowed.
c_j	Problem cell number. A positive entry denotes a cell the particle is entering. A negative entry specifies a cell that particle is leaving. This option provides a means to include only a portion of tracks crossing a certain surface.
Keyword	**Values**
SYM	Symmetry option flag. If SYM=0, no symmetry assumed. (DEFAULT) If SYM=1, spherical symmetry assumed. The list of problem surface numbers must contain only one surface and it must be a sphere. If SYM=2, write particles to a surface bidirectionally. Otherwise, only particles going out of a positive surface and into a negative surface are recorded.
PTY=<pl>$_1$ <pl>$_2$ ...	Controls tracks to record. If PTY is absent, record all tracks for all particle types. (DEFAULT) Each <pl> entry is a particle type selected from those listed in Table 4-1.
CEL=cf_1 cf_2 ...	List of names of all the cells from which KCODE fission source neutrons are to be written, active cycles only.

Default: SYM=0; no PTY keyword (record tracks for all particle types)

Use: Optional, as needed.

Note: This card is used to write a surface source file or KCODE fission volume source file for use in a subsequent MCNPX calculation. Include enough geometry beyond the specified surfaces to account for albedo effects. The card allows a list 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" (as specified by the positive or negative sign on the surface number) 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.

Note: Problem cell numbers, c_i, cannot include chain information; i.e., all cells listed must be at the lowest level. Lattice cells should not be listed because in most cases other cells are filled into a lattice cell. In the rare case that a lattice cell is filled with itself, simply list the lattice cell without any reference to a specific element.

Note: If the SYM=1 option is used, the geometry inside the surface must be spherically symmetric and the materials must be symmetric. The SYM=1 option cannot be used if CEL is specified.

Note: 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.

Note: 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.

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, 7, or 16 in the correct direction will be recorded regardless of what cells it happens to be leaving or entering.

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. Particles created from fission events in cells 8 and 9 will be recorded.

5.5.6 SSR Surface Source Read

Form: SSR KEYWORD=*value(s) ...*

Table 5-55. Surface Source Read Card

Keyword	Value
OLD=s_1 s_2 ...	List of problem surface numbers that are a subset of the surfaces on the SSW card that created the file WSSA, now called RSSA. Negative entries are not allowed as filtering is not available based on crossing direction. A positive value (as on the SSW card) simply means to accept all tracks that have crossed that surface regardless of direction. (DEFAULT: All surfaces in original run.) Restriction: Macrobody surfaces are not allowed.
CEL=c_1 c_2 ...	List of cells in which KCODE fission neutrons or photons were written. (DEFAULT: All cells in original run.)
NEW= s_{a1} s_{a2} ... s_{an} s_{b1} s_{b2} ... s_{bn}	Problem surface numbers upon which the surface source is to start particles in this run. The *n* entries may be repeated to start the surface source in *a, b, ...* transformed locations. (DEFAULT: Surfaces in the OLD list.)
COL	Collision option flag. If COL=−1, start from the surface source file only those particles that came directly from the source without a collision. If COL=1, start from the surface source file only those particles that had collisions before crossing the recording surface. If COL=0, start particles without regard to collisions. (DEFAULT)
WGT	Each particle weight is multiplied by the constant WGT as it is accepted for transport. (DEFAULT: WGT=1)
TR=*n* or TR=D*n*	Transformation number, *n*. 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 TR card, which must be present in the INP file of the current problem. Distribution number, D*n*. Distribution number for a set of SI, SP, and SB cards. If the surface source is transformed into several locations, the SI card lists the transformation numbers and the SP and SB cards give the probabilities and bias of each transformation, respectively. (DEFAULT: no transformation)
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 generates 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. (DEFAULT: No axis)
EXT=D*n*	Distribution number (SI, SP, and SB 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. (DEFAULT: No position bias)

Keyword	Value
POA	Particles with a polar angle cosine relative to the source surface normal that falls between 1 and POA will be accepted for transport. All others are disregarded and no weight adjustment is made. (DEFAULT: POA=0)
BCW=*r zb ze*	Restriction: 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. (DEFAULT: No cylindrical window)

Use: Required for surface source problems.

Note: The particle type is determined primarily by the type of the particle on the RSSA file, but particles incompatible with the problem mode are rejected without weight adjustment.

Note: Problem cell numbers, c_i, cannot include chain information; i.e., all cells listed must be at the lowest level. When a source point is kept for transport, the code determines the cell(s) for all higher levels in the geometry, based on its absolute location (i.e., x, y, z position).

Note: 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 *npp* value is smaller than that used in initial calculation, an appropriate ratio of tracks will be rejected. If this *npp* value is larger than that of the initial calculation, an appropriate duplication of tracks will be sampled. Note that a larger value of *npp* 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).

Note: 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. 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 MCNPX 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-D 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. *Caution*: Remember that the value entered for PSC 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*.

Note: 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 is not required. Total $\bar{\nu}$ is the default for both KCODE and non-KCODE sources. Prompt $\bar{\nu}$ may be invoked by specifying TOTNU NO. The keyword CEL specifies which fission cells to accept of those from the KCODE calculation that wrote the RSSA file.

Note: When heavy ions are specified in the problem, the charge and mass for each heavy ion are stored in the surface source file, WSSA, and will be read back to reconstruct the proper source distribution.

Note: Any variance-reduction technique that requires the input of normalized weight parameters (e.g., weight-window bounds, negative entries on the DD card, etc.) may need to be renormalized for SSR applications.

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    0.4   0.6
SB5    0.3   0.7
```

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    0.5    1
SP99   0.75      1
SB99   0.5     0.5
```

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.

5.5.7 Subroutines SOURCE and SRCDX

Users may write their own source subroutines to bypass the standard source capabilities. If there is no SDEF, SSR, or KCODE card, then MCNPX will look for a subroutine SOURCE, and if there are detectors or DXTRAN, MCNPX will also require a SRCDX routine. When it becomes available, you may refer to the MCNPX developer's guide for more details.

5.6 TALLY SPECIFICATION

F, FC, E, T, C, FQ, FM, DE, DF, EM, TM, CM, CF, SF, FS, SD, FU, FT, TALLYX, TF, PI (FIP), TIR (FIR), TIC (FIC), TALNP, PERT, TMESH

Tally cards are used to specify what type of information the user wants to gain from the Monte Carlo calculation. Options include such tallies as 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 cards described in this section. To obtain tally results, only the F card is required; the other tally cards provide various optional features.

The *n* associated with the tally-type specification is a user-chosen tally number <999; choices of *n* are discussed in the following section. When a choice of *n* is made for a particular tally type, any other input card used to refine that tally description (such as E*n* 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, MCNPX also can provide the total tally summed over appropriate bins (such as over all 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 FM or SD cards.)

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, those with errors between 20% and 50% can be believed to within a factor of a few, those with errors between 10% and 20% are questionable, and results with errors less than 10% are generally (but not always) reliable, except for detectors. Detector results are generally reliable if their associated relative errors are below 5%. The tally fluctuation charts at the end of the output file base their results on the information from one specified bin of every tally. (See the TFC card.) This bin also is used for the weight-window generator and 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. A tally is considered to be converged with high confidence only when it passes all ten statistical checks.

5.6.1 F Tally Card

All tallies are normalized to be per source particle unless a different normalization has been specified with the WGT keyword on the SDEF card, changed by the user with a TALLYX subroutine, or normalized by weight in a criticality (KCODE) calculation.

Mnemonic	Tally Description	F*n* units	*F*n* units
F1:<*pl*>	Current integrated over a surface	particles	MeV
F2:<*pl*>	Flux averaged over a surface	particles/cm^2	MeV/cm^2
F4:<*pl*>	Flux averaged over a cell	particles/cm^2	MeV/cm^2

Mnemonic	Tally Description	F*n* units	*F*n* units
F5*a*:N or F5*a*:P	Flux at a point or ring detector	particles/cm^2	MeV/cm^2
F6:<*pl*>	Energy deposition averaged over a cell	MeV/g	jerks/g
+F6	Collision heating	MeV/g	N/A
F7:N	Fission energy deposition averaged over a cell	MeV/g	jerks/g
F8:<*pl*>	Energy distribution of pulses created in a detector by radiation	pulses	MeV
+F8:<*pl*>	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 a particle designator :<*pl*>, where <*pl*> is chosen from Table 4-1. Thus you may have as many of any basic tally as you need, each with different energy bins, or flagging bins, 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.

Several tally types allow multiple particles. For example, an energy deposition tally for both neutrons and gammas, F6:N,P, may be specified. In the case of collision heating, +F6 always applies to all particles in a problem; therefore this tally has no particle designator. For pulse-height tallies photons/electrons are a special case: F8:P,E is the same as F8:P and F8:E. Also, F8 tallies may have particle combinations such as F8:N,H.

Tally types 1, 2, 4, and 5 are normally weight tallies (particles in the above table); however, if the F card is flagged with an asterisk (for example, *F1:N), energy times weight will be tallied. The asterisk flagging also can be used on tally types 6 and 7 to change the units from MeV/g to jerks/g (1 jerk = 1 GJ = 1e9 J). No asterisk can be used in combination with the + on the +F6 tally. 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 has many options. The standard F8 tally is a pulse-height tally and the energy bins are no longer the energies of scoring events, but rather the energy balance of all events in a history. In conjunction with the FT8 card (Section 5.6.17), the F8 tally can be an anticoincidence light tally, a neutron coincidence capture tally, or a residual nuclei production tally. When flagged with an asterisk, *F8 becomes an energy deposition tally. In addition, F8 can be flagged with a plus (+) to convert it from an energy deposition tally (flagged with an asterisk) to a charge deposition tally. The +F8 tally is the

negative particle weight for electrons and the positive weight for positrons. The +F8:E tally can be checked against an F1:E type surface tally with the FT1:E ELC option to tally charge.

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. (An exception to this statement occurs if one uses a repeated structures format to describe the tally bin. For more information, please see Section 5.6.1.4.) If you need only the segment of a surface, you might segment the full surface with the FS card (see Section 5.6.14) and use the SD card (see Section 5.6.15) 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.

For additional examples involving residual nuclei tally see Appendix E, Section E.9

5.6.1.1 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 ... T

Table 5-56. Surface and Cell Tally Cards (F1:*n*, F2:*n*, F4:*n*, F6:*n*, F7:*n*)

Input Parameter	Description
n	Tally number.
<*pl*>	Particle designator.
s_i	Problem number of surface or cell for tallying.
T	Total over specified surfaces or cells.

Only surfaces bounding cells and listed in the cell card description can be used on F1 and F2 tallies. Tally type 7 allows N only.

In the simple form above, MCNPX 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 Section 5.6.1.4 for an explanation of the repeated structure and lattice tally format.

The symbol T entered on surface or cell F 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 F 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, MCNPX 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.

Energy Deposition Tally (F6) *Note:*

In the energy range where nuclear data tables are available, the neutron, photon, and proton energy deposition is determined using the heating numbers from the nuclear data tables. These heating numbers are estimates of the energy deposited per unit track length. In addition, the de/dx ionization contribution for electrons and/or protons is added in for MODE E or MODE H.

Above that tabular energy limit, or when no tabular data is available, energy deposition is determined by summing several factors. For charged particles, ionization (de/dx) energy is deposited uniformly along the track length (which is important to keep in mind when doing a mesh tally). All other energy deposition is calculated at the time of a nuclear interaction. The energies of secondary particles, if they are not to be tracked (i.e., not included on the MODE card) will be deposited at the point of the interaction. Nuclear recoil energy will be deposited at the point of interaction unless heavy ion transport is specified (i.e., MODE #).[1]

In order to obtain the most accurate energy deposition tallies possible, the user must include all potential secondary particles on the MODE card. (Electrons can be omitted, provided the user fully understands how energy deposition for photons is done.) The energy deposition for non-tracked secondary particles generally assumes all energy is deposited locally at the collision site. The exception is for neutral particles (photons, neutrinos, etc.), which generally travel far from the collision site. Heating is included for these secondary particles only if they are listed on the MODE card and F6 card. The assumption of local energy deposition for non-tracked secondary particles is poor, especially when the energies of the secondaries are high, or when the user is simulating thin volumes. When secondary particles are indicated on the MODE card, MCNPX will

[1] Tracking of residual nuclei is important in small volumes where the recoil nucleus might leave the cell. This is especially important in light ion recoils (such as a scattered hydrogen nucleus). Light ion recoil from elastic collisions is an option on the PHYS:N and PHYS:H cards.

subtract their energies from the heating values, and energy deposition will be handled in the regular process of tracking those particles.[1]

Where there are no libraries available, de/dx, nuclear recoil, and the energies of some non-tracked secondary particles are added to the F6 collision estimator. A secondary particle can be produced either by collision or by particle decay.[2] In MCNPX, the energies of neutral particles will never be added to the collision estimator (this includes neutrons, photons, neutrinos, π^0, and neutral kaons). Therefore, it is especially important for the user to include all possible secondary particles on the MODE card (especially photons and neutrinos), in order to get the most accurate energy deposition tally.

MCNPX has the track-length heating (F6:<*pl*>) tally, where <*pl*> can be any particle or combination of particles. In addition, MCNPX also has a collision heating (+F6) tally, which contains energy deposition from all particles in the problem. Note that the PEDEP keyword in a Type 1 mesh tally is analogous to the F6:<*pl*> tally, and the Type 3 mesh tally is analogous to the +F6 tally, although the normalizations will be different. Since the mesh tallies score energy deposition within a mesh cell, which may contain more than one material, normalization is per unit volume. The units of this tally are MeV/source-particle. In the F6 and +F6 tallies, material density is available for the chosen cells, and normalization is MeV/gm/source-particle.

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
```

[1] Energies of particles that fall below minimum energy cutoffs will also be deposited locally. The user must be certain that the value of these cutoff energies will not cause the results of the F6 tally to be in error.

[2] Note that the π^0, if included on the MODE card, will be transported before it decays, even though its lifetime is 8.4×10^{-17} seconds. This allows the user to use MCNPX tallies for that particle.

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.

5.6.1.2 DETECTOR TALLIES (TALLY TYPE 5)

Form for point detectors: F5:<*pl*> $x_1\ y_1\ z_1\ \pm ro_1\ \ldots\ x_n\ y_n\ z_n\ \pm ro_n$ [ND]

Table 5-57. Point Detector Card (F5 and F5*a*)

Input Parameter	Description
<*pl*>	Particle designator: N for neutrons or P for photons.
$x_i\ y_i\ z_i$	Coordinates of the i^{th} detector point.
$\pm ro_i$	Radius of the sphere of exclusion for the i^{th} detector: a positive entry is interpreted as centimeters; a negative entry is interpreted as mean free paths. (Note that a negative entry is illegal in a void.)
ND	Optional keyword to inhibit the separate printing of the direct contribution for that detector tally.

Form for ring detectors: F5*a*:<*pl*> $ao_1\ r_1\ \pm ro_1\ \ldots\ ao_n\ r_n\ \pm ro_n$ [ND]

Table 5-58. Ring Detector Card

Input Parameter	Description
a	The letter X, Y, or Z.
<*pl*>	Particle designator: N for neutrons or P for photons.
ao_i	Distance along axis "*a*" where the ring plane of the i^{th} detector intersects the axis.
r_i	Radius of the ring of the i^{th} detector in centimeters.
$\pm ro_i$	Same meaning as for point detectors, but describes a sphere about the point selected on the i^{th} ring detector.
ND	Optional keyword to inhibit the separate printing of the direct contribution for that detector tally.

Default: None.

Note: Ring detectors (as opposed to point detectors) should be used in all problems with axial symmetry. A detector located right on a surface 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. Detectors used with reflecting, white, or periodic surfaces give wrong answers.

Note: The radius of the sphere of exclusion, $\pm ro_i$, 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 ro 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. The exclusion sphere must not encompass more than one material.

Note: Point and ring detectors use an assumption of isotropic scatter for contributions from collisions within the model regime. These estimators require the angular distribution data for particles produced in an interaction to predict the "next event." Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region.

5.6.1.3 PULSE-HEIGHT TALLY (TALLY TYPE 8)

Simple Form: `F8:<pl>` s_1 ... s_k

General Form: `F8:<pl>` s_1 (`(`s_2 ... s_3`)` `(`s_4 ... s_5`)` s_6 s_7 ...

Table 5-59. Pulse-Height Tally Card (F8)

Input Parameter	Description
<pl>	Particle designator.
s_j	Problem number of cell for tallying, or `T`.

Note: The `F8` tally provides the energy distribution of pulses created in a detector by radiation. 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. Use of the dose energy (`DE`) and dose function (`DF`) cards is also disallowed with the `F8` tally. 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. 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 charge. Energy binning is not recommended with the `+F8` tally.

Note: Limited variance reduction may be applied to `F8` pulse-height tallies for electrons and photons [HEN04b]: DXTRAN and secondary particle-production

biasing are fatal errors with F8 tallies. Full variance reduction is allowed for energy pulse-height tallies (*F8) if there are no energy bins.

Note: With the FT8 special tally treatments card (Section 5.6.17) the F8 tally can become an anticoincidence light tally (FT8 PHL) or a different kind of tally altogether. For example, FT8 CAP is a neutron coincidence capture tally, and FT8 RES tallies the residual nuclides from physics-model evaporation and fission models. These variations have special rules regarding possible variance reduction, time bins, and other issues.

Note: The energy bins in the F8 pulse-height tally are different than those of all other tallies. Rather than tally the particle energy at the time of scoring, the numbers of pulses depositing energy within the bins are tallied. 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.

5.6.1.4 REPEATED STRUCTURES TALLIES (TALLY TYPES 1, 2, 4, 6, 7, AND 8)

Simple Form: F*n*:<*pl*> s_1 ... s_k

General Form: F*n*:<*pl*> s_1 (s_2 ... s_3) ((s_4 s_5)<(c_1 c_2[i_1 ... i_2])<U=# <(c_3 c_4 c_5)) ... T

Table 5-60. Repeated Structure Tally Cards

Input Parameter	Description
n	Tally number.
<*pl*>	Particle designator.
s_i	Problem number of a surface or cell for tallying.
c_j	Problem number of a cell filled with a universe.
T	Total over specified surfaces or cells.
U=#	Problem number of a universe used on a FILL card.

Input Parameter	Description
i_i	Index data for a lattice cell element, with three possible formats (always in brackets): If i_i=i_1, then i_i indicates the 1st lattice element of cell c_2, as defined by the FILL array. If i_i=i_1:i_2 i_3:i_4 i_5:i_6, then i_i indicates a range of one or more lattice elements. Use the same format as on the FILL card. If i_i=i_1 i_2 i_3, i_4 i_5 i_6 , then i_i indicates individual lattice elements (i_1, i_2, i_3), (i_4, i_5, i_6), etc. See LAT and FILL cards for indices explanation.

Example:

```
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).

Important: The arrows separate different universe levels. Cell 5 in U=2 is inside cell 4 in U=1. For c_1<c_2, c_1 must *not* be in the same universe as c_2. The input tally bin chain involving multiple levels *must* be enclosed by an outer set of parentheses.

Note: Input files with large lattice tallies run 10 to 1000 times faster than version 2.4.0 of MCNPX and MCNP4C3 if the following apply:

- The lattice is specified fully on the cell fill card, e.g., FILL −50:50 −50:50 −50:50.
- The tally chain refers to no more than one cell at each level, except for the lattice cell, which must include the entire range of all indices specified on the corresponding FILL card: F4:P (1 < 2 < 3[−50:50 −50:50 −50:50] < 4).

  Example:

```
21x21x21 void lattice of balls
11 0 -31 u=1 imp:p=1
12 0  31 u=1 imp:p=1
16 0 -32 u=2 imp:p=1
     lat=1 fill= -10:10 -10:10 -10:10 1 9260R
17 0 -33 fill=2 imp:p=1
18 0  33        imp:p=0

31 sph 0 0 0 .5
32 rpp -1 1 -1 1 -1 1
33 rpp -21 21   -21 21   -21 21
```

```
mode    p
print
prdmp 2j -3
sdef
nps    10000
f4:p (11<16[-10:10 -10:10 -10:10]<17)
```

This example runs 70 times faster with MCNPX than with MCNPX 2.4.0 or MCNP4C. Larger lattices and nested lattices offer even more dramatic speedups.

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. For example,

$((s_4\ s_5)<(c_1\ c_2\ [i_1\ \ldots\ i_2])<(c_3\ c_4\ c_5))$

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 ... 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, i.e.,

$(s_4\ s_5 < (c_1\ c_2\ [i_1\ \ldots\ i_2]) < c_3\ c_4\ c_5)$

results in the creation of 2*1*3=6 bins as follows:

$(s_4<(c_1\ c_2\ [i_1\ \ldots\ i_2])<c_3)$, $(s_5<(c_1\ c_2\ [i_1\ \ldots\ i_2])<c_3)$,

$(s_4<(c_1\ c_2\ [i_1\ \ldots\ i_2])<c_4)$, $(s_5<(c_1\ c_2\ [i_1\ \ldots\ i_2])<c_4)$, and

$(s_4<(c_1\ c_2\ [i_1\ \ldots\ i_2])<c_5)$, $(s_5<(c_1\ c_2\ [i_1\ \ldots\ i_2])<c_5)$.

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. 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< symbol 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 < symbol:

```
3     1   -1.0   -1234   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.

5.6.2 FC Tally Comment

Form: FC*n* *info*

Table 5-61. Tally Comment Card (FC)

Input Parameter	Description
n	Tally number and type.
info	Provides title for tally in output and MCTAL file.

Default: No comment.

Use: Encouraged.

Note: The FC card can be continued only by blanks in columns 1–5 on succeeding lines.

5.6.3 E Tally Energy

Form: E*n* e_1 ... e_k [NT] [C]

Table 5-62. Tally Energy Card (E)

Input Parameter	Description
n	Tally number.
e_i	Upper bound (in MeV) of the i^{th} energy bin for tally *n*.
NT	Optional notation at the end of the input line to inhibit the automatic total over all specified energy bins.
C	Optional notation at the end of the input line to cause the bin values to be cumulative and the last energy bin to be the total over all energy bins.

Default: If the E card is absent, there will be one bin over all energies unless this default has been changed by an E0 card.

Use: Required if EM card is used.

Note: The energies on the E card must be entered in the order of increasing magnitude. If a particle has energy greater than the last entry, it will not be tallied and a warning will be issued. If the last entry is greater than the upper energy limit (*emax* or *emcpf*) specified on the PHYS card(s), the last bin will be lowered to the PHYS card(s) limit(s). If there are several bins above this upper limit, the extra bins are eliminated.

Note: An E0 card can be used to set up a default energy-bin structure for all tallies. A specific E card will override the default structure for tally *n*.

Example:

```
E11    0.1  1  20
```

This card 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.

5.6.4 T Tally Time

Form: T*n* $t_1 \ldots t_k$ [NT] [C]

Table 5-63. Tally Time Card (T)

Input Parameter	Description
n	Tally number.
$t_1 \ldots t_k$	Upper bound (in shakes) of the i^{th} time bin for tally *n*.
NT	Optional notation at the end of the input line to inhibit the automatic total over all specified time bins.
C	Optional notation at the end of the input line to cause the bin values to be cumulative and the last time bin to be the total over all time.

Default: If the T card is absent, there will be one bin over all times unless this default has been changed by a T0 card.

Use: Required if TM card is used. Consider FQ card.

Reminder: 1 shake = 1e-8 seconds

Note: The times on the T card must be entered in the order of increasing magnitude. If a particle has a time greater than the last entry, it will not be tallied and a warning will be issued. The last time bin entry should always be less than or equal to the time cutoff on the 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.

Note: A T0 card can be used to set up a default time-bin structure for all tallies. A specific T card will override the default structure for tally *n*.

Example:

```
T2      -1   1   1.0+37   NT
```

This will separate an F2 flux surface tally into three time bins: (1) from -∞ 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.

5.6.5 C Cosine Card (tally type 1 and 2)

Form 1: C*n* c_1 ... c_k

Form 2: *C*n* ϕ_1 ... ϕ_k

Table 5-64. Cosine Card (C)

Input Parameter	Description
n	Tally number.
c_i	Upper cosine limit of the i^{th} angular bin for surface current tally *n*. Restrictions: c_1>-1 c_k=1, where c_k is the entry for the last bin
ϕ_i	Upper angular limit expressed in degrees. Restrictions: ϕ_1<180 ϕ_k=0, where ϕ_k is the entry for the last bin

Default: If the C 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 and 2. Required if CM card is used. Consider FQ card.

Note: The asterisk (*) on the C1 card interprets cosines as in degrees. Entries must be such that the cosine is monotonically increasing.

Note: A C0 card can be used to set up a default angular bin structure for all tallies. A specific C card will override the default structure for tally *n*. The selection of a single cosine bin for an F1 tally gives the total and not the net current crossing a surface.

Note: The angular limits described by the C card are defined with respect to the positive normal to the surface at the particle point of entry. An FT card with an FRV v_1 v_2 v_3 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.

Examples:

```
C1     -0.866  -0.5   0   0.5  0.866  1
*C1       150   120  90    60     30  0
```

This will tally currents within the following angular limits (1) 180° to 150°, (2) 150° to 120°, (3) 120° to 90°, (4) 90° to 60°, (5) 60° to 30°, and (6) 30° to 0° with respect to the positive normal. No total will be provided.

5.6.6 FQ Print Hierarchy

Form: FQ*n* a_1 a_2 . . .

Table 5-65 Print Hierarchy Card (FQ)

Input Parameter	Description
n	Tally number
a_i	Letters representing all eight possible types of tally bins: $1 \le i \le 8$ 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. The tally will be printed in the output file in blocks of time (rows) and energy (columns) for each cosine bin, etc.

Use: Highly recommended. Prints tallies in more easily readable blocks in the output file without affecting answers.

Note: A subset of the letters can be used, in which case MCNPX places them at the end of the FQ 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, and the last set of bins goes horizontally in the table. (Default order is a table in E and T.)

Note: An FQ0 card can be used to change the default order for all tallies. A specific FQ card will then override that order for tally *n*.

Example:

```
FQ4    E    S    M
```

The output file printout will be tables with multiplier bins across the top, segments listed vertically, and these segment-multiplier blocks printed for each energy.

5.6.7 FM Tally Multiplier

Form: FM*n* (*bin set 1*) (*bin set 2*) ... [T] [C]

Table 5-66. Tally Multiplier Card (FM)

Input Parameter	Description
n	Tally number.
(*bin set i*)	Represents ((*multiplier set 1*) (*multiplier set 2*) ... (*attenuator set*)) , where *attenuator set*=*c* −1 m_1 px_1 m_2 px_2 ... and *multiplier set i*=*c* *m* (*reaction list 1*) (*reaction list 2*) and *special multiplier set i*=*c* *-k* .
c	Multiplicative constant.
−1	Flag indicating attenuator rather than multiplier set.
m	Material number identified on an M card.
px	Density times thickness of attenuating material; interpreted as atom density if positive, and mass density if negative.
k	Special multiplier option.
(*reaction list i*)	Sums and products of ENDF or special reaction numbers, described in Appendix G.
T	Optional notation at the end of the input line to require the automatic total over all bins. (If absent, a total over all bins is not provided.)
C	Optional notation at the end of the input line to cause the bin values to be cumulative and the last time bin to be the total over all bins.

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.

Note: 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.

Note: Photonuclear and proton cross sections may be used in tally multipliers on the FM card, however the applicability of the tally is limited to the upper energy included in the related cross-section library.

Note: (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 FM 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.

Note: The FM card is used to calculation 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 MCNPX cross-section libraries or specially designated quantities. Note that some MCNPX cross-section library reaction numbers are different from ENDF/B reaction numbers. The constant *c* is any arbitrary scalar quantity that can be used for normalization. The material number *m* must appear on an M*n* 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. No parentheses are allowed within the reaction list.

The reaction cross sections are microscopic (with units of barns) and not macroscopic. Therefore, if the constant *c* is the atomic density (in atoms/barn-cm), the results will include the normalization "per cm^3." Any number of ENDF/B or special reactions can be used in a multiplier set as long as they are present in the MCNPX cross-section libraries, or in special libraries of dosimetry data. If neither a material number nor any reactions are given, the tally simply is multiplied by the constant *c*.

Note: The FM card basically multiplies by any tallied quantity (flux, current) by any cross section to give nearly all reaction rates plus heating, criticality, etc. A list of many of the ENDF reaction numbers can be found in Appendix G. In addition to the standard ENDF reaction numbers, the following list includes some of the nonstandard special R numbers that may be used:

	Neutrons	Photons	Protons†	Photonuclear‡
Total cross section	-1	-5	1	1
Absorption cross section	-2			
Nonelastic cross section			2	2
Elastic cross section	-3		3	3
Average heating number	-4	-6	4	4

† Proton reaction numbers are similar to the neutron reaction numbers. The principal proton cross sections are the following: ±1=total, ±2=nonelastic, ±3=elastic, ±4=heating, >4=various reactions. On the LA150H proton library, the only available reaction (beyond ±1,2,3,4) is *mt*=5 and its multiplicities, 1005, 9005, 31005, etc. The multiplicity reaction numbers are specified by adding 1000 times the secondary particle number to the reaction number. For interaction reaction *mt*=5, the multiplicities are 1005 for neutrons, 9005 for protons, 31005

for deuterons, etc. The proton multiplicity, *mt*=9001, 9004, 9005, etc., is generally available, along with the total cross section and heating number, *mt*=1, *mt*=4.

‡ Photonuclear cross-section reaction numbers all are positive, unlike the photoatomic reaction numbers, which are negative. The principal photonuclear cross sections are the following: 1=total, 2=nonelastic, 3=elastic, 4=heating, and >4=various reactions such as 18=(γ,*f*). The photonuclear yields (multiplicities) for various secondary particles are specified by adding 1000 times the secondary particle number to the reaction number. For example, 31001 is the total yield of deuterons (particle type D=31), 34001 is the total yield of alphas (particle type A=34), and 1018 is the total number of neutrons (particle type N=1) from fission.

It is always wise to plot the desired cross sections first to see if they are available with the expected reaction numbers in the data library. The tally multipliers treat the data the same as the data are treated in transport: the cross section at the lowest energy is extended down to E=0 for protons with reaction identifier *mt*<0; the cross section at the highest energy of the table is extended to E=∞ for proton interaction cross sections with *mt*<0; and for photonuclear interaction cross sections, *mt*<1000. These extrapolations can be seen in the cross-section plots.

Note: 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.

Note: An attenuator set 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.

Note: In perturbed problems, the PERT card 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. 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.

Example 1:

FM*n* c *m* r_1 r_2 : r_1 r_3

Example 2:

FM*n* *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     (c1) (c2) (c3) (c4)  T
```

Example 4:

```
F12:N   1  2  3  4
FM12    c1
```

Example 5:

```
F22:N   (1 2 3)  4  T
FM22    (c1) (c2) (c3) (c4)
```

These three examples illustrate the syntax when only the constant-multiplier feature is used. All parentheses are required in these examples. Tally `F2` 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 `F12` creates 4 bins: the flux across each of surfaces `1`, `2`, `3`, and `4` with each multiplied by the constant c_1. Tally `F22` 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 `FQ` 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.

Example 6:

```
F4:P     1
FM4     -1 2 -5 -6
SD4      1
F6:P     1
SD6      1
```

Multiplying the photon flux by volume (`SD4 1`) times the atom density (`-1`) for material `2` times the photon total cross section (`-5`) times the photon heating number (`-6`) is the same as the `F6:P` photon heating tally multiplied by mass (`SD6 1`), namely the total energy deposition in cell `1`. Note that positive photon reaction numbers are photonuclear reactions. Note also that the `SD` card replaces the normal divisor (volume for `F4` and mass for `F6`) with new values (both `1` in this example). By

overriding the MCNPX-computed cell volume and mass with values of 1, you effectively multiply the unmodified F4 and F6 tallies by the volume and mass, respectively, yielding the score for the entire cell.

Example 7:

```
F4:n    1
FM4    -1 3 -6 -7
SD4     1
```

Multiplying the neutron flux by volume (SD4 1) times the atom density (-1) for material 3 times the fission multiplicity, $\bar{\nu}$ (-7), times the fission cross section (-6) gives the track-length estimate of criticality for cell 1.

5.6.8 DE and DF Dose Energy and Dose Function

Form: DE*n* *a* e_1 ... e_k
and DF*n* *b* f_1 ... f_k

or DF*n* IU=*j* FAC=*f* INT IC=*i*

Table 5-67. User-Specified Dose Energy (DE) & Dose Function (DF) Cards

Input Parameter	Description
n	Tally number.
e_i	The i^{th} energy value (in MeV).
f_i	The value of the dose function corresponding to e_i. (See Appendix H
a	Interpolation method for energy table. If *a*=LOG, logarithmic interpolation. (DEFAULT) If *a*=LIN, linear interpolation.
b	Interpolation method for dose function table. If *b*=LOG, logarithmic interpolation. (DEFAULT) If *b*=LIN, linear interpolation.

Keyword	Value
IU	Controls units. If IU=1, US units (rem/h/source_particle[1]). If IU=2, international units (sieverts/h/source_particle) (DEFAULT)
FAC	Normalization factor for dose. (DEFAULT=1.0) If FAC=−1, then use ICRP60 (1990) normalization (i.e., normalize results to Q=20) If FAC=−2, then use LANSCE albatross response function. If FAC>0, then is user-supplied normalization factor. (DEFAULT: FAC=1)
IC	IC is standard dose function as given in Table 5-68. (DEFAULT: IC=10)
INT	Energy interpolation. (Note: Dose interpolation always linear.) If INT=LOG, then LOGLIN interpolation.† (DEFAULT) If INT=LIN, then LINLIN interpolation.†

† Note that the interpolation parameter INT=LOG or INT=LIN may be placed anywhere.

Default: If *a* or *b* is missing, LOG is chosen for that table.

Default: IC=10; for IC=10 and 40, INT=LOG; for IC=20 and 31−39, recommended analytic parameterization.

Use: Optional.

Note: When both the DE and DF cards are present to provide a user-specified dose table, they 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.

Note: If *n* is zero on the DE and DF cards, the function will be applied to all tallies that do not have DE and DF cards specifically associated with them.

Note: In addition to allowing user-supplied dose functions, the dose conversion capability provides several standard default dose functions. These are invoked by omitting the DE card and using keywords on the DF card:

DF*n* IU=*j* FAC=*f* INT IC=*i*

[1] Conversion factor is based on units: (rem/hr)/(dose_tally_particle/cm^2-s)

Table 5-68. Standard Dose Functions

Value of IC	Description
Neutron Dose Function	
10	ICRP-21 1971
20	NCRP-38 1971, ANSI/ANS-6.1.1-1977
31	ANSI/ANS-6.1.1-1991 (AP anterior-posterior)
32	ANSI/ANS-6.1.1-1991 (PA posterior-anterior)
33	ANSI/ANS-6.1.1-1991 (LAT side exposure)
34	ANSI/ANS-6.1.1-1991(ROT normal to length & rotationally symmetric)
40	ICRP-74 1996 ambient dose equivalent
Photon Dose Function	
10	ICRP-21 1971
20	Claiborne & Trubey, ANSI/ANS 6.1.1-1977
31	ANSI/ANS-6.1.1-1991 (AP anterior-posterior)
32	ANSI/ANS-6.1.1-1991 (PA posterior-anterior)
33	ANSI/ANS-6.1.1-1991 (LAT side exposure)
34	ANSI/ANS-6.1.1-1991(ROT normal to length & rotationally symmetric)
35	(ISO isotropic)

Example 1:

```
DE5          e1  e2  e3  e4 ... ek
DF5   LIN    f1  f2  f3  f4 ... fk
```

This example will cause a point detector tally to be modified according to the dose function $f(\mathrm{E})$ using logarithmic interpolation on the energy table and linear interpolation on the dose function table.

Example 2:

```
DF0    IC 40  IU 1  LIN  FAC 123.4
```

This example will cause all tallies to use standard dose function 40 (neutron ambient dose equivalent ICRP-74 1996) with US units (rem/h/source_particle), linear interpolation, and a normalization of 123.4.

5.6.9 EM Energy Multiplier

Form: EM*n* m_1 ... m_k

Table 5-69. Energy Multiplier Card (EM)

Input Parameter	Description
n	Tally number.
m_i	Multiplier to be applied to the i^{th} energy bin.

Default: None.

Use: Requires E card. Tally comment recommended.

Note: The EM card can be used with any tally to scale the usual current, flux, etc. by a response function. There should be one entry for each energy entry on the corresponding E card. Note that this card modifies the tally by an energy-dependent function that has the form of a histogram and not a continuous function.

Note: A set of energy multipliers can be specified on an EM0 card that will be used for all tallies for which there is not a specific EM card.

Example: Tallies can be changed to be per unit energy if the entries are $1/\Delta E$ for each bin, where ΔE is the width or the corresponding energy bin.

5.6.10 TM Time Multiplier

Form: TMn m_1 ... m_k

Table 5-70. Time Multiplier Card (TM)

Input Parameter	Description
n	Tally number.
m_i	Multiplier to be applied to the i^{th} time bin.

Default: None.

Use: Requires T card. Tally comment recommended.

Note: The TM card can be used with any tally to scale the usual current, flux, etc. by a response function. There should be one entry for each time entry on the corresponding T card. Note that this card modifies the tally by a time-dependent function that has the form of a histogram and not a continuous function.

Note: A set of time multipliers can be specified on a TM0 card that will be used for all tallies for which there is not a specific TM card.

Example: Tallies can be changed to be per unit time if the entries are $1/\Delta T$ for each bin, where ΔT is the width or the corresponding time bin.

5.6.11 CM Cosine Multiplier (tally types 1 and 2 only)

Form: CM*n* m_1 ... m_k

Table 5-71. Cosine Multiplier Card (CM)

Input Parameter	Description
n	Tally number.
m_i	Multiplier to be applied to the i^{th} cosine bin.

Default: None.

Use: Tally types 1 and 2. Requires C card. Tally comment recommended.

Note: The CM card can be used with an F1*n* tally to scale the usual current by a response function. There should be one entry for each cosine entry on the corresponding C 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.

Note: A set of cosine multipliers can be specified on an CM0 card that will be used for all F1*n* tallies for which there is not a specific CM card.

Example: To get the directionally dependent F1 tally results to be per steradian, the i^{th} entry on the CM1 card is $1/\left[2\pi\left(\cos\theta_i - \cos\theta_{i-1}\right)\right]$ where θ_0 is 180°.

5.6.12 CF Cell-Flagging (tally types 1, 2, 4, 6, 7)

Form: CF*n* c_1 ... c_k

Table 5-72. Cell-Flagging Card (CF)

Input Parameter	Description
n	Tally number.
c_j	Problem cell numbers whose tally contributions are to be flagged.

Default: None.

Use: Not with detectors or pulse-height tallies; instead consider the FT card with the ICD keyword. Consider FQ card.

Note: 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.

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 flux 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.

5.6.13 SF Surface-Flagging (tally types 1, 2, 4, 6, 7)

Form: SF*n* s_1 ... s_k

Table 5-73. Surface-Flagging Card (SF)

Input Parameter	Description
n	Tally number.
s_i	Problem surface numbers whose tally contributions are to be flagged.

Default: None.

Use: Not with detectors; instead consider the FT card with the ICD keyword. Not with pulse-height tallies (F8).Consider FQ card.

Note: Particle tracks can be "flagged" when they cross designated surfaces and the contributions of these flagged tracks to a tally are listed separately in addition to the normal total tally.

5.6.14 FS Tally Segment (tally types 1, 2, 4, 6, 7)

Form: FS*n* s_1 ... s_k [T] [C]

Table 5-74. Tally Segment Card (FS)

Input Parameter	Description
n	Tally number.
s_i	Signed problem number of a segmenting surface.
T	Optional notation at the end of the input line to require the automatic total over all bins. (If absent, a total over all bins is not provided.)
C	Optional notation at the end of the input line to cause the bin values to be cumulative and the last time bin to be the total over all bins.

Default: No segmenting.

Use: Not with F8 pulse-height tallies. May require SD card. Consider FQ card.

Note: This card allows you to subdivide a cell or a surface of the problem geometry into segments for tallying purposes without having to specify extra cells just for tallying. The segmenting surfaces specified on the FS 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.

Note: If *k* surfaces are entered on the FS card, *k*+1 surface or volume segments (and tally bins) are created. If the symbol T is on the FS card, there will be an additional total bin. Tally *n* is subdivided into *k*+1 segment bins according to the order and sense of the segmenting surfaces listed on the FS card as follows:

Bin #1 The portion of tally *n* with the same sense with respect to surface s_1 as the sign given to s_1;

Bin #2 The portion of tally *n* 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.

Bin #*k* The portion of tally *n* 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.

Bin #*k*+1 The remaining portion of tally *n* not yet tallied, i.e., everything else.

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 third 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.

5.6.15 SD Segment Divisor (tally types 1, 2, 4, 6, 7)

Form: SD*n* $(d_{11}\ d_{12}\ \ldots\ d_{1m})\ (d_{21}\ d_{22}\ \ldots\ d_{2m})\ \ldots\ (d_{k1}\ d_{k2}\ \ldots\ d_{km})$

Table 5-75. Segment Divisor Card (SD)

Input Parameter	Description
n	Tally number (*n* cannot be zero).
k	Number of cells or surfaces of F card, including T if present.

m	Number of segmenting bins on the FS card, including the remainder segment, and the total segment if FS has a T.
d_{ij}	Area, volume, or mass of j^{th} segment of the i^{th} surface or cell bin for tally *n*.

Use: Not with detectors. The parentheses [( )] are optional. May be required with FS card. Can be used without FS card.

Note: For segmented cell volumes or surface areas defined by the FS card that are not automatically calculated by MCNPX, the user can provide volumes (tally type 4), areas (tally type 2), or masses (tally types 6 and 7) on this segment divisor card to be used by tally *n*. 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 tally surface current density. This card is similar to the VOL and AREA cards but is used for specific tallies, whereas the other two are used for the entire problem geometry.

Example:

```
F4:N    1  2  3  T
SD4     1  1  1  1
```

Note that the SD 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 MCNPX-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 SD card. These entries override entries on the VOL and AREA cards. See Section 5.6.15.1 for use with repeated structure tallies.

5.6.15.1 USE OF SD CARD FOR REPEATED STRUCTURES TALLIES

MCNPX may be unable to calculate required volumes or areas for tallies involving repeated-structure and lattice geometries. 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 SD 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 F card tally descriptions in the left column while the right column shows the SD card entries:

```
F4:N   (1 < 4 5 6 < 7 8)              SD4    v1
       (1 2 3 < 4 5 6 < 7 8)                 v1 v2 v3
       (1 2 3 < (4 5 6) < (7 8))             v1 v2 v3
       ((1 2 3) < 4 5 6 < 7 8)               v123
```

In this example, v_j is the volume of cell j and v_{123} is the 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 F card:

```
F4:N   (1 < 4 5 6 < 7 8)              SD4    v1(1) v1(2) v1(3) v1(4) v1(5) v1(6)
       (1 2 3 < 4 5 6 < 7 8)                 v1(1) v2(1) v3(1) v1(2) v2(2) v3(2) v1(3) ... v1(16) v2(16) v3(16)
       (1 2 3 < (4 5 6) < (7 8))             v1 v2 v3
       ((1 2 3) < 4 5 6 < 7 8)               v123(1) v123(2) v123(3) v123(4) v123(5) v123(6)
```

In this example, v_i^j is the volume of cell i for bin j and v_{123}^j is the 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 for each generated bin will not be calculated. The bin generation order is explained previously in the F 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 above 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.

5.6.16 FU Special Tally or TALLYX Input

Form: FU*n* [x_1 x_2 ... x_k] [NT] [C]

Table 5-76. TALLYX Input Card (FU)

Input Parameter	Description
n	Tally number.
x_i	Input parameter establishing user bin i.
NT	Optional entry to inhibit MCNPX from automatically providing the total over all specified bins.
C	Optional entry that causes the bin values to be cumulative.

Default: If the FU card is absent, subroutine TALLYX is not called.

Use: Used with a user-supplied TALLYX subroutine or FT card.

Note: This card is used with a user-supplied tally modification subroutine TALLYX and some cases of the FT card. If the FU card has no input parameters, TALLYX will be called but no user bins will be created. The *k* entries on the FU 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. The MCNPX developer's guide (not yet released) will contain additional information.

5.6.17 FT Special Treatments for Tallies

Form: FT*n* id_1 $p_{1,1}$ $p_{1,2}$ $p_{1,3}$ ... id_2 $p_{2,1}$ $p_{2,2}$ $p_{2,3}$ ...

Table 5-77. Special Treatment for Tallies Card (FT)

Input Parameter	Description
n	Tally number.
id_i	The alphabetic keyword identifier for a special treatment. (See list below.)
$p_{i,j}$	Input parameters for the treatment specified by id_i: either a number, a parenthesis, or a colon
Keyword	**Description**
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.†
ELC	Electron current tally.
PTT	Put different multigroup particle types in different user bins.†
PHL	Pulse-height light tally with anticoincidence.
CAP	Coincidence capture.
RES	Residual nuclei.

† Requires an FU card; treatments that require or allow an FU card are not compatible with each other.

Default: If the FT card is absent, there is no special treatment for tally *n*.

Use: Optional; as needed.

A description of the twelve available special treatments follows with an explanation of the allowed parameters for each:

1. 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.

2. GEB *a b c*

   The parameters specify the full width at half maximum (FWHM) 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 1/MeV, respectively. The energy actually scored is sampled from a Gaussian with that FWHM.

3. 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*.

4. INC

   No parameters follow the INC keyword but an FU 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. The result is that the tally is subdivided into bins according to how many collisions have occurred.

5. ICD

   No parameters follow the keyword ICD but an FU 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 FU card, the score is not made. The result is that the detector tally is subdivided into bins according to which cell had the source or collision resulting in the detector score.

6. SCX *k*

   The parameter *k* is the name of one of the source distributions and is the *k* that appears on the SI*k* 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*.

7. SCD

No parameters follow the keyword SCD but an FU card is required. Its bins are a list of source distribution numbers from SI*k* cards. The scores for tally *n* are then binned according to which distribution listed on the FU 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 FU 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 FC 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.

8. ELC *c*

The single parameter *c* of ELC specifies how the charge of a particle is to affect the scoring of a tally. Normally, a tally gives particle current without regard for the charge of the particles. Additionally, this treatment can create separate bins for particles and antiparticles. There are three possible values for *c*:

- specify *c*=1 to cause negatively charged particles to make negative scores,
- specify *c*=2 to put charged particles and antiparticles into separate user bins, and
- specify *c*=3 for the effect of both *c*=1 and *c*=2.

If *c*= 2 or 3, three user bins (e.g., positrons, electrons, and total) are created.

9. PTT

No parameters follow the keyword PTT but an FU 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, 0.511 0 would be for electrons and photons masquerading as neutrons.

10. PHL n t_{a1} b_{a1} t_{a2} b_{a2} ... m t_{b1} b_{b1} t_{b2} b_{b2} ...

The PHL option models a pulse-height light tally with anticoincidence. This option allows the F8 tally to be based on energy/light deposition in one or two other regions as specified via one or two F6 tallies.

The parameters for keyword PHL are the following:

n	is the number of F6 tallies for the first detector region,
t_{ai} b_{ai}	are the pairings of tally number and F-bin number (see Table 5-78) for the n F6 tallies of the first detector region,
m	is the number of F6 tallies for the second detector region, and
t_{bi} b_{bi}	are the pairings of tally number and F-bin number for the m F6 tallies of the second detector region.

When m is nonzero, indicating the use of two detector regions, an FU card is required for the F8 tally. The entries on the FU card are presented in units of electron-equivalent light (MeV_{ee}) and must increase monotonically. The particle type indicated on the F8 tally does not matter because this tally allows a combination of light output from various particle types. If b_{an} is zero, then the number of cell bins on the F8 card must match that on the corresponding t_{an} tally card. Setting b_{an} to zero allows for a lattice pulse-height PHL tally.

Examples:

Case 1

```
F8:N       5
FT8   PHL  1  6  1  0
E8         1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0
F6:E       5
DE6   LIN  1.0  1.5  2.0  2.5  3.0  3.5 10.0
DF6   LIN  1.0  1.1  1.2  1.3  1.4  1.5  1.6
FT6   GEB  A  B  C
```

Case 2

```
F8:N 5
FT8   PHL  1  6  1  1  16  1
E8         1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0
FU8        1.5  2.5  3.5  4.5  5.5  6.5  7.5  8.5
F6:E       5
DE6   LIN  1.0  1.5  2.0  2.5  3.0  3.5 10.0
DF6   LIN  1.0  1.1  1.2  1.3  1.4  1.5  1.6
FT6   GEB A B C
```

```
F16:E      6
DE16  LIN  1.0  1.5  2.0  2.5  3.0  3.5 10.0
DF16  LIN  1.0  1.1  1.2  1.3  1.4  1.5  1.6
FT16  GEB  A  B  C
```

In both cases, the F6 tallies convert energy deposition to equivalent light (units in millielectron volts). SD cards are not required with the F6 tallies because these divisors renormalize only the printed output for the F6 tallies and not the values stored in the tally arrays (thus, the F8 tally will result in the same value, regardless of whether the F6 tally has an SD card). The DE/DF conversion is based on the incident particle energy, and the values on the DF card should be the dL/dE for that incident particle energy. Thus, the F6 tally will multiply the dL/dE values by the energy deposition to give the light output (ΔL) summed over each track. Also, no energy bins exist for the F6 tallies. The F8 tally uses the total light output. Energy bins (E6 card) can be added, but the F8 tally will use the value from the total bin. Similarly, for other bins associated with the F6 tally, in each case, the TFC bin is used to extract the value for the F8 tally (see the TF card to alter this). The FT GEB cards are used to perform Gaussian broadening on these tally values; however, this is done only at the end of the particle history to determine the light output value used in the pulse-height tally.

In Case 1, the electron light output from only one region (cell 5) is used to subdivide the pulse-height tally. In this case, a pulse of 1 (input source weight) is put into the first E8 bin when the light output in cell 5 is <1 MeV. It is placed in the second E8 bin when the light output is between 1 and 2 MeV, etc. A zero F6 tally will result in no F8 tally.

In Case 2, the light output from two regions (cells 5 and 6) is used to subdivide the pulse-height tally. This case is useful for coincidence/anticoincidence applications. A pulse of 1 (input source weight) is put into the first E8 bin and into the first FU8 bin when the light output in cell 5 is <1.0 MeV *and* the light output in cell 6 is <1.5 MeV. This pulse is put into the first E8 bin and into the second FU8 bin when the light output in cell 5 is <1.0 MeV *and* the light output in cell 6 is between 1.5 and 2.5 MeV. A zero light output in both cells will result in no F8 tally. A zero light output in cell 5 (tally 6) with a nonzero light output in cell 6 (tally 16) will result in a pulse in the corresponding FU8 bin. Similarly, for a zero light output in cell 6 and a nonzero light output in cell 5, a pulse will be put into the corresponding E8 bin. Note that the E8 and FU8 bins do not have to be the same and typically would not be unless the detector regions were of similar material and size. Separate F6 tallies (as in Case 2, F6 and F16) are needed only when the two regions have different light conversion functions. If the two regions are of the same material, then a single F6 tally can be used as follows:

```
F8:N 5
```

```
FT8   PHL  2  6  1  6  2  0
E8         1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0
FU8        1.5  2.5  3.5  4.5  5.5  6.5  7.5  8.5
F6:E       5  6
DE6   LIN  1.0  1.5  2.0  2.5  3.0  3.5  10.0
DF6   LIN  1.0  1.1  1.2  1.3  1.4  1.5  1.6
```

Currently, it is not important what cell is listed on the F8 card because this tally is made only at the end of a particle history and depends only on the tally results of the listed F6 tallies. Having multiple cells listed on the F8 card is meaningful only when the F-bin parameter (i.e., b_{an} or b_{bn}) of the FT PHL option is zero, indicating a lattice grid of detector regions. Otherwise, each additional F8 cell bin simply will be a duplicate of the first cell bin.

11. CAP [$-m_c$] [$-m_o$] i_1 i_2 [GATE td tw] ...

The FT8 capture tally scores the number of captures in specified combinations of nuclides at the end of each history. Time gating with predelay and gate width is optional [SWI04]. It is particularly useful for neutron coincidence detectors. In addition, captures may be written to an auxiliary output file, PTRAC. Section 5.8.7 describes the PTRAC capture file.

The FT8 CAP option converts the pulse-height tally to a neutron capture tally. Variance reduction is no longer allowed, time bins are allowed (unlike other F8 tallies), cosine bins are used to store capture frequencies and moments, and print table 118 is created in the output file.

The parameters for keyword CAP are described as follows:

m_c is the optional maximum number of captures (DEFAULT=21),
m_o is the optional maximum number of moments (DEFAULT=12), and
i_n are the capture nuclides such as 3006 or 5010 for ^{6}Li or ^{10}B.

In addition, the time gate keyword GATE may appear with its parameters, td and tw, where

td is the predelay time and
tw is the gate width.

Example 1:

```
F8:N       2  (5  6)  7  T
FT8   CAP  3006   5010
T8         1   7LOG   1E8
```

In this example, captures and moments are tallied in cells 2, 7, in the combination of 5 and 6 and in the total over cells 2, 5, 6, 7. The captures by either ^{6}Li or ^{10}B are

tallied. Results are tabulated in time bins at 1, 10, 100, 1000, 1e4, 1e5, 1e6, 1e7, and 1e8 shakes—that is, in the range of 10 nanoseconds to 1 second.

Example 2:

```
F8:N          4
FT8 CAP    2003   GATE  0.5  0.4
```

In this example, ^{3}He captures and moments are tallied in cell `4`. There is a time gate with a predelay of `0.5` shakes (5e-9 seconds) and a width of `0.4` shakes (4e-9 seconds).

The addition of the predelay and time gate width changes the capture tally scoring. When a neutron is captured at time t_0 in the specified cell by the specified nuclide, the gate is "turned on." If the predelay is t_1 and the gate width is t_2, then all captures between $t_0 + t_1$ and $t_0 + t_1 + t_2$ are counted. For a history with no captures, no events are scored. With one capture, 0 events are scored. With two captures, the first turns on the time gate at time t_0 and scores 0; the second will score one event if it is captured between $t_0 + t_1$ and $t_0 + t_1 + t_2$, or score another 0 if outside the gate.

CAUTION: Coincidence counting of capture multiplicities and moments requires analog capture: `CUT:N 2J 0 0`. Calculations must be totally analog with no variance reduction. Fission multiplicity also is required: `PHYS:N J 100 3J -1`. An `FT8 CAP` tally in an input file will automatically set analog capture, fission multiplicity, and exit with error messages if variance reduction is used.

The capture tallies may be written to a PTRAC file for further analysis by auxiliary codes. See Section 5.8.7 on the `PTRAC` card extensions.

12. `RES [`z_1 z_2`]` or `RES [`za_1 za_2 `...]`

The interaction of high-energy particles with target nuclei causes the production of many residual nuclei. The generated residual nuclei can be recorded to an `F8` tally if used with an `FT8 RES` special treatment option. The residuals are recorded at each interaction in the model physics; residual nuclei are not tabulated at collisions using table physics.

By default, the `FT RES` card with no entries causes the corresponding tally to create a user bin for each of the 2200+ possible residual nucleus ion types. A range of bins may be selected by specifying lower and upper proton numbers, z_1 and z_2, which correspond to a range of possible z values. If z_1 and z_2 are specified and a residual is generated with a higher or lower z, the residual will not be scored in the tally. To specify an explicit list of heavy ions to be tallied, provide ZZZAAA identifiers (za_i) after the `RES` keyword. When using the heavy ion particle type (`#`), the `FT RES`

options will work with type 1, 2, 4, and 6 tallies. The FT RES capability still works as a special feature for F8 tallies where it functions as a residual tally.

Example:

```
F4:#    6
FT4 RES  8016  20040  26000  92238
```

This combination of tally cards creates a track length tally in cell 6 and then creates four user bins for the isotopes 8016, 20040, 26000, and 92238. Specifying the elemental ZAID for iron (26000) will lump all iron isotopes into one bin.

The FT8 RES capability is particularly useful with the eighth LCA card entry, *noact*. When *noact*=–2 on the LCA card, the source particle immediately collides in the source material. All subsequent daughter particles then are transported without further collision, as if in a vacuum. The F8 tally with an FT8 RES special tally treatment is then simply the distribution of nuclides resulting from a single collision.

For additional information involving fission multiplicity see the example presented in Appendix E, Section E.7. More capture tally information and examples appear in Appendix E, Section E.8. To inspect a residual nuclei tally example, go to Appendix E, Section E.9.

5.6.18 TALLYX User-supplied Subroutine

Use: Called for tally *n* only if an FU card is in the INP file.

Note: TALLYX is called whenever a tally with an associated FU card but no FT card is scored. A discussion will appear in the MCNPX developer's guide, which is yet to be released.

5.6.19 TF Tally Fluctuation

Form: TF*n* i_f i_d i_u i_s i_m i_c i_e i_t

This card specifies the bin for which the tally fluctuation chart statistical information is calculated and the weight-window generator results are optimized.

Table 5-78. Tally Fluctuation Card (TF)

Input Parameter	Description
n	Non-zero tally number.
i_f	Ordinal number of cell, surface, or detector bin (F-bin) on F card. (DEFAULT: i_f=1, first bin)
i_d	Total, flagged, or uncollided flux (D-bin). (DEFAULT: i_d=1, total flux)
i_u	Ordinal number of user bin (U-bin). (DEFAULT: i_u=*last bin*)
i_s	Ordinal number of segment bin (S-bin). (DEFAULT: i_s=*last bin*)
i_m	Ordinal number of multiplier bin on FM card (M-bin). DEFAULT: i_m=1, first bin)
i_c	Ordinal number of cosine bin (C-bin). (DEFAULT: i_c=*last bin*)
i_e	Ordinal number of energy bin (E-bin). (DEFAULT: i_e=*last bin*)
i_t	Ordinal number of time bin (T-bin). (DEFAULT: i_t=*last bin*)

Use: Whenever one or more tally bins are more important than the default bin. Particularly useful in conjunction with the weight-window generator.

Example:

Suppose an F2 tally has four surface entries, is segmented 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 we wish a chart for the fifth energy bin of the third surface in the first segment, we would use

```
TF2   3  2J  1  2J  5
```

5.6.20 The Radiography Tally

MCNPX can generate simulated radiography images as one would expect to see from an x-ray or pinhole projection of an object containing the particle source. This allows the recording of both the direct (source) image as well as that due to background (scatter). This tool is an invaluable aid to the problem of image enhancement, or extracting the source image from a background of clutter. MCNPX includes two types of image capability; the pinhole image projection and the transmitted image projection. Radiography tallies may be input with either the standard MCNPX card names (PI, TIR, TIC) or the MCNP5 card names (FIP, FIR and FIC).

The radiography capability is based on point detector techniques, and is extensively described in SNO96 and SNO98. In essence, the radiography focal plane grid is an array of point detectors.

Radiography tallies use an assumption of isotropic scatter for contributions from collisions within the model regime. These estimators require the angular distribution data for particles produced in an interaction to predict the "next event." Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region.

5.6.20.1 PI (FIP) PINHOLE IMAGE PROJECTION

Form 1 (MCNPX): PI*n*:<*pl*> x_1 y_1 z_1 r_0 x_2 y_2 z_2 f_1 f_2 f_3

Form 2 (MCNP5): FIP*n*:<*pl*> x_1 y_1 z_1 r_0 x_2 y_2 z_2 f_1 f_2 f_3

Table 5-79. Pinhole Radiography Card (PI or FIP)

Input Parameter	Description
n	Tally number, tally type 5.
<*pl*>	Particle designator. Restriction: N or P only.
x_1, y_1, z_1	The coordinates of the pinhole.
r_0	Always 0 (zero) for this application. Note: Neither the pinhole nor the grid should be located within a highly scattering media.
x_2, y_2, z_2	The reference coordinates (center of object) that establish the reference direction cosines for the normal to the detector grid. This direction is defined as being from x_2, y_2, z_2 to the pinhole at x_1, y_1, z_1.
f_1	If f_1>0, this value is the radius of a cylindrical collimator, centered on and parallel to the reference direction, which establishes a radial field of view through the object.
f_2	The radius of the pinhole perpendicular to the reference direction. If f_2=0, this represents a perfect pinhole. If f_2>0, the point through which the particle contribution will pass is picked randomly. This simulates a less-than-perfect pinhole.
f_3	The distance from the pinhole at x_1, y_1, z_1 to the detector grid along the direction established from x_2, y_2, z_2 to x_1, y_1, z_1, and perpendicular to this reference vector.

Note: In the pinhole image projection case, a point is defined in space that acts much like the hole in a pinhole camera and is used to focus an image onto a grid which acts much like the photographic film. The pinhole is actually a point detector and is used to define the direction cosines of the contribution that is to be made to the grid. The pinhole position relative to the grid is also used to define the element of the grid into which this contribution is scored. Once the direction is established, a ray-trace contribution is made to the grid bin with attenuation being determined for

the material regions along that path. The source need not be within the object being imaged, nor does it need to produce the same type of particles that the detector grid has been programmed to score. The grid and pinhole will image either source or scattered events produced within the object (see NOTRN card in Section 5.8.5) for either photons or neutrons. These event type contributions can be binned within the grid tallies by binning as source only, total, or by using special binning relative to the number of collisions contributing cells, etc.

Note: The grid plane is in the two-dimensional *s*-*t* coordinate system where the *s*- and *t*-axes are orthogonal to the reference direction. The *s*- and *t*-dimensions are established from entries on tally segment (FS) and cosine (C) cards. In this use, the first entry sets the lower limit of the first bin, and the other entries set the upper limit of each of the bins. These limits are set relative to the intersection of the reference direction.

Note: The directions of the *t*-axis and *s*-axis of the grid are set up such that if the reference direction (the outward normal to the grid plane), is not parallel to the z-axis of the geometry, the *t*-axis of the grid is defined by the intersection of the grid plane and plane formed by the z-axis and the point where the reference direction would intersect the grid plane. 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 x-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.

Example:

```
FSn    -20.   99i   20.
Cn     -20.   99i   20.
```

These two cards set up a 100 x 100 grid that extends from -20 cm to 20 cm in both directions, and has 10,000 equal sized bins. These bins need not be equal in size nor do they need to be symmetric about the reference direction.

5.6.20.2 TIR (FIR) AND TIC (FIC) TRANSMITTED IMAGE PROJECTION

Rectangular grid:

Form 1 (MCNPX): TIR*n*:<*pl*> $x_1\ y_1\ z_1\ \ r_0\ \ x_2\ y_2\ z_2\ \ f_1\ f_2\ f_3$

Form 2 (MCNP5): FIR*n*:<*pl*> $x_1\ y_1\ z_1\ \ r_0\ \ x_2\ y_2\ z_2\ \ f_1\ f_2\ f_3$

Cylindrical grid:

Form 1 (MCNPX): TIC*n*:<*pl*> $x_1\ y_1\ z_1\ \ r_0\ \ x_2\ y_2\ z_2\ \ f_1\ f_2\ f_3$

Form 2 (MCNP5): FIC*n*:<*pl*> $x_1\ y_1\ z_1\ \ r_0\ \ x_2\ y_2\ z_2\ \ f_1\ f_2\ f_3$

Table 5-80. Transmitted Image Projection Cards (TIR or FIR and TIC or FIC)

Input Parameter	Description
n	Tally number, tally type 5.
<pl>	Particle designator. Restriction: N or P only.
x_1, y_1, z_1	The coordinates of the center of the grid defined by the tally segment (FS) and cosine (C) cards. In the cylindrical grid case, this defines the center of the cylinder on which the grid is established.
r_0	Always 0 (zero) in this application.
x_2, y_2, z_2	The reference coordinates (center of object) that establish the reference direction cosines for the outward normal to the detector grid plane, as from x_2, y_2, z_2 to x_1, y_1, z_1. This is used as the outward normal to the detector grid plane for the TIR case, and as the centerline of the cylinder for the TIC case.
f_1	If f_1=0, both the direct (source) and scattered contributions will be scored at the detector grid. If f_1=−1, only the scattered contributions will be scored.
f_2	Radial field of view. Plane grid case: Radial restriction relative to the center of the grid for contributions to be made. Cylindrical case: Radius of the cylinder on which the grid is to be established.
f_3	If f_3=0, all contributions are directed to the center of each grid bin. If f_3=−1, contributions are made with a random offset from the center of the grid bin. This offset remains fixed and is used as the offset for contributions to all of the grid bins for this event.

Note: In the transmitted image projection case, the grid acts like a film pack in an x-ray type image, or transmitted image projection. There is a cylindrical grid for generating an image. In both cases, for every source or scatter event a ray-trace contribution is made to every bin in the detector grid. This eliminates statistical fluctuations across the grid that would occur if the grid location of the contribution from each event were to be picked randomly, as would be the case if one used a DXTRAN sphere and a segmented surface tally. For each event, source or scatter, the direction to each of the grid points is determined, and an attenuated ray-trace contribution is made. As in pinhole image projection, there are no restrictions as to location or type of source used. These tallies automatically bin in a source-only and a total contribution, but could be further binned as described for the pinhole tally.

Note: The grid itself is established with the use of tally segment (FS) and cosine (C) cards in the same manner as described for the pinhole case in Section 5.6.20.1. However, x_1, y_1, z_1 are now the coordinates of the intersection of the reference direction and the grid plane. In the cylindrical grid case, the entries on the FS card are the distances along the symmetry axis of the cylinder and the entries on the C

card are the angles in degrees as measured counterclockwise from the positive *t*-axis.

Note: When this type of detector is being used in a problem, if a contribution is required from a source or scatter event, an attenuated contribution is made to each and every detector grid bin. Since for some types of source distributions, very few histories are required to image the direct or source contributions, an additional entry has been added to the NPS card to eliminate unwanted duplication of information from the source. (See Section 5.8.1.)

5.6.20.3 READING OR PLOTTING THE RADIOGRAPHY TALLY OUTPUT

The output of the two radiography tally options is contained in the MCTAL file. It can be formatted for use with external graphics programs with the GRIDCONV routine. The user is referred to Section 5.6.23.7 for information on how to use GRIDCONV. Pinhole and radiography tallies can also be plotted directly in the MCNPX tally plotter from RUNTPE or MCTAL files using the "FREE SC" command to give a 2-D contour plot of the *s*- and *t*-axes. They can also be plotted during the course of a calculation by incorporating an MPLOT card into the input file or by using the TTY interrupt capability to invoke MCPLOT.

5.6.21 TALNP Negate Printing of Tallies

Form: TALNP $-tal_1$ $-tal_2$ ... $-tal_i$

Table 5-81. Tally No Print (TALNP)

Input Parameter	Description
tal_i	List of (negative) tally numbers to be excluded from output file.

Default: None.

Use: Turns off printing of all of values in each of the grid bins in the OUTP file. The card TALNP with no arguments turns off the bin print for all tallies in the problem. If there are entries, it turns off the bin print for the tally numbers that are listed. If, after the run is completed, 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. The tally numbers are entered on the TALNP card as negative numbers.

5.6.22 PERT Perturbation

Form: PERT*n*:<*pl*> KEYWORD=*value(s)* ...

Table 5-82 Perturbation Card (PERT)

Input Parameter	Description
n	Unique, arbitrary perturbation number.
<*pl*>	Particle designator. Only three options allowed: neutron (N); photon (P); or combined neutron-photon (N,P). Not available for other particles.
Basic Keywords	**Description**
CELL	Comma or space delimited list of cells, c_1 ... c_K, to which to apply perturbation. Required.
MAT	Single material number, *m*, with which to fill all cells listed in CELL keyword.† Must have a corresponding M card.
RHO	Single value of perturbed density of cells listed after CELL keyword. If RHO>0, the perturbed density is given in units of atom density. If RHO<0, the perturbed density is given in units of gram density.
Advanced Keywords	**Description**
METHOD	Controls tally printing and controls perturbation method. If METHOD=+1, perform 1st and 2nd order perturbation calculation and print the differential change in the tally. (DEFAULT) If METHOD=−1, perform 1st and 2nd order perturbation calculation and print the perturbed tally. If METHOD=+2, perform 1st order perturbation calculation only and print the differential change in the tally. If METHOD=−2, perform 1st order perturbation calculation only and print the perturbed tally. If METHOD=+3, perform 2nd order perturbation calculation only and print the differential change in the tally. If METHOD=−3, perform 2nd order perturbation calculation only and print the perturbed tally.
ERG	Two entries, e_{LB} and e_{UB}, that provide the lower and upper bounds of the perturbations. (DEFAULT=all energies)
RXN	Reaction number(s) to which to apply perturbation. (DEFAULT=1) Restriction: RXN reaction numbers must be identical to FM card reaction numbers.

† Use MAT only if the perturbation changes the material from one cell material to another. Use with caution especially if more than one nuclide in the material is changed. New nuclide cannot be added in the new material card.

Use: Optional.

Note: Allows perturbations in cell material density, composition, or reaction cross-section data. Uses the first and second order differential operator technique. 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.

Note: The CELL keyword is required. Either the MAT or RHO keyword must be specified.

Limitations/Cautions:

1. Large (>30%) perturbations may be wrong if the 2nd-order Taylor Series expansion is insufficient. Look at the 1st and 2nd order terms separately for large perturbations to determine the significance of the 2nd order terms. If 2nd order terms are a significant fraction (20%–30%) of the total, the magnitude of the perturbation should be reduced to satisfy this condition. (No warning or error message is generated.)
2. Nuclide fraction changes (MAT option) are assumed to be independent. Differential cross terms are ignored. Stated another way, the perturbation estimate does not include the 2nd-order differential term when multiple isotopes are perturbed at once. This term is usually small unless two similar isotopes are involved. (No warning or error message is generated.)
3. FM tallies in perturbed cells can be wrong. Surface tallies and tallies in perturbed cells are safe. (WARNING message is generated.)
4. Detectors and pulse-height tallies fail (i.e., gives zero perturbation).
5. DXTRAN fails. (FATAL error message is generated.)
6. Cannot unvoid a region. (FATAL error message is generated.)
7. Cannot introduce a new nuclide into the perturbation. (FATAL error message is generated.)
8. Although there is no limit to the number of perturbations, each perturbation increases running time by 10%–20%.
9. Some perturbations (those with small changes) converge slowly.
10. The track length estimate of k_{eff} in criticality calculations assumes the fundamental eigenvector (fission distribution) is unchanged in the perturbed configuration.
11. Use caution when 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.
12. Limited to N and/or P problems.

Example 1:

```
PERT1:N,P    CELL=1   RHO=0.03
```

This perturbation specifies a density change to 0.03 atoms/b-cm 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  0.334    1002  0.333    8016  0.333
C     M8 material is heavy water
M8     1002  0.667    8016  0.333
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 -0.2  8016 -0.2  13027 -0.2  26000 -0.2  29000 -0.2
M15    1001 -0.2  8016 -0.2  13027 -0.2  26000 -0.2  29000 -0.4
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 (−0.2 to −0.4) 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 -0.167  8016 -0.167  13027 -0.167  26000 -0.167  29000 -0.333
```

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. Note that RHO=$-2.34 \times 2 = -4.68$ g/cm^3.

Example 5:

```
M4        6000.60C  0.5   6000.50C  0.5
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  0.1   8016  0.2    92235  0.7
M9       1001  0.1   8016  0.22   92235  0.7
F14:N    1
FM14    -1  1  -6  -7                $ k_eff 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 Limitation/Caution #10.)

Example 7:

```
1  1  -1.5    -1  2 -3  4 -5  6  $ mat 1 at 1.5 g/cm^3
.
.
.
M1      1001 0.4333  6000 0.2000  8016 0.3667   $ half water/plastic
M2      1001 0.6666  8016 0.3334                $ water
M3      1001 0.2000  6000 0.4000  8016 0.4000   $ 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.

5.6.23 TMESH The Mesh Tally

TMESH, CORA, CORB, CORC, ERGSH, MSHMF, RMESH, CMESH, SMESH, ENDMD

The mesh tally is a method of graphically displaying particle flux, dose, or other quantities on a rectangular, cylindrical, or spherical grid overlaid on top of the standard problem geometry. Particles are tracked through the independent mesh as part of the regular transport problem. The contents of each mesh cell are written to the RUNTPE file and can be plotted with the MCNPX geometry plotter superimposed over a plot of the problem geometry. The mesh tally data are also written to the MCTAL file and can be plotted with the MCNPX tally plotter, MCPLOT.

Further, the mesh tally data are written to the MDATA file at the end of each initial or continue run. The MDATA file can be converted into a number of standard formats suitable for reading by various graphical analysis packages. The conversion program, GRIDCONV, is supplied as part of the overall MCNPX package (Section 5.6.23.7). Analysis of this data is limited only by the capabilities of the graphical program being used.

For additional information involving superimposed geometry mesh tally see Appendix B, Section B.3.

5.6.23.1 SETTING UP THE MESH IN THE INP FILE

A mesh tally is defined by several cards that are described below. All of the control cards for mesh tallies must be in a block preceded by a card containing the word TMESH in the first five columns, and terminated by a card containing the word ENDMD in the first five columns. For each mesh tally card, the following set of cards must be present which give details about the mesh characteristics:

CORA*n* *corra(n,1), corra(n,2), ...*,
CORB*n* *corrb(n,1), corrb(n,2), ...*, and
CORC*n* *corrc(n,1), corrc(n,2), ...*,

where *n* is a user-defined mesh number. The mesh number *n* must end in 1, 2, 3, or 4 corresponding to the mesh tally type, and must not be the number of any other tally in the problem.

The entries on the CORA, CORB, and CORC cards describe a mesh in three coordinate directions as defined by the mesh type (rectangular, cylindrical, or spherical), prior to any transformation as specified by the TRANS keyword described below. The $ line terminator (often used to add comments to an input line) is not permitted within the mesh tally block.

To describe a rectangular mesh, the entries on the CORA card represent planes perpendicular to the x-axis, CORB entries are planes perpendicular to the y-axis, and CORC entries are planes perpendicular to the z-axis. Bins do not have to be equally spaced.

To describe a cylindrical mesh, the middle coordinate, CORB, is the untransformed z-axis, which is the symmetry axis of the cylinder, with radial meshes defined on the CORA input line. The first smallest radius must be equal to zero. The values following CORB define planes perpendicular to the untransformed z-axis. The values following CORC are positive angles relative to a counter-clockwise rotation about the untransformed z-axis. These angles, in degrees, are measured from the positive x-axis and must have at least one entry of 360, which is also required to be the last entry. The lower limit of zero degrees is implicit and never appears on the CORC card.

For spherical meshes, scoring will happen within a spherical volume, and can also be further defined to fall within a conical section defined by a polar angle (relative to the +z-axis) and azimuthal angle. The CORA card entries are sphere radii; inner and outer radii are required. The CORB entries define the polar angle meshing in which the polar angle ranges from 0 to 180 degrees, the 1st bin must be greater than 0 degrees, and the last bin must be 180. The CORC entries are the same as in the cylindrical case, with the 1st bin greater than 0 degrees and the last bin equal to 360. It is helpful in setting up spherical problems to think of the longitude-latitude coordinates on a globe.

The "I" data-input notation (Section 4.1.7.1) is allowed, enabling a large number of regularly spaced mesh points to be defined with a minimum of entries on the coordinate lines. All of the coordinate entries must be monotonically increasing for the tally mesh features to work properly, but do not need to be equally spaced. It should be noted that the size of these meshes scales with the product of the number of entries for the three coordinates. Machine memory could become a problem for very large meshes with fine spacing.

Additional cards which can be used with mesh tallies include the following:

ERGSH*n* e_1 e_2 ,
MSHMF*m* e_1 f_1 e_2 f_2 ... e_i f_i , and
FM*n* ... ,

where the values on the ERGSH card, e_1 and e_2, are the lower and upper energy limits for information to be stored to mesh tally *n*. The default is to consider all energies. The

value of *m* on the MSHMF card does not refer to a corresponding mesh tally; instead, *m* is an arbitrary user-assigned value between 1 and 9. The entries on the MSHMF card, e_i and f_i, are pairs of energies and the corresponding response functions; as many pairs as needed can be designated. Use of the FM card is limited to Type 1 mesh tallies (Section 5.6.23.2).

The structure of the mesh and what quantities are to be stored to the mesh tally are defined by control cards in the MCNPX INP file. The general forms of the mesh control cards are as follows:

```
RMESHn:<pl>    KEYWORD=value(s) ...
CMESHn:<pl>    KEYWORD=value(s) ...
SMESHn:<pl>    KEYWORD=value(s) ...
```

RMESH is a rectangular mesh, CMESH is a cylindrical mesh, and SMESH is a spherical mesh. (The notation (R/C/S)MESH will be used in subsequent sections to indicate any of the three mesh geometries.) The *n* is a user-defined mesh number in which the last digit of *n* defines the type of information to be stored in the mesh. The mesh tally number must be different from any other tally in the problem. For example, an F1:N tally will conflict with a RMESH1:N tally. The parameter <*pl*> is the particle type being tallied, which may be absent depending on the type of mesh tally. Up to 10 keywords are permitted, depending on mesh type. In MCNPX, there are four general types of mesh tally cards, each with a different set of keywords. These four mesh-tally types are described in the sections that follow.

The type 1 (particle track) and type 3 (energy deposition) mesh tallies work with heavy ions although there is no capability to separate out contributions from particular heavy ion species. In void regions, electron mesh tallies will generate zeros; to circumvent this issue, a material of very low density (but ≥1e-15 g/cm^3) may be specified in these regions.

For additional examples involving mesh tally see Appendix B, Section B.3.1.

5.6.23.2 TRACK-AVERAGED MESH TALLY (TYPE 1)

The first mesh type scores track averaged data: flux, fluence, or current. The values can be weighted by an MSHMF card, through a dose conversion-coefficient function (Section 5.6.23.6), or for energy deposition.

Form: (R/C/S)MESH*n*:<*pl*> KEYWORD=*value(s)* ...

where n= 1, 11, 21, 31, ..., and <*pl*> is the particle type. (Note: Number must not duplicate one used for an F1 tally.) There is no default. (See Table 4-1.)

Table 5-83. Track-Averaged Mesh Tally (type 1)

Keyword	Description
TRAKS	If TRAKS appears on the input line, tally the number of tracks through each mesh volume. No values accompany the keyword.
FLUX	If FLUX appears on the input line, then the average fluence is particle weight times track length divided by volume in units of number/cm^2. If the source is considered to be steady state in particles per second, then the value becomes flux in number/cm^2/second. No values accompany the keyword. (DEFAULT)
DOSE	Causes the average flux to be modified by an energy-dependent dose function. The DOSE keyword may be followed by up to four entries, where If the first entry is 1 to 9, an energy-dependent dose function must be supplied by the user on an MSHMF card. If the first entry is 10, 20, 31–35, or 40, the dose function is an ANSI standard dose as on the DF card. The next three optional entries define additional standard dose options: *it*, iu, and *fac*. See Section 5.6.23.6 and Section 5.6.8—DF card. If no entries follow the DOSE keyword, the default entries are 10, 1, 1, and 1.0, which form inputs into the dose conversion-coefficient function. Results are in rem/hour/source_particle.
POPUL	If POPUL appears on the input line, tally the population (i.e., weight times the track length) in each volume.
PEDEP	If PEDEP appears on the input line, scores the average energy deposition per unit volume (MeV/cm^3/source_particle) for the particle type <*pl*>. In contrast to the 3rd type of mesh tally, energy deposition can be obtained in this option for any particular particle. This option allows one to score the equivalent of an F6:<*pl*> (see Section 5.6.1) heating tally for the particle type <*pl*>. Note, the mesh is independent of problem geometry, and a mesh cell may cover regions of several different masses. Therefore the normalization of the PEDEP option is per mesh cell volume, not per unit mass.

Keyword	Description
MFACT	Can have from one to four numerical entries following it. The value of the first entry, *m*, is an arbitrary number that refers to an energy-dependent response function given on an MSHMF*m* card. If *m*=-1, then it is followed by a single value that is used as a constant multiplier. (No default) The second entry is 1 for linear interpolation and 2 for logarithmic interpolation. (DEFAULT=1) If the third entry is zero, the response is a function of the energy deposited; otherwise the response is a function of the current particle energy. (DEFAULT=0) The fourth entry is a constant multiplier and is the only floating-point entry allowed. (DEFAULT=1.0) If any of the last three entries is used, the entries preceding it must be present so that the order of the entries is preserved. Only one MFACT keyword may be used per tally.
TRANS	Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.

Note: It is possible to use the FM tally multiplier card (Section 5.6.7) to calculate reaction rates in a type 1 mesh tally if both of the following criteria hold:

- the FM card must *not* appear within the mesh data block between the TMESH and ENDMD cards; and
- if the multiplier involves a *mt* reaction identifier, the FM card must be included in an equivalent F4 tally specification.

Note: If a TR card is used with a mesh tally, it must appear outside of the mesh data block between the TMESH and ENDMD cards.

5.6.23.3 SOURCE MESH TALLY (TYPE 2)

The second type of mesh tally scores source-point data, in which the weight of the source particles $\langle pl \rangle_1$, $\langle pl \rangle_2$, $\langle pl \rangle_3$, ..., and $\langle pl \rangle_n$ are scored in mesh arrays 1, 2, 3, ..., *n*. A separate mesh tally grid will be produced for each particle chosen.

The usefulness of this method involves locating the source of particles entering a certain volume, or crossing a certain surface. The user asks the question, "If particles of a certain type are present, where did they originally come from?" In shielding problems, the user can then try to shield the particles at their source.

This mesh tally is normalized as number of particles per SDEF source particle.

Form: (R/C/S)MESH*n* $\langle pl \rangle_1$ $\langle pl \rangle_2$ ... TRANS

where *n*= 2, 12, 22, 32, …. (Note: Number must not duplicate one used for an F2 tally.)

Table 5-84. Source Mesh Tally (type 2)

Input Parameter	Description
$<pl>_i$	Particle designators, i.e., N, P, E, etc. (See Table 4-1.) Restriction: $i \leq 10$ Source particles are considered to be those that come directly from the source defined by the user and those new particles created during nuclear interactions. One should be aware that storage requirements can get very large, very fast, depending on the dimensions of the mesh, because a separate histogram is created for each particle chosen. If there are no entries on this card, the information for neutrons is scored by default.
Keyword	**Description**
TRANS	Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.

5.6.23.4 ENERGY DEPOSITION MESH TALLY (TYPE 3)

The third type of mesh tally scores energy deposition data in which the energy deposited per unit volume from *all particles* is included. This can be due to the slowing of a charged particle, the recoil of a nuclei, energy deposited locally for particles born but not tracked, etc. The results are similar to the scoring of an +F6 tally as described in Section 5.6.1.1.

Note that in MCNPX the option to track energy deposition from one type of particle alone in a problem is included in the first mesh tally type. (See Table 5-83, keyword PEDEP.) The energy deposition mesh tally described here will give results for all particles tracked in the problem, and has no option to specify a particular particle.

Note: Because the mesh is independent of problem geometry, a mesh cell may cover regions of several different masses. Therefore the normalization of the output is per unit volume (MeV/cm^3/source_particle), not per unit mass.

Form: (R/C/S)MESH*n* TOTAL DE/DX RECOL TLEST DELCT MFACT NTERG TRANS

where *n*= 3, 13, 23, 33, ...

Table 5-85. Energy Deposition Mesh Tally (type 3)

Keyword	Description
TOTAL	If TOTAL appears on the input line, score energy deposited from any source. (DEFAULT)
DE/DX	If DE/DX appears on the input line, score ionization from charged particles.
RECOL	If RECOL appears on the input line, score energy transferred to recoil nuclei above tabular limits.
TLEST	If TLEST appears on the input line, score track length folded with tabular heating numbers.
DELCT	If DELCT appears on the input line, score non-tracked particles assumed to deposit energy locally.
MFACT	Can have from one to four numerical entries following it. The value of the first entry, *m*, is an arbitrary number that refers to an energy-dependent response function given on an MSHMF*m* card. If *m*=-1, then it is followed by a single value that is used as a constant multiplier. (No default) The second entry is 1 for linear interpolation, and 2 for logarithmic interpolation. (DEFAULT=1) If the third entry is zero, the response is a function of the energy deposited; otherwise the response is a function of the current particle energy. (DEFAULT=0) The fourth entry is a constant multiplier and is the only floating-point entry allowed (DEFAULT=1.0). If any of the last three entries are used, the entries preceding it must be present so that the order of the entries is preserved. Only one MFACT keyword may be used per tally.
NTERG	If NTERG appears on the input line, the local energy deposition due to particles otherwise not considered or tracked in this problem is recorded in a separate mesh array. This allows the user to ascertain the potential error in the problem caused by allowing energy from non-tracked particles to be deposited locally. This can be a serious problem in neglecting the tracking of high-energy photons or electrons.
TRANS	Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.

5.6.23.5 DXTRAN MESH TALLY (TYPE 4)

The fourth type of mesh tally scores the tracks contributing to all detectors defined in the input file for the <*pl*> particle type. If this mesh card is preceded by an asterisk (*), tracks contributing to DXTRAN spheres (see Section 5.7.8) are recorded. Obviously, a point detector or DXTRAN sphere must already be defined in the problem, and the tally will record tracks corresponding to all such defined items in the problem. The user

should limit the geometrical boundaries of the grid to focus on a specific detector or DXTRAN sphere in order to prevent confusion with multiple detectors (although the convergence of the particle tracks should help in the interpretation).This tally is an analytical tool useful in determining the behavior of detectors and how they may be effectively placed in the problem.

Form: (R/C/S)MESH*n*:<*pl*> TRANS

where *n*= 4,14, 24, 34, ..., and <*pl*> is a particle type [neutron (N) or photon (P)]. (Note: Number must not duplicate one used for an F4 tally.) There is no default. (See Table 4-1.)

Table 5-86. DXTRAN Mesh Tally (type 4)

Keyword	Description
TRANS	Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.

5.6.23.6 DOSE CONVERSION COEFFICIENTS

MCNPX contains a number of standard dose conversion coefficients. This feature is accessed through the DOSE keyword of the type 1 mesh tally. (See Section 5.6.23.2 and Appendix H.)

Form: DOSE *ic int iu fac*

Table 5-87. DOSE Parameter Descriptions

Parameter	Description
ic	Choice of conversion coefficient. Note: The 10 and 20 options are *dose equivalent* (H), i.e., absorbed dose at a point in tissue weighted by a distribution of quality factors (Q) related to the LET distribution of radiation at that point. The 30 options *are equivalent dose* (H_t) based on an average absorbed dose in the tissue or organ (D_t), weighted by the radiation weighting factor (w_r), summed over all component radiations. Neutrons: If *ic*=10 ⇒ ICRP-21 1971 (DEFAULT) If *ic*=20 ⇒ NCRP-38 1971, ANSI/ANS 6.1.1—1977 If *ic*=31 ⇒ ANSI/ANS 6.1.1—1991 (AP anterior-posterior) If *ic*=32 ⇒ ANSI/ANS 6.1.1—1991 (PA posterior-anterior) If *ic*=33 ⇒ ANSI/ANS 6.1.1—1991 (LAT side exposure) If *ic*=34 ⇒ ANSI/ANS 6.1.1—1991 (ROT normal to length & rotationally symmetric) If *ic*=40 ⇒ ICRP-74 1996 ambient dose equivalent Photons If *ic*=10 ⇒ ICRP-21 1971 (DEFAULT) If *ic*=20 ⇒ Claiborne & Trubey, ANSI/ANS 6.1.1-1977 If *ic*=31 ⇒ ANSI/ANS 6.1.1—1991 (AP anterior-posterior) If *ic*=32 ⇒ ANSI/ANS 6.1.1—1991 (PA posterior-anterior) If *ic*=33 ⇒ ANSI/ANS 6.1.1—1991 (LAT side exposure) If *ic*=34 ⇒ ANSI/ANS 6.1.1—1991 (ROT normal to length & rotationally symmetric) If *ic*=35 ⇒ ANSI/ANS 6.1.1—1991 (ISO isotropic)
int	Interpolation method If *int*=1, then use logarithmic interpolation in energy, linear in function. (DEFAULT) If *int*=2, then use linear interpolation in energy and function. If *int*=3, then use recommended analytic parameterization (not available for *ic*=10).
iu	Units of the result. If *iu*=1, units will be (rem/h)/(particles/cm^2-sec). If *iu*=2, units will be (sieverts/h)/(particles/cm^2-sec). (DEFAULT)
fac	Normalization factor for dose. The dose conversion-coefficient function result will be multiplied by any factor greater than or equal to 0.0. (For example, *fac*=1.0 means no change.) The value must be a real number. (DEFAULT: fac=1.0) Certain special options are also available. If *fac*=-1.0, then normalize dose conversion results to Q=20 by dividing out the parametric form of Q, which equals 5.0+17.0*exp(-(ln(2E))/*2/6) from ICRP60 (1990), paragraph A12. If *fac*=-2.0, then apply LANSCE albatross response function.

5.6.23.7 PROCESSING THE MESH TALLY RESULTS

The values of the coordinates, the tally quantity within each mesh bin, and the relative errors are all written by MCNPX to the RUNTPE file, the optional MCTAL file, and an unformatted binary file named MDATA.

The mesh tallies may be plotted with the MCNPX geometry plotter either during the course of a run (by placing an MPLOT card in the input file or by using the TTY interrupt capability to invoke MCPLOT) or after a run using the RUNTPE file and the MCNPX geometry plotter. These plots are superimposed over 2-D views of the problem geometry. Note that the geometry plotter must be accessed via the tally plotter. For example,

```
MCNPX Z
MCPLOT>RUNTPE=<filename>
MCPLOT>PLOT
PLOT>py 4 ex 40 or 0 4 0 la 0 1 tal12 color on la 0 0 con 0 100 %
```

After the PLOT command, the MCNPX interactive geometry plotter appears. If the Plot> button (bottom center) is clicked, then the above command after the PLOT> prompt can be entered. Alternatively, the mesh tally superimposed on the geometry can be viewed by clicking buttons (tal, etc.) of the interactive tally plot. Note that the command tal12 has no space between tal and 12 and that the cell labels (la 0 1 tal12) must be turned on to set the color (color on) and then be turned off (la 0 0).

The second mesh tally processing option is to use the MCNPX tally plotter (MCPLOT) after a run with the optional MCTAL file (see PRDMP card). For example,

```
MCNPX Z
MCPLOT>RMCTAL=<filename>
tal 12 free ik
```

Note that there is a space between tal and 12 and that the mesh tally dimensionality (i,j,k) corresponding to CORA, CORB, and CORC) must be specified.

The third mesh tally processing option is to postprocess the MDATA (or MCTAL) file with GRIDCONV and then use an external graphics package.

The GRIDCONV program is a post-processing code used with the MDATA output file. It can also be used with the MCTAL output file from the radiography tally as described in Section 5.6.20.3. GRIDCONV converts the data arrays in MDATA to forms compatible with various external graphics packages. Those supported in MCNPX include the following:

PAW — PAW (Physics Analysis Workstation) is distributed through the CERN Program Library.

(http://wwwasd.web.cern.ch.wwwasd/paw/index.html)

IDL	IDL (Interactive Data Language) is a product of ITT Visual Information Solutions, 4990 Pearl East Circle, Boulder, CO 80301 (http://www.ittvis.com/idl/index.asp)
Tecplot	Tecplot is a product of Amtec Engineering, Inc., 13920 SE Eastgate Way, Ste. 220, Bellevue, WA 98005 (http://www.amtec.com)
GNUPLOT	Freeware. (http://www.gnuplot.info). Only 1- and 2-D plots supported.

Like MCNPX, GRIDCONV will compile on several platforms. However, currently the PAW part of the code will not compile on the Linux operating system, since some of the PAW subroutines needed by the code are not Linux compatible. GRIDCONV may be compiled with a 'NOPAW' option.

Once GRIDCONV is compiled, one need type only the word 'GRIDCONV' to execute the code. The code will then prompt the user for information that is required such as file type, filenames, etc. In most cases the default value is used and a return is all that is necessary.

Once the header information from MDATA has been read from the file, GRIDCONV can either produce an ASCII file from a binary or generate the required graphics input files as requested by the user. (Note that the ASCII file contains raw data not normalized to the number of source particles.) The reason for the option to write an ASCII file is that sometimes users will want to look at the numbers in the MDATA file before doing any plotting, or check the numerical results for a test case. The ASCII option is also very useful for porting the MDATA file to another computer platform, and for reading the data into graphics packages not currently supported by GRIDCONV.

GRIDCONV is currently set up to generate one-, two-, or three-dimensional graphics input files with any combination of binning choices. Once the input file has been generated, GRIDCONV gives the user the option of producing another file from the currently selected mesh tally, selecting a different mesh tally available on this MDATA file, or reading information from a different file. Of course there is always the option to exit the program.

The capabilities of GRIDCONV have recently been expanded so that any and all tallies written to MCTAL can be processed. The code is still interactive, but now shows all tallies in the problem, from which any may be selected. The user has the option of generating one- or two-dimensional output. The user is then told about the bin structure so the one or two free variables may be selected. The energy is the default independent variable in the one-dimensional case. There is no default for the two-dimensional case. The order in which the two-dimensional bin variables are selected does not make any difference to the output, in that the order of the processing will be as it appears on the

MCTAL file. GRIDCONV will work with MCTAL files produced both by MCNPX and MCNP.

For additional information involving superimposed geometry mesh tallies see Appendix B, Section B.3.2.

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5.7 VARIANCE REDUCTION

IMP, WWG, WWGE, WWGT, WWP, WWN, WWE, WWT, MESH, EXT, VECT, FCL, DD, PD, DXT, DXC, BBREM, SPABI, ESPLT, PWT

5.7.1 IMP Cell Importance

Form 1 (cell card entry): IMP:<*pl*>=*x*

Form 2 (data card): IMP:<*pl*> x_1 x_2 ... x_j ...

Table 5-88. Cell Importance Card (IMP:<*pl*>)

Input Parameter	Description
<*pl*>	Any particle symbol or IPT number from Table 4-1.
x	Cell importance.
x_j	Importance of cell j. Number of entries must equal number of cells in the problem.

Default: The default importance for all particles listed on the MODE card is unity. If a cell importance is set to zero for any particle, all importances for that cell will be set to zero unless specified otherwise.

Use: An IMP:<*pl*> card is required with an entry for every cell unless a WWN weight-window bound card is used.

Note: The importance of a cell is used (1) to terminate the particle's history if the importance is zero, (2) for geometry splitting and Russian roulette to help particles move to more important regions of the geometry, (3) and in the weight cutoff game. An importance assigned to a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell.

Note: Assignment of IMP=0 for some particle types within a cell and not others is a fatal error. This condition is allowed only with the FATAL option (See Table 3-2.)

Note: 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.

Note: 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.

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 the cases (that is, with probability=0.5), but it will be followed in the remaining cases with twice the weight.

5.7.2 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 cards) and energy splitting (ESPLT cards) for specifying space, energy, and time importance functions. The advantages of weight windows are that they (1) provide an importance function in space and time, space and energy, or space and energy and time; (2) control particle weights; (3) are more compatible with other variance-reduction features such as the exponential transform (EXT card); (4) can be applied at surface crossings, collisions, or both; (5) can control the severity of splitting or Russian roulette; (6) can be turned off in selected space, time, 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.

A cell-based weight-window lower bound of a cell that is in a universe is interpreted as a multiplier of the weight-window lower bound of the filled cell. Mesh-based windows are recommended in repeated structures.

5.7.2.1 WWG WEIGHT-WINDOW GENERATOR

Form: WWG i_t i_c w_g J J J J i_E

Table 5-89. Weight-Window Generator Card (WWG)

Input Parameter	Description
i_t	Problem tally number (n of the F card). The particular tally bin for which the weight-window generator is optimized is defined by the TF card.
i_c	Invokes cell- or mesh-based weight-window generator. If i_c>0, then invoke cell-based weight-window generator with i_c as the reference cell (typically a source cell). If i_c=0, then invoke mesh-based weight-window generator. (MESH card required.)
w_g	Value of the generated lower weight-window bound for cell i_c or for the reference mesh. (See MESH card.) If w_g=0, then the lower bound will be half the average source weight.
J J J J	Unused placeholders.
i_E	Toggles energy- or time-dependent weight windows. If i_E=0, then interpret WWGE card as energy bins. If i_E=1, then interpret WWGE card as time bins. (Note: Parameter i_E remains to allow backward compatibility. See WWGT card for time-dependent weight windows.)

Default: No weight-window values are generated.

Use: Optional.

Note: For cell-based weight windows, the value w_g of the lower weight-window bound for reference cell i_c is chosen so that the source weight will start within the weight window, when possible. The reference cell i_c is often chosen as the source cell. For mesh-based weight windows, a reference point (REF) is provided instead of a cell number. (See MESH card, Section 5.7.2.8.)

Note: 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 WWN*i* cards that are printed, evaluated, and summarized in the OUTP file and are also written to the weight-window generator output file WWOUT. For the mesh-based weight-window generator, the importance function and the mesh description are written only to the WWOUT file. 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.

5.7.2.2 WWGE WEIGHT-WINDOW GENERATION ENERGIES

Form: WWGE:<*pl*> $e_1\ e_2\ \ldots\ e_j$

where $j \leq 15$.

Table 5-90. Weight-Window Generation Energies Card (WWGE)

Input Parameter	Description
<*pl*>	Particle designator.
e_i	Upper energy 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 interval will be established corresponding to the energy limits of the problem being run. If the card is present but has no entries, ten energy bins will be generated with energies of $e_i = 10^{i-8}$ MeV, for $i = 1, 2, \ldots, 10$. Both the single energy and the energy-dependent windows are generated.

Use: Optional.

Note: If this card is present, energy-dependent weight windows are generated and written to the WWOUT file and, for cell-based weight windows, to the OUTP file. In addition, single-group energy-independent weight windows are written to a separate output file, WWONE. Energy-independent weight windows are useful for trouble-shooting the energy-dependent weight windows on the WWOUT file. The WWONE file format is the same as that of the WWOUT file.

5.7.2.3 WWGT WEIGHT-WINDOW GENERATION TIMES

Form: WWGT:<*pl*> $t_1\ t_2\ \ldots\ t_j$

where $j \leq 15$.

Table 5-91. Weight-Window Generation Times Card (WWGT)

Input Parameter	Description
<*pl*>	Particle designator.
t_i	Upper energy or time bound for weight-window group to be generated, $t_{i+1} > t_i$.

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

card is present but has no entries, ten time bins will be generated with times of $t_i=10^{i-8}$ shakes, for $i=1,2,...,10$. Both the single time and the or time-dependent windows are generated.

Use: Optional.

Note: If this card is present, time-dependent weight windows are generated and written to the WWOUT file and, for cell-based weight windows, to the OUTP file. In addition, single-group time-independent weight windows are written to a separate output file, WWONE. Time-independent weight windows are useful for trouble-shooting the time-dependent weight windows on the WWOUT file. The WWONE file format is the same as that of the WWOUT file.

5.7.2.4 WWP WEIGHT-WINDOW PARAMETER

Form: WWP:<*pl*> *wupn wsurvn mxspln mwhere switchn mtime mult* J *wu*

Table 5-92. Weight-Window Parameter Card (WWP)

Input Parameter	Description
<*pl*>	Particle designator.
wupn	If the particle weight goes above *wupn* times the lower weight bound, the particle will be split. Restriction: *wupn*≥2
wsurvn	If the particle survives the Russian roulette game, its weight becomes MIN(*wsurvn* times the lower weight bound, WGT × *mxspln*). Restriction: 1<*wsurvn*<*wupn*
mxspln	No particle will ever be split more than *mxspln*-for-one or be rouletted more harshly than one-in-*mxspln*. In zero window cells or meshes, *mxspln*=2. Restriction: *mxspln*>1
mwhere	Controls where to check a particle's weight. If *mwhere*=−1, check the weight at collisions only. If *mwhere*=0, check the weight at surfaces and collisions. If *mwhere*=1, check the weight at surfaces only.
switchn	Controls where to get the lower weight-window bounds. If *switchn*<0, get the lower weight-window bounds from an external WWINP file containing either cell- or mesh-based lower weight-window bounds. If *switchn*=0, get the lower weight-window bounds from WWN*i* cards. If *switchn*>0, set the lower weight-window bounds equal to *switchn* divided by the cell importances from the IMP card.
mtime	If *mtime*=0, energy-dependent windows (WWE card). If *mtime*=1, time-dependent windows (WWE card). (Note: Parameter i_E remains to allow backward compatibility. See WWT card for time-dependent weight windows.)

Input Parameter	Description
mult	If *mult*>1, multiplicative constant for all lower weight bounds on WWN*i*:<*pl*> cards or WWINP file mesh-based windows of particle type <*pl*>.
J	Use J to jump over this entry. Reserved for use by MCNP5.
wu	Limits the maximum lower weight-window bound for any particle, energy, or time to *wu*. If *wu*=0, there is no limit.

Default: *wupn*=5; *wsurvn*=0.6 × *wupn*; *mxspln*=5; *mwhere*=0; *switchn*=0; *mtime*=0; *mult*=1.0; *wu*=0

Note: 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 WWN*i* cards is a fatal error. The WWINP file is a weight-window generator output file, either WWOUT or WWONE, that has been renamed in the local file space or equivalenced on the 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. (See Appendix J.)

Note: 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 0.25 times the source weight. If that is not possible, your window is probably too narrow or you need to re-specify your source.

Note: Unreasonably high weight-window bounds can be generated if 1) tracks that pass through a cell score only rarely or score very low, or 2) adjoint Monte Carlo is used. When weight windows with very high bounds are used in a subsequent run, the ultra-high windows will roulette nearly all particles in those phase-space regions. This results in no future estimate in these regions by the weight-window generator and potentially biased results. Use the 9th entry, *wu*, to limit the maximum lower weight window bound. A good value of *wu* is often 1–10 times the maximum source weight.

5.7.2.5 WWN CELL-BASED WEIGHT-WINDOW BOUNDS

Form 1 (cell card entry): WWN*i*:<*pl*>=w_i

Form 2 (data card): WWN*i*:<*pl*> w_{i1} w_{i2} ... w_{ij} ...

Table 5-93. Cell-Based Weight-Window Bounds Card (WWN*i*)

Input Parameter	Description
<*pl*>	Particle designator.
i	Energy or time index.
w_i	If $w_i>0$, then value is the lower weight bound in the cell and in energy interval $e_{i-1}<e<e_i$, where $e_0=0$, or time interval $t_{i-1}<t<t_i$, where $t_0=-\infty$. If no WWE or WWT card is included in INP file, then $i=1$. If $w_i=0$, then no weight-window game is played. If $w_i=-1$, then any particle entering the cell is killed (equivalent to zero importance).
w_{ij}	If $w_{ij}>0$, then value is the lower weight bound in cell j and in energy interval $e_{i-1}<e<e_i$, where $e_0=0$, or time interval $t_{i-1}<t<t_i$, where $t_0=-\infty$. If no WWE or WWT card is included in INP file, then $i=1$. If $w_{ij}=0$ then no weight-window game is played. If $w_{ij}=-1$, then any particle entering cell j is killed (equivalent to zero importance). Note: The number of entries equals the 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.

Note: The WWN card specifies the lower weight bound of the space-, time-, and energy-dependent weight windows in cells. It must be used with the WWP card and, if the weight windows are energy and/or time dependent, with the WWE and/or WWT card. For a particular particle type, both IMP and WWN cards should not be used.

Note: If negative entries are used for one energy group, they should be used for all the other energy groups in the same cell.

Note: In terms of the weight window, particle weight bounds are always absolute and not relative; the user has to explicitly account for weight changes from any other variance-reduction techniques such as source biasing. The user must specify one lower weight bound per cell per energy or time interval. There must be no holes in the specification; that is, if WWN*i* is specified, WWN*k* for $1<k<i$ 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 intervals and the weight-window bounds for a four-cell neutron problem.

Example 2:

```
WWN1:P   w11  w12  w13
```

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

Example 3:

```
WWG       111   45  .25
WWGE:p    1  100
WWGT:p    1  100  1.e20
```

The cell-based windows generated from the above cards would look like:

```
WWP:p  5  3  5
WWE:p  1  100
WWT:p  1  100  1.e20
WWN1:p  w1  w2  w3 ...   $ energy 1 time 1
WWN2:p  w1  w2  w3 ...   $ energy 2 time 1
WWN3:p  w1  w2  w3 ...   $ energy 1 time 2
WWN4:p  w1  w2  w3 ...   $ energy 2 time 2
WWN5:p  w1  w2  w3 ...   $ energy 1 time 3
WWN6:p  w1  w2  w3 ...   $ energy 2 time 3
```

This example generates a 2-energy group, 3-time group weight window. In particular, the WWG card would generate weight windows to optimize tally 111. The lowest weight window bound in any energy-time bin group in cell 45 (the reference cell) would be 0.25. The WWGE and WWGT cards would generate two energy bins and three time bins for photons.

5.7.2.6 WWE WEIGHT-WINDOW ENERGIES

Form: WWE:<pl> e_1 e_2 ... e_i ... e_j

where $j \leq 99$.

Table 5-94 Weight-Window Energies Card (WWE)

Input Parameter	Description
<pl>	Particle designator.
e_i	Upper energy bound of i^{th} window.

Input Parameter	Description
e_{i-1}	Lower energy bound of i^{th} window.
e_0	e_0=0, by definition.

Default: One weight-window energy interval.

Use: Optional. Use only with WWN card.

Note: 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 -∞. Whether energy or time is specified is determined by the 6th entry on the WWP card. For time-dependent weight windows, consider using the WWT card (Section 5.7.2.7).

5.7.2.7 WWT WEIGHT-WINDOW TIMES

Form: WWT:<*pl*> t_1 t_2 ... t_i ... t_j

where $j \leq 99$.

Table 5-95. Weight-Window Times Card (WWT)

Input Parameter	Description
<*pl*>	Particle designator.
t_i	Upper time bound of i^{th} window.
t_{i-1}	Lower time bound of i^{th} window.
t_0	t_0=–∞, by definition.

Default: One weight-window time interval.

Use: Optional. Use only with WWN card.

Note: The WWT card defines the time intervals in shakes for which weight-window bounds will be specified on the WWN card. The minimum time is -∞.

5.7.2.8 MESH SUPERIMPOSED IMPORTANCE MESH FOR MESH-BASED WEIGHT-WINDOW GENERATOR

Form: MESH KEYWORD=*value(s) ...*

Table 5-96. Superimposed Mesh Variables (MESH)

Keyword	Description
GEOM	Controls mesh geometry type. If GEOM=XYZ or GEOM=REC, mesh geometry is Cartesian. If GEOM=RZT or GEOM=CYL, mesh geometry is cylindrical. If GEOM=RPT or GEOM=SPH, mesh geometry is spherical. (DEFAULT: GEOM=XYZ)
REF	x-, y-, and z-coordinates of the reference point. (DEFAULT: none) Restriction: Must be specified.
ORIGIN	x-, y-, and z-coordinates in MCNPX cell geometry of the origin (bottom, left, rear for rectangular; bottom center for cylindrical; center for spherical) of the superimposed mesh. (DEFAULT: ORIGIN=0. 0. 0.)
AXS	Vector giving the direction of the (polar) axis of the cylindrical or spherical mesh (DEFAULT: AXS=0. 0. 1.)
VEC	Vector defining, in conjunction with AXS, the plane for θ=0. For spherical geometry, VEC must be orthogonal to φ. (DEFAULT: VEC=1. 0. 0.)
IMESH	Locations of the coarse meshes in the x-direction for rectangular geometry or in the r-direction for cylindrical or spherical geometry. (DEFAULT: none)
IINTS	Number of fine meshes within corresponding coarse meshes in the x-direction for rectangular geometry or in the r-direction for cylindrical or spherical geometry. (DEFAULT: IINTS=10 fine mesh in each coarse mesh)
JMESH	Locations of the coarse meshes in the y-direction for rectangular geometry, in the z-direction for cylindrical geometry, or the phi (φ) polar angle bounds for spherical geometry. (DEFAULT: none)
JINTS	Number of fine meshes within corresponding coarse meshes in the y-direction for rectangular geometry, in the z-direction for cylindrical geometry, or in the φ-direction for spherical geometry. (DEFAULT: JINTS=10 fine mesh in each coarse mesh)
KMESH	Locations of the coarse meshes in the z-direction for rectangular geometry or in the θ-direction for cylindrical or spherical geometry. (DEFAULT: none)
KINTS	Number of fine meshes within corresponding coarse meshes in the z-direction for rectangular geometry or in the θ-direction for cylindrical or spherical geometry. (DEFAULT: KINTS=10 fine mesh in each coarse mesh)

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

Note: For both the cylindrical and spherical meshes, the lower radial and angular mesh bounds (R-φ-θ) are implicitly zero.

Note: Polar and azimuthal angles may be specified in revolutions ($0 \le \varphi \le 0.5$ and $0 \le \theta \le 1$), radians, or degrees. MCNPX recognizes the appropriate units by looking for 0.5, 3.14, or 180 for the last spherical geometry JMESH entry and for 1, 6.28, or 360 for the last spherical or cylindrical KMESH entry.

Note: In the XYZ (REC) mesh, the IMESH, JMESH, and KMESH are the actual x,y,z coordinates. In the RZT (CYL) mesh, IMESH (radius) and JMESH (height) are relative to ORIGIN and KMESH (theta) is relative to VEC. In the RPT (SPH) mesh, IMESH (radius) is relative to ORIGIN, JMESH (phi) is relative to AXS, and KMESH (theta) is relative to VEC.

Note: 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 MCNPX cell coordinate system; thus, the ORIGIN point is the most negative point of the mesh. For a cylindrical mesh, ORIGIN corresponds to the bottom center point. The coarse mesh locations must increase monotonically.

Note: 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.

Note: 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.

Note: The code uses a default value of 10 fine meshes 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.

Note: A second method of providing a superimposed mesh is to use one that already exists, either written to the WWOUT file or to 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, MCNPX expects to read a file called WWINP. The WWINP file is a weight-window generator

output file, either WWOUT or WWONE, that has been renamed in the local file space or equivalenced on the execution line using WWINP=*filename*. (See Appendix J.)

Note: 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.

Note: 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.

Note: 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. The code prints the total number of particles escaping the mesh (if any) after the tally fluctuation charts in the standard output file. 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. The code prints the total number of particles starting outside the mesh (if any) after the tally fluctuation charts in the standard output file.

Note: Specifying 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.

Example 1:

```
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   0.5     1
       KINTS   5     5
```

Example 2:

```
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.
```

Example 3:

```
MESH  GEOM sph  ORIGIN 7 -9 -12  REF -23 39 -10  AXS .4 -.5 .2
      VEC .1 -.2 -.7
      IMESH     60.                  IINTS  3
      JMESH    0.1   0.35   0.5      JINTS  1 1 1
      KMESH    0.2   0.85   1        KINTS  1 1 1
```

In this example a spherical mesh is located at `ORIGIN=7 -9 -12`. The reference location in the XYZ coordinate system of the problem is at `REF=-23 39 -10`. The weight window generator lower weight window bound will be `W` for whatever mesh cell contains this location, where `W` is half the source weight by default or whatever is the 3rd entry on the `WWG` weight window generator card. The polar (φ) axis of the spherical mesh (as in latitude on the globe) is `AXS=0.4 -0.5 0.2`, which MCNPX will normalize to a unit vector. The azimuthal planes (as in longitude on a globe, or orange slices, or cylindrical mesh theta bins) are measured relative to the azimuthal vector, theta (θ), `VEC=.1 -.2 -.7`. `VEC` will also be renormalized by MCNPX and must be orthogonal to φ. The radial mesh bins have three interpolates between 0 and 60—that is, the mesh bounds are at 0, 20, 30, and 60 cm. The polar angles (φ) are at 0.1, 0.35, and 0.5 revolutions from the `AXS` vector. The azimuthal angles (θ) are at 0.2, 0.85. and 1 revolutions from the `VEC` vector. Note that 0≤φ≤0.5 and 0≤θ≤1 are always required.

For examples that show how to plot superimposed weight-window meshes see Appendix B, Section B.7.

5.7.3 EXT Exponential Transform

Form 1 (cell card entry): `EXT:`*pl*`=`*a*

Form 2 (data card): `EXT:`*pl* $a_1\ a_2\ \ldots\ a_j\ \ldots$

Table 5-97. Exponential Transform Card (EXT)

Input Parameter	Description
$\langle pl \rangle$	Any particle designator or IPT number in Table 4-1.
a	Each entry a is of the form a=QVm, where Q describes the amount of stretching and Vm defines the stretching direction for the cell. (See Table 5-98.)
a_j	Each entry a_j is of the form a_j=QVm, where Q describes the amount of stretching and Vm defines the stretching direction for cell j. (See Table 5-98.) Number of entries equals the number of cells in the problem.

Default: No transform, a_j=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. The transform works well only when the particle flux has an exponential distribution, such as in highly absorbing mediums.

Note: 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^* is the artificially adjusted total cross section, Σ_t is the true total cross section, p is the stretching parameter, and μ is the cosine of the angle between the particle direction and the stretching direction.

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

If p=0, then Q=0 and the exponential transform is not used.
If 0<p<1, then Q=p and a constant stretching parameter is specified.
If p=Σ_a/Σ_t, then Q=S where Σ_a is the capture cross section.

Note: If the Vm part of the a_j entry is omitted (i.e., a_j=Q), then the stretching is in the particle direction, independent of the particle direction. This is not recommended unless you want to do implicit capture along a flight path, in which case a_j=Q=Σ_a/Σ_t=S and the distance to scatter rather than the distance to collision is sampled.

Note: The stretching direction may be specified as Vm, where m is a unique integer that is associated with the vector entry provided on the VECT card. The stretching direction is defined as the line from the collision point to the point (x_m,y_m,z_m), where (x_m,y_m,z_m) is provided on the VECT card. 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_j governs whether stretching is toward or away from (x_m,y_m,z_m).

Note: The stretching direction may also be specified as Vm=X or 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_j governs whether stretching is toward or away from the x–, y–, or z–axis.

Caution: 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.

Example:

```
EXT:N    0  0  0.7V2  S  -SV2  -0.6V9  0  0.5V9  SZ  -0.4X
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.

Table 5-98 Exponential Transform Stretching Parameter

Cell	a_i	Q	Vm	Stretching Parameter	Stretching Direction
3	0.7V2	0.7	V2	p = 0.7	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	-0.6V9	0.6	-V9	p = 0.6	Away from origin
8	0.5V9	0.5	V9	p = 0.5	Toward origin
9	SZ	S	Z	$p = \Sigma_a/\Sigma_t$	Along +z-axis
10	-0.4X	0.4	-X	p = 0.4	Along -y-axis

5.7.4 VECT Vector Input

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

Table 5-99. Vector Input Card (VECT)

Input Parameter	Description
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 (Section 5.7.3) for a usage example.

5.7.5 FCL Forced Collision

Form 1 (cell card entry): FCL:<*pl*>=*x*

Form 2 (data card): FCL:<*pl*> x_1 x_2 ... x_j ...

Table 5-100. Forced-Collision Card (FCL)

Input Parameter	Description
<*pl*>	Particle designator.
x	Forced-collision control for cell. Restriction: $-1 \le x \le 1$ If $x>0$, forced collision applies to particles entering cell and to those surviving weight cutoff/weight-window games in the cell. If $x<0$, forced collision applies only to particles entering cell. If $x=0$, no forced collision in cell. (DEFAULT)
x_j	Forced-collision control for cell *j*. Restriction: $-1 \le x_j \le 1$ If $x_j>0$, forced collision applies to particles entering cell *j* and to those surviving weight cutoff/weight-window games in the cell. If $x_j<0$, forced collision applies only to particles entering cell *j*. If $x_j=0$, no forced collision in cell *j*. (DEFAULT) The number of entries is equal to the number of cells in the problem.

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

Use: Optional. Exercise caution.

Note: 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.

Note: If $x_j=0$, all particles entering cell j are split into collided and uncollided parts with the appropriate weight adjustment. If $|x_j|<1$, Russian roulette is played on the collided parts with survival probability $|x_j|$ to keep the number of collided histories from getting too large. Fractional x_j entries are recommended if a number of forced-collision cells are adjacent to each other.

Note: When cell-based weight-window bounds bracket the typical weight entering the cell, choose $x_j>0$. When cell-based weight-window bounds bracket the weight typical of forced-collision particles, choose $x_j<0$. For mesh-based windows, $x_j>0$ usually is recommended. When using importances, $x_j>0$ because $x_j<0$ turns off the weight cutoff game.

5.7.6 DD Detector Diagnostics

Form: DD*n* k_1 m_1 k_2 m_2 ...

Table 5-101. Detector Diagnostics Card (DD)

Input Parameter	Description
n	If *n*=0 or blank, diagnostic parameters apply to all detector tallies and DXTRAN spheres unless overridden with a separate DD*n* card. If *n*=1, provide detector diagnostics for neutron DXTRAN spheres. If *n*=2, provide detector diagnostics for photon DXTRAN spheres. If *n* is a multiple of 5, then is tally number for a specific detector tally.
k_i	Criterion for playing Russian roulette for DXTRAN or detector *i of tally n*. Let A_i be the average score per history to a DXTRAN sphere or a detector *i of tally n*.. Then, If $k_i<0$, DXTRAN or detector scores $>|k_i|$ will always be made and contributions $<|k_i|$ are subject to Russian roulette; or If $k_i>0$ (where $k_i\leq 1$), all DXTRAN or detector contributions are made for the first *dmmp* histories. Then, any contribution to the detector or sphere $>k_iA_i$ will always be made, but any contribution $<k_iA_i$ is subject to Russian roulette; or If $k_i=0$, no Russian roulette is played on small DXTRAN or detector scores.

Input Parameter	Description
m_i	Criterion for printing large contributions for DXTRAN or detector i. If m_i=0, no diagnostic print. If m_i>0 and k_i≥0, then no diagnostic print made for the first *dmmp* histories. Thereafter, the first 600 contributions larger than $m_i k_i A_i$, will be printed. If m_i>0 and k_i<0, then the first 600 contributions larger than $m_i \lvert k_i \rvert$ will be printed.

Default: If k_i is not specified on a DD*n* 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 PD or DXC cards.

Note: The average contribution per history, A, to a particular DXTRAN sphere or detector is calculated from all contributions to the detector or sphere made by particle histories until the first tally fluctuation chart (TFC) interval is reached (see the *dmmp* entry on the PRDMP card). The default is 1000 particles per interval for fixed-source problems or one KCODE cycle. The average is then updated at all subsequent tally fluctuation chart intervals.

Note: This card (1) can speed up calculations significantly by using a Russian roulette game to limit 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.

Note: The DD card eliminates *tracks* with DXTRAN but only *contributions* with detectors.

Example:

```
DXT:N   x1  y1  z1   ri1  ro1
        x2  y2  z2   ri2  ro2
        x3  y3  z3   ri3  ro3
DXT:P   x4  y4  z4   ri4  ro4
F15X:P   a1  r1  R1
         a2  r2  R2
DD        0.2   100  0.15  2000
DD1   -1.1E25  3000     J     J    J  3000
```

```
DD15      0.4   10
```

This input results in the following interpretation for the DD parameters for the detectors and DXTRAN spheres:

	k	*m*
sphere 1	-1.1E25	3000
sphere 2	0.15	2000
sphere 3	0.2	3000
sphere 4	0.2	100
detector 1	0.4	10
detector 2	0.15	2000

5.7.7 PD Detector Contribution

Form 1 (cell card entry): PD*n*=*p*

Form 2 (data card): PD*n* p_1 p_2 ... p_j ...

Table 5-102. Detector Contribution Card (PD)

Input Parameter	Description
n	Tally number.
p	Probability of contribution to detector *n* from cell. (DEFAULT: *p*=1)
p_j	Probability of contribution to detector *n* from cell *j*. (DEFAULT: p_j=1) Number of entries is equal to the number of cells in the problem.

Default: p_j=1

Use: Optional. Consider also using the DD card, Section 5.7.6.

Note: The PD 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 *j*, the detector tallies are made with probability p_j. The tally is then increased by the factor $1/p_j$ to obtain unbiased results for all cells except those where p_j=0. This enables you to increase the running speed by setting p_j<1 for cells many mean free paths from the detectors. It also selectively eliminates detector contributions from cells by setting the p_j values to zero.

Note A default set of probabilities can be established for all tallies by use of a PD0 card. These default values will be overridden for a specific tally *n* by values entered on a PD card.

5.7.8 DXT DXTRAN Sphere

Form: DXT:<*pl*> 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*

Table 5-103. DXTRAN Card (DXT)

Input Parameter	Description
<*pl*>	Particle designator.
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. Note: The inner sphere is only used to aim 80% of the DXTRAN particles. All particles start on the outer sphere.
ro_i	Radius of the i^{th} outer sphere.
dwc_1	Upper weight cutoff in the spheres. (DEFAULT=0)
dwc_2	Lower weight cutoff in the spheres. (DEFAULT=0)
dpwt	Minimum photon weight. Entered on DXT:N card only. (DEFAULT=0)

Defaults: Zero for dwc_1, dwc_2, and *dpwt*.

Use: Optional. Consider using DXC:N, DXC:P, or DD cards when using DXT.

Note: Use DXTRAN deterministic transport method. At each source or collision point, a particle is put on the outermost DXTRAN sphere, ro_1, by the next-event estimator. The particles are then transported inside the DXTRAN sphere.

Note: DXT is used to improve the particle sample in the vicinity of a tally. 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.

Note: 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.

Rule of Thumb for *ri* and *ro*: The inner radius *ri* should be at least as large as the tally region, and the difference between *ro* and *ri* should be about one mean free path for particles of average energy at the spheres. DXTRAN spheres can be

used around detectors, but the combination may be very sensitive to reliable sampling.

Note: There can be up to five sets of *x, y, z, ri, and 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 DXT particle tracks inside the outer radii and have default values of zero. The DXT 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:<*pl*> card. The DXT weight cutoffs dwc_1 and dwc_2 are ignored when mesh-based weight windows are used.

Note: 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.

Note: DXT can be used in a problem with the $S(\alpha,\beta)$ thermal treatment, but contributions to the DXTRAN spheres are approximate. DXT should not be used with reflecting surfaces, white boundaries, or periodic boundaries. DXT is incompatible with a monodirectional source because direct contributions from the source are ignored.

Note: 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 DXT 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.

Note: All collisions producing neutrons and photons contribute to DXTRAN and point detectors, including model physics interactions. When the secondary neutron/photon angular scattering distribution function is unknown, isotropic scattering, which may be a poor approximation, is assumed. Although the extension to higher energies often is approximate, energy bins for the point detector tally can

identify what portion of the tally is coming from high energies. Further, this approximation is superior to neglecting charged-particle and high-energy neutron collisions altogether.

Note: DXTRAN use an assumption of isotropic scatter for contributions from collisions within the model regime. These estimators require the angular distribution data for particles produced in an interaction to predict the "next event." Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region.

Note: All calculations with detectors or DXTRAN generally do not track unless the twenty-first entry on the DBCN card is set to nonzero or the default Russian roulette detector game (DD card) is not played.

5.7.9 DXC DXTRAN Contribution

Form 1 (cell card entry): DXC*m*:<*pl*>=*p*

Form 2 (data card): DXC*m*:<*pl*> p_1 p_2 ... p_j ...

Table 5-104. DXTRAN Contribution Card (DXC)

Input Parameter	Description
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. (DEFAULT: *m*=0)
<*pl*>	Particle designator.
p	Probability of contribution to DXTRAN sphere *m* from cell. (DEFAULT: *p*=1)
p_j	Probability of contribution to DXTRAN sphere *m* from cell *j*. (DEFAULT: p_j=1) Number of entries equals number of cells in the problem.

Use: Optional. Consider also using the DD card, Section 5.7.6. The DXC card is analogous to the PD card for detector contributions.

5.7.10 BBREM Bremsstrahlung Biasing

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

Table 5-105. Bremsstrahlung Biasing Card (BBREM)

Input Parameter	Description
b_1	Any positive value (currently unused).
b_2 ... b_{49}	Bias factors for the bremsstrahlung energy spectrum.
m_1 ... m_n	List of *n* materials for which the biasing is invoked.

Default: None.

Use: Optional.

Example/Discussion:

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.

5.7.11 SPABI Secondary Particle Biasing

Form: `SPABI:`<*pl*> *xxx... e_1 s_1 e_2 s_2 ...*

Table 5-106. Secondary Particle-Biasing Argument Descriptions (SPABI)

Input Parameter	Description
<*pl*>	Secondary particle designator. (See Table 4-1.)
xxx	List of primary particles to be considered. For example, NPHE represents reactions of neutrons, photons, protons, and electrons. No spaces are allowed. If all particles are to be considered, the entry should be ALL.
e_i	Upper energy bin limit of secondary particles. The lower bin limit is considered to be zero.
s_i	Use splitting if $s_i>1$. Use roulette if $0 \le s_i \le 1$.

Note: Secondary particle biasing allows the user to adjust the number and weight of secondary particles produced at the time of their creation. Multiple SPABI cards for different secondary particles are allowed.

Example:

```
SPABI:N   NHE   1  0.1  5  1  10  2  20  4
```

This example specifies that neutron secondaries produced by neutron, proton, and electron primaries will be biased in the following manner: Below 1 MeV, the secondary neutrons will be rouletted by a factor of 0.1. At energies, 1 to 5 MeV, no biasing is performed. At energies from 5 to 10 MeV, the secondary neutrons will be split by a factor of 2, and from 10 to 20 MeV, the secondary neutrons will be split into 4 (with a corresponding reduction in particle weights).

5.7.12 ESPLT Energy Splitting and Roulette

Form: ESPLT:<*pl*> n_1 e_1 ... n_5 e_5

Table 5-107. Energy Splitting and Roulette Card (ESPLT)

Input Parameter	Description
<*pl*>	Any particle symbol or IPT number from Table 4-1.
n_i	Number of tracks into which a particle will be split when the particle's energy falls below e_i. Restriction: $1 \le i \le 5$
e_i	Energy (MeV) below which particles are to undergo splitting or rouletting and above which the inverse game is played. Restriction: $1 \le i \le 5$

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

Use: Optional; use energy-dependent weight windows instead.

Note: The entries consist of pairs of energy-biasing parameters, n_i and e_i, with a maximum of five pairs permitted. The parameter n_i can be noninteger and also can be between 0 and 1, in which case Russian roulette on energy is played. For n_i between 0 and 1, the quantity becomes the survival probability in the roulette game.

Example:

```
ESPLT:N    2  0.1   2  0.01   0.25  0.001
```

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 when the energy falls below 0.001 MeV with a 25% chance of surviving.

5.7.13 PWT Photon Weight

Form 1 (cell card entry) PWT=*w*

Form 2 (data card) : PWT w_1 w_2 ... w_j ...

Table 5-108. PWT Card

Variable	Description
w	Relative threshold weight of photons produced at neutron collisions in cell. If *w*>0, only neutron-induced photons with weights greater than $w \times I_s/I_i$ are produced, where I_s and I_i are the neutron importances of the collision and source cells, respectively. If *w*<0, only neutron-induced photons with weights greater than $-w \times w_s \times I_s/I_i$ 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. If *w*=0, exactly one photon will be generated at each neutron collision in the cell, provided that photon production is possible. If *w*=-1.0E6, photon production in the cell is turned off.

Variable	Description
w_j	Relative threshold weight of photons produced at neutron collisions in cell j. Number of entries is equal to number of cells in the problem. If $w_j>0$, only neutron-induced photons with weights greater than $w_j \times I_s/I_i$ are produced, where I_s and I_i are the neutron importances of the collision and source cells, respectively. If $w_j<0$, only neutron-induced photons with weights greater than $-w_j \times w_s \times I_s/I_i$ 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. If $w_j=0$, exactly one photon will be generated at each neutron collision in cell j, provided that photon production is possible. If $w_j=-1.0E6$, photon production in cell j is turned off.

Use: Recommended for `MODE N P` and `MODE N P E` problems without weight windows.

Note: 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 MCNPX.

Note: The `PWT` card is ignored if a `WWP:P` (photon weight window) exists.

5.8 OUTPUT CONTROL AND MISCELLANEOUS CARDS

NPS, CTME, PRDMP, PRINT, NOTRN, MPLOT, PTRAC, HISTP, HTAPE3X, DBCN, LOST, IDUM, RDUM, FILES, STOP

5.8.1 NPS History Cutoff

Form: `NPS` *npp* *npsmg*

Table 5-109. History Cutoff Card (NPS)

Input Parameter	Description
npp	Total number of histories to be run in the problem.
npsmg	Number of histories for which direct source contributions are to be made to a radiography grid. (See Section 5.6.20.2.)

Note: When the number of source histories exceeds *npsmg*, the time-consuming process of determining the attenuation of the direct contribution is avoided by adding

the average of the previous direct contributions into each of the appropriate tally bins. Depending on the time required for a particular problem, this can save from a few seconds to upward of ten minutes per history in some cases. For a monoenergetic isotropic point source, or a monoenergetic monodirectional surface source, *npsmg*=1 is adequate.

5.8.2 CTME Computer Time Cutoff

Form: CTME *tme*

where *tme*=maximum amount of computer time (in minutes) to be spent in the Monte Carlo calculation.

Default: Infinite.

Use: As needed.

Note: 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.

5.8.3 PRDMP Print and Dump Cycle

Form: PRDMP *ndp ndm mct ndmp dmmp*

Table 5-110. Print & Dump Cycle Card (PRDMP)

Input Parameter	Description
ndp	Increment for printing tallies. If *ndp*>0, increment is in histories or KCODE cycles If *ndp*<0, increment is in running time in minutes.
ndm	Increment for dumping to RUNTPE file. If *ndm*>0, increment is in histories or KCODE cycles If *ndm*<0, increment is in running time in minutes.
mct	If *mct*>0, write MCTAL file at problem completion. If *mct*=0, do not write MCTAL file. If *mct*=−1, MCTAL file is written at problem completion, but 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. If *mct*=−2, additional prints in OUTP are turned off to assist in comparing multitasking output.

Input Parameter	Description
ndmp	Maximum number of dumps on RUNTPE file.
dmmp	Control how frequently tally fluctuation chart (TFC) entries occur. If *dmmp*<0, write charts every 1000 particles. If *dmmp*=0, write charts every 1000 particles or, if multiprocessing, 10 times total during the run. If *dmmp*>0, write charts every *dmmp* particles or number of KCODE cycles for a KCODE problem.

Default: Print only after the calculation has successfully ended. Dump to RUNTPE every 15 minutes and at the end of the problem. Do not write a MCTAL file. Write all dumps to the RUNTPE file. Write charts and rendezvous for fixed-source problems every 1000 particles or, if multiprocessing, 10 times total during the run (*dmmp*=0); for KCODE problems, write charts and rendezvous at the end of each cycle.

Use: Recommended, especially for complex problems.

Note: The rendezvous frequency of a multiprocessor run is the minimum interval of parameters or *ndp, ndm, and dmmp*.

Note: 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.

Note: The MCTAL file is an ASCII file of tallies that can be subsequently plotted with the MCNPX MCPLOT option. 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 MCNPX MCPLOT option, the MCTAL file can be manipulated into whatever format is required by the user's own local plotting algorithms.

5.8.4 PRINT Output Print Tables

Form: PRINT x_1 x_2 ... x_i ...

Table 5-111. Output Print Tables (PRINT)

Input Parameter	Description
x_i	List of table numbers to be included in the output file. If there are no entries for x_i, the basic output print is provided. If x_i>0, the tables specified by each positive x_i are provided in addition to the basic output. If x_i<0, the full output applicable to the problem is printed with the exception of those tables identified by negative x_i values.

Default: Absence of a PRINT card or a PRINT option on the MCNPX execution line produces only the tables in Table 5-112 marked "basic," "default," and "shorten."

Use: Optional.

Note: 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 in Table 5-112 as basic and default.

Note: With one exception, 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. However, print table 128 can never be printed if it was 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 print table 110).

Note: Be aware that print table 87 does not follow the standard default convention of most other MCNPX print tables because stopping powers for all 100 elements for each material would result in huge output files. To print table 87, specify the table number on the PRINT card.

Table 5-112. MCNPX Output Tables

Table Number	Type	Table Description
10	optional	Source coefficients and distribution.
20	optional	Weight-window information.
30	optional	Tally description.
35	optional	Coincident detectors.
38	optional	Fission multiplicity data; controlled by table 30
40	optional	Material composition.
50	optional	Cell volumes and masses, surface areas.
55	default	Burnup results
60	basic	Cell importances.
62	basic	Forced collision and exponential transform.
70	optional	Surface coefficients.
72	basic	Cell temperatures.

Table Number	Type	Table Description
85	optional	Charged-particle stopping powers and straggling
		Multigroup: flux values for biasing adjoint calculations.
86	optional	Electron bremsstrahlung and secondary production.
87	optional	Secondary heavy ion stopping powers and straggling.
90	optional	KCODE source data.
98	optional	Physics constant and compile options.
100	basic	Cross-section tables.
102	optional	Assignment of $S(\alpha, \beta)$ data to nuclides.
110	optional	First 50 starting histories.
117	default	Spontaneous fission source multiplicity and moments.
118	default	Neutron captures, moments & multiplicity distributions.
120	optional	Analysis of the quality of your importance function.
126	basic	Particle activity in each cell.
128	optional	Universe map.
130	optional	Neutron/photon/electron weight balance.
140	optional	Neutron/photon nuclide activity.
150	optional	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	optional	Source distribution frequency tables, surface source.
175	shorten	Estimated k_{eff} results by cycle.
178	optional	Estimated k_{eff} results by batch size.
180	optional	Weight-window generator bookkeeping summary controlled by WWG(7), not print card.
190	basic	Weight-window generator summary.
198	optional	Weight windows from multigroup fluxes.
200	basic	Weight-window-generated windows.
210	default	Burnup summary table.
220	default	Burnup summary table summed over all materials.

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 `print table 175`, and all the optional tables applicable to your problem, except tables `70`, `110`, and `170`.

Example 3:

```
PRINT    -1   87
```

Prints all output including `print table 87`.

5.8.5 NOTRN Direct Contributions Only

Form: `NOTRN`

Default: None.

Use: If the `NOTRN` card appears in the INP file, no transport of the source particles takes place, and only the direct or source contributions are made to the detector grid. This is especially useful for checking the problem setup or doing a fast calculation to generate the direct source image. This option works with either the pinhole or transmitted image options.

5.8.6 MPLOT Plot Tally while Problem is Running

Form: `MPLOT  KEYWORD=`*`value(s)`*

Default: None.

Use: Optional.

This card specifies a plot of intermediate tally results that is to be produced periodically during the run. The entries are MCPLOT commands (see Table 6-5) for one picture. 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; it returns to MCRUN after each plot is displayed. See Section 6.3 for a complete list of MCPLOT commands available.

Another way to plot intermediate tally results is to use the TTY interrupt <ctrl-c>MCPLOT or <ctrl-c>M 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 can not be used: RMCTAL, RUNTPE, DUMP, and END.

5.8.7 PTRAC Particle Track Output

Form: PTRAC KEYWORD=*value(s)* ...

Default: See Table 5-113.

Use: Optional.

Table 5-113. Particle Track Output (PTRAC)

Output Control Keyword	Description
BUFFER	Determines the amount of storage available for filtered events. A small value results in increased I/O and a decrease in required memory; a large value minimizes I/O and increases memory requirements. Single integer entry. (DEFAULT: BUFFER=100) Restriction: BUFFER>0
FILE	Controls file type. If FILE=ASC, generates an ASCII output file. If FILE=BIN, generates a binary output file. (DEFAULT) If FILE=AOV, generates an ASCII output file by overwriting an existing ASCII PTRAC file to a named pipe on UNIX systems. Requires a PTRAC file to exist prior to execution. If FILE=BOV, generates a binary output file by overwriting an existing binary PTRAC file to a named pipe on UNIX systems. Requires a PTRAC file to exist prior to execution.
MAX	Sets the maximum number of events to write to the PTRAC file. Single integer entry. (DEFAULT: MAX=10000) If MAX<0, MCNPX is terminated when |MAX| events have been written to PTRAC. Restriction: MAX≠0

MEPH	Determines the maximum number of events per history to write to the PTRAC file. Single integer entry. (DEFAULT: write all events) Restriction: MEPH>0
WRITE	Controls what particle parameters are written to the PTRAC file. If WRITE=POS, write only the x, y, z location of the particle with related cell and material numbers. (DEFAULT) If WRITE=ALL, write the x, y, z location of the particle with related cell and material numbers and the u, v, w direction cosines, as well as particle energy, weight, and time.
Event Filter Keyword	**Description**
EVENT	Specifies the type of events written to the PTRAC file. Up to six mnemonic entries: If EVENT=SRC, write initial source events. If EVENT=BNK, write bank events. These include secondary sources (e.g., photons produced by neutrons, as well as particles created by variance-reduction techniques). If EVENT=SUR, write surface events. If EVENT=COL, write collision events. If EVENT=TER, write termination events. If EVENT=CAP, write coincident capture events. (DEFAULT: write all events)
FILTER	Specifies additional MCNPX 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 5-114 for available mnemonics.) A single numerical entry requires an exact value; two numerical entries represent a range. When a range is specified, the first entry must be less than or equal to the second. (DEFAULT: no additional filtering) Example: FILTER=2,ICL writes only those events that occur in cell 2. Example: FILTER=0,10,X writes only those events in which the particle's x-coordinate is between 0 and 10 cm. 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 is between 0 and 1 *and* the particle's energy is between 1 and 2 MeV.
TYPE	Filters events based on one or more particle types. May specify filtering of a single particle or multiple particles, where <pl_i> is a particle identifier specified in Table 4-1: TYPE=<pl_1>,<pl_2>,... (DEFAULT: Write events for all particles.)

History Filter Keyword	Description
NPS	Sets the range of particle histories for which events will be output. A single value produces filtered events only for the specified history. (DEFAULT: Events for all histories) Restriction: NPS>0
CELL	List of cell numbers to be used for filtering. If any track enters the listed cell(s), all filtered events for the history are written to the PTRAC file. Restriction: CELL>0
SURFACE	List of surface numbers to be used for filtering. If any track crosses the listed surface(s), all filtered events for the history are written to the PTRAC file. Restriction: SURFACE>0
TALLY	List of tally numbers to be used for filtering. If any track contributes to the TFC bin of listed tallies, all filtered events for the history are written to the PTRAC file. (See TF card for specification of the TFC bin for tally *n*.) Note: A negative TALLY entry indicates that the corresponding VALUE entry (below) is a multiplier rather than an absolute value. Restriction: TALLY≠0
VALUE	Specifies the tally cutoff above which history events will be written. The number of entries must equal the number of entries 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. 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 (see PRDMP card). (DEFAULT: VALUE=10)

Note: The PTRAC card generates an output file, default name PTRAC, of user-filtered particle events. (See Appendix I.) Using this card without any keywords causes all particle events to be written to the PTRAC file. In Table 5-113 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. The PTRAC card is not allowed in a continue-run input file.

Note: For EVENT=CAP, most of the standard PTRAC capabilities are bypassed (for speed) and the data written to each line (or record) of the PTRAC file are very different from the usual PTRAC data. For binary files, the entries on each PTRAC

line include the particle history number ("NPS"), the time from source event to analog capture in any FT8 CAP tally ("Time"), and the cell number in which the analog capture occurred ("Cell"). Additionally, for ASCII files, a fourth column, "Source," provides the source particle number of a given history.

Note: The PTRAC file will contain the heavy ion particles and their track information, but **not** individual heavy ion identities (ZZZAAAs).

Caution: If all particle events are written to the PTRAC file, an extremely large file likely will be created unless NPS is small. Use of one or more keywords listed in Table 5-113 will reduce significantly the PTRAC file size.

Example:

```
PTRAC  FILTER=8,9,ERG  EVENT=SUR  NPS=1,50  TYPE=E  CELL=3,4
```

When multiple keywords are entered on the PTRAC card, the filter criteria for each keyword must be satisfied to obtain an output event. This input line will write only surface crossing events for 8–9-MeV electrons generated by histories 1–50 that have entered cells 3 or 4.

Table 5-114. Mnemonic Values for the FILTER Keyword

Mnemonic	MCNPX 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	LII	1st lattice index of particle location
JJJ	JJJ	2nd lattice index of particle location
KKK	KKK	3rd lattice index of particle location

5.8.8 HISTP and HTAPE3X

Form: HISTP [*-lhist*] [icl_1 icl_2 ...]

Table 5-115. HISTP Card

Input Parameter	Description
-lhist	Controls the number of words written to a HISTP file. Once this limit is exceeded, a new file will be written with the name HISTPA and the incrementing of the name will continue until all particles are run. Entered as a negative number, *lhist* may appear anywhere on the card. (DEFAULT: *-lhist*=-500000000)
icl_i	List of cell numbers: Only events occurring within these cells will be written to HISTP file. If no icl_i values are provided, all events will be written to HISTP.

Note: In order to produce the LAHET-compatible HISTP files, the HISTP card must be added to the INP deck. This card controls the writing of information to an external file for analysis by the HTAPE3X program. (See Appendix C.)

Note: Writing HISTP files during multiprocessing is still under development.

Note: No heavy ion transport information is written to the HISTP file aside from the usual recoils from which the heavy ions are started.

Example 1:

```
HISTP  -100000  5  6  3  10
```

Each HISTP file will contain a maximum of 100,000 words. Only events within cells 3, 5, 6, and 10 will be written to the HISTP file.

Example 2:

```
HISTP
```

Each HISTP file will contain a maximum of 500,000,000 words (which virtually ensures that only one file will be written). All events in all cells will be written to the file.

5.8.9 DBCN Debug Information

Form: DBCN x_1 x_2 ... x_{21}

Table 5-116. Debug Information Card (DBCN)

Input Parameter	Description
x_1	The pseudorandom number used for starting the transport of the first particle history in a run. [DEFAULT= (5^{19}) Recommended: Use x_8 instead.
x_2	Debug print interval. Print out information about every x_2^{th} particle.
x_3 and x_4	History number limits for event-log printing. Event-log printing is done for histories x_3 through x_4, inclusively.
x_5	Maximum number of events the event log will print per history. (DEFAULT=600)
x_6	Detector/DXTRAN underflow limit.† (DEFAULT=80) Restriction: $50 \le x_6 \le 200$ If the attenuation factor, λ, to the detector or DXTRAN sphere is $>x_6$, then the score is terminated as "underflow in transmission."
x_7	If x_7=1, a detailed print from the volume and surface area calculations is produced.
x_8	Causes the starting pseudorandom number of the problem to be that which would normally start the x_8^{th} history. That is, causes the x_8^{th} history to be the first history of a problem for debugging purposes; can also be used to select a random number sequence different from that in an identical problem to compare statistical convergence.
x_9	Defines the distance allowed between coincident repeated-structures surfaces for them still to be considered coincident. (DEFAULT=1.E-4)
x_{10}	Seconds between time interrupts for checking if a history has run too long or is in an infinite loop. (DEFAULT=100 seconds)
x_{11}	If x_{11}=1, the collision lines in the lost-particle event log are printed.
x_{12}	Expected number of random numbers for this calculation.
x_{13}	Random number stride.(DEFAULT=152917) Note: The period of the random number generator is 2^{46}=7.104E13. Therefore, the number of histories beyond which the period is exceeded is 460 million.
x_{14}	Random number multiplier. (DEFAULT=5^{19})
x_{15}	If x_{15}=1, the shifted confidence interval and the variance of the variance for all tally bins are printed.

Input Parameter	Description
x_{16}	Scale the history score grid for the accumulation of the empirical $f(x)$ in `print tables 161` and `162`.
x_{17}	If x_{17}=0, use default angular treatment for partial substeps to generation sites of secondary particles. If x_{17}>0, use alternate angular treatment for secondary generation. If x_{17}<0, use MCNP4A treatment of electron angles at secondary generation sites.
x_{18}	If x_{18}=0, use default "MCNP-style" energy-indexing algorithm; also called the "bin-centered" treatment. If x_{18}=1, use Integrated Tiger Series (ITS)-style energy-indexing algorithm; also called the "nearest group boundary" treatment.
x_{19}	Unused.
x_{20}	Track version MCNPX 2.5.0 if x_{20} is nonzero.
x_{21}	If x_{21}=1, then MCNPX tracks MCNP version 2.5d without the MPI speedup capability and without new $S(\alpha,\beta)$ algorithm.
x_{22}	Unused.
x_{23}	Unused.
x_{24}	Used to toggle between different matrix implementations for criticality source convergence acceleration [FIN06]. If x_{24}=0, no matrix method is applied. If x_{24}=−1, the cell-based collisional vacation matrix is written to the screen. If x_{24}=1, the cell-based collisional vacation matrix will be used and written to the screen. If x_{24}=2, the cell-based collisional vacation matrix will be used and not printed to the screen. If x_{24}=3, the mesh-based collisional vacation matrix will be used. The mesh is taken from the `MESH` card. If x_{24}=4, the mesh-based track-length vacation matrix will be used. The mesh is taken from the `MESH` card. If `IDUM(3)` is non-zero, the combined k_{eff} estimator is used instead of the track-length estimator. If x_{24}=5, the cell-based track-length vacation matrix will be used. If `IDUM(3)` is non-zero, the combined k_{eff} estimator is used instead of the track-length estimator.

† If DXTRAN or detector underflow is significant in the calculation, generally there are serious problems, such as not sampling enough collisions near the detector. Changing the underflow limit should be done only with extreme caution.

Use: Optional.

Note: 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.

Caution: The contributions neglected because of underflow are typically insignificant to the final answer. However, in some cases, the underflow contribution is significant and necessary. When DXTRAN spheres for point detectors are used to get tally contributions for generating weight windows, sometimes these underflow contributions cannot be neglected.

Caution: When trying to duplicate a particle history by setting the starting random number with either x_1 or x_8, 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 x_1 or x_8 are (a) to turn off the Russian roulette game on the DD card by setting *k*=0; (b) to play the roulette game with a fixed criterion by setting *k*<0 on the DD card; or (c) to reproduce a history with *npp*<1000.

Note: All calculations with DXTRAN or detectors—not just KCODE or parallel calculations—generally do not track. Answers are correct, but these next-event estimator problems do not track unless the twenty-first entry on the DBCN card is set to nonzero or the default Russian roulette detector game (DD card) is not played. The tracking difference occurs because the default Russian roulette game no longer adjusts the roulette criteria at the two-hundredth history. The Russian roulette criteria are still set at all tally fluctuation chart intervals, *dmmp* the fifth entry on the PRDMP card. The default for *dmmp* is still 1000 histories for fixed-source problems but is now *dmmp*=1 (at the end of each cycle) for KCODE problems. Thus, a fixed-source problem that previously started playing Russian roulette on next-event estimates at history 200 now waits until history 1000.

Note: When DBCN(24) is used to turn on eigenfunction convergence, the following IDUM card entries are valid:

IDUM(1) = 0, bias B range of 0.7<B<2.3 (default)
≠ 0, bias B range of 0.1·IDUM(1)<B<3.0–0.1·IDUM(1)

IDUM(2) = 0 or 6, average vacation matrix (default)
= 5, raw (cycle) vacation matrix
= 4, average fission matrix

IDUM(3) = 0, no change to fission estimate (default)
≠ 0, used with DBCN(24)=4 or 5, combined fission estimate

If cell-based geometry is used, each fissionable cell defined in the problem occupies one dimension of the solution matrix. If mesh-based geometry is used, the MESH card must be used to define the superimposed mesh, and the WWG card must be used with an arbitrary tally (1st entry equal to tally number, 2nd entry zero). The mesh is defined exactly as for the weight-window generator, and it must overlay all fissionable material. When mesh-based geometry is used, the solution matrix is dynamically

accumulated according to whether each mesh zone through which the tracked particles pass is fissionable.

5.8.10 LOST Lost Particle

Form: LOST *lost1 lost2*

Table 5-117. Lost Particle Card (LOST)

Input Parameter	Description
lost1	Number of particles which can be lost before the job terminates with BAD TROUBLE. (DEFAULT=10)
lost2	Maximum number of debug prints that will be made for lost particles. (DEFAULT=10)

Defaults: 10 lost particles and 10 debug prints.

Use: Discouraged. Losing more than 10 particles is rarely justifiable.

Note: 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.

5.8.11 IDUM Integer Array Card

Form: IDUM $i_1 \ldots i_n$

where $1 \le n \le 50$.

Default: All array values zero.

Use: Useful only in user-modified versions of MCNPX.

Note: Up to 50 entries can be provided to fill the COMMON block IDUM array with integer numbers. If floating-point numbers are entered, they will be truncated and converted to integers.

5.8.12 RDUM Floating-Point Array Card

Form: RDUM $r_1 \ldots r_n$

where $1 \le n \le 50$.

Default: All array values zero.

Use: Useful only in user-modified versions of MCNPX.

Note: Up to 50 entries can be provided to fill the COMMON block RDUM array with floating-point (real) numbers.

5.8.13 FILES File Creation Card

Form: FILES *unit_no. filename access form record_length ...*

Table 5-118. File Creation Card (FILES)

Variable	Description
unit_no.	Restriction: $1 \le unit\_no. \le 99$.
filename	Name of the file.
access	Options are SEQUENTIAL or DIRECT access. (DEFAULT= SEQUENTIAL)
form	Options are FORMATTED or UNFORMATTED. (DEFAULT=FORMATTED if SEQUENTIAL, UNFORMATTED if DIRECT.)
record_length	Record length in direct access file. (DEFAULT=not required if SEQUENTIAL, no default if DIRECT.)

Default: None; none; sequential; formatted if sequential, unformatted if direct; not required if sequential, no default if direct.

Use: When a user-modified version of MCNPX needs files whose characteristics may vary from run to run. Not allowed in continue-run.

Note: If this card is present, the first two entries are required and must not conflict with existing MCNPX units and files. The words SEQUENTIAL, DIRECT, FORMATTED, and UNFORMATTED can be abbreviated. The maximum number of files allowed is six, unless the dimension of the KUFIL array in FIXED COMMON is increased.

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 clobber 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 MCNPX will start reading the file at the beginning.

Example 1:

```
FILES    21  ANDY  S  F  0    22  MIKE  D  U  512
```

Example 2:

```
FILES    17  DUMN1
MCNPX INP=TEST3 DUMN1=POST3
```

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.

5.8.14 STOP Problem Termination Card

Form: STOP KEYWORD=*value(s) ...*

Table 5-119. Problem Termination (STOP)

Keyword	Description
NPS *n*	Stop calculation after *n* particle histories.
CTME *m*	Stop calculation after *m* minutes of computer time.
F*k e*	Stop calculation when the tally fluctuation chart of tally *k* has a relative error less than *e*.

Use: To enable termination of calculations when a desired tally precision is reached. If values for any (or all) of the keywords are supplied, MCNPX will terminate the problem at the first met criteria.

Note: For radiography problems, a second NPS keyword entry, *nn*, may be provided to specify how many histories are used for direct radiography tally contributions:

```
STOP   NPS n nn    .
```

Note: For multitasking calculations, CTME will be checked only at rendezvous points, where all tasks rendezvous for tally fluctuations and other activities.

Note: The tally precision stop will be checked only at rendezvous points for the tally bin of the tally fluctuation charts. Thus, the calculation usually will proceed for a short time after the desired error is achieved. Thus

```
STOP   F111  .05
```

will cause MCNPX to stop at the first rendezvous for which the relative error is less than 0.05. That is, MCNPX may stop at error=0.048 or other value slightly less than 0.05.

5.9 SUMMARY OF MCNPX INPUT CARDS

The following table lists the various input cards and when they are required. Two kinds of defaults are involved in the following 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 5-120. Summary of MCNPX Input Cards

Use	Card	Defaults	Page
General Categories			
optional	Message block plus blank terminator		4-5
required	Problem title card		4-5
optional	C Comment card		4-5
required	Data cards plus blank terminator		4-5
optional	READ	ECHO	5-1
Geometry cards			**Section 5.2 on page 5-2**
required	Cell cards plus blank terminator		4-5, 5-3
required	Surface cards plus blank terminator		4-5, 5-6
optional	VOL	Use MCNPX-calculated volumes	5-17
optional	AREA	Use MCNPX-calculated surface areas	5-18
optional	U	0 ("real world" universe)	5-19
optional	FILL	0 ("real world" universe)	5-20
optional	TRCL	0 (no transformation)	5-22

Use	Card	Defaults	Page
optional	LAT	0 (not a lattice)	5-23
optional	TR	0 0 0 1 0 0 0 1 0 0 0 1 1	5-24
Material Specification Cards			**Section 5.3 on page 5-26**
optional	M	No ZAID or ZAID fraction default; GAS=0; ESTEP set internally; HSTEP set internally; NLIB, PLIB, PNLIB, ELIB, and HLIB=first match in XSDIR; COND=0	5-26
(d)	MT	None	5-28
optional	MX	None.	5-29
(d)	TOTNU	Total $\bar{\nu}$ if card absent or has no entry.	5-30
(d)	NONU	Fission treated as real fission if card not used.	5-30
optional	AWTAB	Atomic weights from cross-section tables if card not used.	5-31
optional	XS	None	5-32
optional	VOID	Use problem materials.	5-32
optional	PIKMT	No neutron-induced photon-production biasing if card not used. If card used, any ZAID not listed has $IPIK_i$=-1.	5-33
optional	MGOPT	Fully continuous if card not used. If card is used, *iplt*=0, *isb*=0, *icw*=0, *fnw*=1, and *rim*=1000.	5-34
(d)	DRXS	Continuous-energy cross-section treatment if card not used.	5-35
Energy and Thermal Cards			**Section 5.4 on page 5-36**
(a)	MODE $\langle pl \rangle_1 \ldots$		5-36
optional	PHYS:N	100 0 0 -1 -1 0 0; However is FMULT card present or if PAR=SF on SDEF card, then 100 0 0 -1 -1 1 0	5-37
optional	PHYS:P	100 (or *emax* from PHYS:N or PHYS:E card) 0 0 0 1 0	5-40
optional	PHYS:E	100 0 0 0 0 1 1 1 1 0	5-42
optional	PHYS:H	100 (or *emax* from PHYS:N card) 0 -1 J 0 J 0	5-43
optional	PHYS:$\langle pl \rangle$	100 (or *emax* from PHYS:N card) 3J 0	5-45
(d)	TMP	2.53×10-8	5-45
(d)	THTME	0	5-46

Use	Card	Defaults	Page
optional	CUT:<*pl*>	Neutron: *t*=very large; *e*=0.0; *wc*$_1$=-0.5; *wc*$_2$=-0.25; *swtm*=minimum source weight if the general source is used. Photon: *t*=neutron cutoff; *e*=0.001; *wc*$_1$=-0.5; *wc*$_2$=-0.25; *swtm*=minimum source weight if the general source is used. If there are pulse-height tallies, *wc*$_1$=*wc*$_2$=0 Electron: *t*=neutron cutoff; *e*=0.001; *wc*$_1$=0; *wc*$_2$=0; *swtm*=minimum source weight if the general source is used.	5-47
optional	ELPT	CUT card energy cutoff.	5-49
optional	LCA	2 1 1 0023 1 1 0 1 0	5-50
optional	LCB	3500 3500 2500 2500 800 800 -1.0 -1.0	5-53
optional	LCC	1 45	5-55
optional	LEA	1 4 1 0 1 0 0 1	5-55
optional	LEB	1.5 8.0 1.5 10.0	5-56
optional	FMULT	See print table 38.	5-57
Source Specification Cards			**Section 5.5 on page 5-59**
optional	SDEF	CEL=determined from position of particle; SUR=0; ERG=14; TME=0; DIR=isotropic for volume source, cosine distribution for surface source; VEC=vector normal to surface for surface source; NRM=+1; POS=0,0,0; RAD=0; EXT=0; WGT=1; EFF=0.01; PAR=N if no MODE card, =lowest IPT number represented on MODE card.	5-60
optional	SI	H i_1 ... i_k	5-69
optional	SP	D p_1 ... p_k	5-70
optional	SB	D b_1 ... b_k	5-73
optional	DS	H j_1 ... j_k	5-74
optional	SC	None	5-76
(b)	KCODE	1000 1 30 (*ikz*+100) max(4500,2×*nsrck*) 0 6500 1	5-76
(c)	KSRC	None	5-77
optional	BURN	TIME=1; PFRAC=1; POWER=1; BOPT=1 1 -1; MAT=all materials; *af*$_1$=1.0E-10; *af*$_2$=1.0E-10	5-77
optional	SSW	SYM=0, record all tracks	5-85

Use	Card	Defaults	Page
optional	SSR	OLD=all surfaces in original run; CEL=all cells in original run; NEW=surfaces in the OLD list; COL=0; WGT=1; POA=0	5-87
optional	SOURCE & SRCDX	None	5-91
Tally Specification Cards			**Section 5.6on page 5-91**
optional	F	None	5-92
optional	FC	None	5-102
optional	E	One bin over all energies	5-103
optional	T	One bin over all times	5-104
optional	C	One bin over all angles	5-105
optional	FQ	F D U S M C E T	5-106
optional	FM	None	5-107
optional	DE/DF	Logarithmic interpolation of energy and dose; IU=2; FAC=1; IC=10; INT=LOG	5-111
optional	EM	None	5-113
optional	TM	None	5-114
optional	CM	None	5-115
optional	CF	None	5-115
optional	SF	None	5-116
optional	FS	None	5-117
optional	SD	None	5-118
optional	FU	If FU card is absent, subroutine TALLYX is not called.	5-120
optional	FT	If FT card is absent, there is no special treatment for tally.	5-121
optional	TALLYX	None	5-128
optional	TF	1 1 *last last* 1 *last last last*	5-128
optional	PI (FIP)	Tally type 5; r_0=0	5-130
optional	TIR (FIR)	Tally type 5; r_0=0	5-131
optional	TIC (FIC)	Tally type 5; r_0=0	5-131
optional	TALNP	None	5-133

Use	Card	Defaults	Page
optional	PERT	METHOD=+1; ERG=all energies; RXN=1	5-133
optional	TMESH	Type 1: linear interpolation; response is a function of the energy deposited; constant multiplier=1.0 Type 2: Neutrons scored Type 3: Score energy deposited from any source, linear interpolation; response is a function of the energy deposited; constant multiplier=1.0 Type 4: None	5-138
Variance-Reduction Cards			**Section 5.7 on page 5-149**
required	IMP	1; if IMP is set to 0 for any particle, all importances for that cell are set to 0 unless otherwise specified.	5-149
optional	WWG	None	5-150
optional	WWGE	If card omitted, single energy interval; if card with no entries, 10 energy bins generated	5-152
optional	WWGT	If card omitted, single time interval; if card with no entries, 10 time bins generated	5-152
optional	WWP	5 0.6 × wupn 5 0 0 0 1 J 0	5-153
required	WWN	None	5-154
optional	WWE	One weight-window energy interval.	5-156
optional	WWT	One weight-window time interval.	5-157
optional	MESH	GEOM=XYZ; ORIGIN=0 0 0; AXS=0 0 1; VEC=1 0 0; IINTS, JINTS, KINTS=10	5-157
optional	EXT	a_j=0, no transform	5-161
optional	VECT	None	5-163
optional	FCL	x_j=0; no forced collisions	5-164
optional	DD	0.1 1000	5-165
optional	PD	p_j=1	5-167
optional	DXT	dwc_1, dwc_2, dpwt=0	5-168
optional	DXC	m=0, p_j=1	5-170
optional	BBREM	None	5-170
optional	SPABI	None	5-171
optional	ESPLT	No energy splitting or roulette if card not used.	5-172
optional	PWT	None	5-173

Use	Card	Defaults	Page
Output Control and Miscellaneous Cards			**Section 5.8 on page 5-174**
optional	NPS	None	5-174
optional	CTME	Infinite	5-175
	PRDMP	Print tallies at end; dump to RUNTPE every 15 minutes and at end; do not write MCTAL file; write all dumps to RUNTPE; for fixed-source problems, write tally fluctuation charts and rendezvous every 1000 particles or, if multiprocessing, 10 times during the run; for KCODE problems, write charts and rendezvous at end of each cycle	5-175
	PRINT	Print "basic," "default," and "shorten" tables.	5-176
optional	NOTRN	None	5-179
	MPLOT	None	5-179
	PTRAC	BUFFER=100; FILE=BIN; MAX=10000; MEPH=write all events; WRITE=POS; FILTER=no additional filtering; TYPE=all particle types; NPS=events for all histories; VALUE=10	5-180
	HISTP & HTAPE3X	*lhist*=500000000; all events written to HISTP	5-184
	DBCN	$x_1=(5^{19})^{152917}$; x_5=600; x_9=1.e-4; x_{10}=100; x_{13}=152917; $x_{14}=5^{19}$	5-185
	LOST	10 10	5-188
	IDUM	All array values 0	5-188
	RDUM	All array values 0	5-189
	FILES	*access*=SEQUENTIAL; *form*=FORMATTED if *access*=SEQUENTIAL, *form*=UNFORMATTED if *access*=DIRECT	5-189
optional	STOP		5-190

(a) Required for all but MODE N
(b) Neutron criticality problems only.
(c) KCODE only
(d) Neutron problems only

6 PLOTTING

MCNPX has two plotting capabilities. The first, PLOT, is used to plot two-dimensional slices of a problem geometry specified in the INP file. The user can perform interactive plotting in either of two ways: "point-and-click" mode or "command-prompt" mode. In addition, generation of plot files can be done in batch mode using a command file.

The second plotting capability, MCPLOT, plots tally results produced by MCNPX and cross-section data used by MCNPX. Section 6.1 addresses system issues external to MCNPX related to graphics. Section 6.2 discusses how to invoke the PLOT features, whereas Section 6.3 discusses the MCPLOT features. A explanation of each set of input commands is given.

Mesh tallies may be plotted either in MCPLOT from MCTAL files or superimposed over geometry plots in PLOT from RUNTPE files.

6.1 SYSTEM GRAPHICS INFORMATION

Installation-specific plotting information is provided in Appendix B.

The X-window graphics library 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 (e.g., OPENWINDOWS, MOTIF, etc.). Prior to running MCNPX, perform the following steps to use these capabilities. Note that these steps use UNIX C-shell commands.

1. On the host that will execute MCNPX, enter:

   `setenv DISPLAY` *`displayhost`*`:0`

   where *`displayhost`* is the name of the host that will receive the graphics.

2. In the CONSOLE window of the display host enter:

   `xhost` *`executehost`*

   where *`executehost`* is the name of the host that will execute MCNPX.

With either the `setenv` or `xhost` commands, the host IP address can be used in place of the host name. For example,

```
setenv DISPLAY 128.10.1:0
```

This option is useful when one remote system does not recognize the host name of another.

6.2 THE GEOMETRY PLOTTER

The geometry plotter is used to plot two-dimensional slices of a problem geometry specified in the INP file. This feature of MCNPX is invaluable for debugging geometries. You should first verify your geometry model with the MCNPX geometry plotter before running the transport part of MCNPX, especially with a complicated geometry in which it is easy to make mistakes. The time required to plot the geometry model is small compared with the potential time lost working with an erroneous geometry.

6.2.1 PLOT Input and Execute Line Options

To plot geometries with MCNPX, enter the following command:

```
MCNPX IP INP=filename KEYWORD[=value(s)]
```

where IP stands for initiate and plot. The allowed keywords are explained in Table 6-1. The most common method of plotting is with an interactive graphics terminal. MCNPX will read the input file, perform the normal checks for consistency, and then the interactive point-and-click window appears.

Table 6-1. PLOT Execution Line Keywords

Keyword Options	Description
NOTEK	Suppress plotting at the terminal and send all plots to the graphics metafile, PLOTM. The keyword NOTEK is for production and batch situations and is used when the user's terminal has no graphics capability.
COM=*filename*	Use file *filename* as the source of plot requests. When an end-of-file (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=*filename*	Name the graphics metafile *filename*. The default name is PLOTM. For some systems this metafile is a standard postscript file and is named PLOTM.PS. When CGS is being used, there can be no more than six characters in *filename*. Unique names for the output file, PLOTM, will be chosen by MCNPX to avoid overwriting existing files.
COMOUT=*filename*	Write all plot requests to file *filename*. The default name is COMOUT. PLOT 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 file, COMOUT, will be chosen by MCNPX to avoid overwriting existing files.

6.2.2 Geometry Plotting Basic Concepts

Before describing the individual plotting commands, it may help to explain the mechanics of two-dimensional plotting. To obtain a two-dimensional slice of a geometry, you 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 two-dimensional plane that may be arbitrarily oriented in space; therefore, the first problem is to decide the plane position and orientation. In an orthogonal three-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 two-dimensional 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 ORIGIN, which serves two purposes: first, for planes not corresponding to simple coordinate planes, it determines the position of the plane being viewed, and 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 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 is along the horizontal axis of the plot window and points toward the right side of the window. The second BASIS vector 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 ±x, ±y, or ±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-components, 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.

All the plot parameters for the MCNPX plotter have defaults. You can respond to the first MCNPX prompt with a carriage return and obtain a plot. The default 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. In command-prompt mode, 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, you can obtain any desired 2-D plot. Most parameters remain set until you change them, 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. Several things can result. 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 these unpleasantries, move the plot plane some tiny amount away from surfaces.

6.2.3 Geometry Debugging

Surfaces appearing on a plot as red 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 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 indicate a cookie cutter cell or a DXTRAN sphere. These are not errors. The reason for the presence of dashed lines on an MCNPX plot should be understood before running a problem.

When checking a geometry model, errors may not appear on the two-dimensional slice chosen, but one or more particles will 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.

6.2.4 Interactive Geometry Plotting in Point-and-Click Mode

Table 6-2. Point-and-Click Geometry Plotter Commands

Command	Result
Top Margin Commands	
UP, RT, DN, LF	When selected, moves the plot frame up, right, down, or left, respectively.
Origin	After activated, moves the origin to a point selected on the plot.
.1 .2 .5 Zoom 1 2 5	If double-clicked at any point on the continuum, results in a zoom of the current plot corresponding to the selected fraction/multiple. If single-clicked, followed by selecting a point in the picture, zooms to that point.
Left Margin Commands	
Edit	Provides information for the plot cell number and coordinates at the most recent cursor selection point.
CURSOR	Forms a cursor to zoom into a part of the picture.
SCALES	Adds scales showing the dimensions of the plot.
ROTATE	Rotates the picture 90°.
PostScript	Creates a PostScript publication-quality picture in the file PLOTM.PS.
COLOR *var*	Toggles colors on and off (producing a line-only drawing). The parameter *var* will either register `off` with `COLOR` toggle, or `mat` (DEFAULT), or can be changed using any parameters in the right margin control string as appropriate to the problem.
XY YZ ZX	Alter plot perspective to corresponding planar combinations.
LABEL	Controls surface and cell labels.
LEVEL	Toggles through universe levels in repeated structures geometry.
Cell line	Toggles through the following settings: `No Lines` Plot cells not outlined in black. `CellLine` Plot geometric cells, outlined in black. `WW MESH` Plot WW superimposed mesh (`WWINP` file and card `WWP 4j -1` required). `WW+Cell` Plot WW superimposed mesh + `CellLine` (`WWINP` file and card `WWP 4j -1` required). `WWG MESH` Plot WWG mesh (`MESH` card and card `WWG J 0` required). `WWG+Cell` Plot WWG mesh + `CellLine` (`MESH` card and card `WWG J 0` required). `MeshTaly` Plot mesh tally boundaries. `MT+Cell` Plot mesh tally boundaries + `CellLine`. The `CellLine` and `No Lines` options are always available. `WW MESH` and `WW+Cell` are available only when the `WWP` card calls for using a superimposed weight-window mesh (5th entry negative) and a WWINP file is provided. `WWG MESH` and `WWG+Cell` are available only when a `MESH` card appears in the input and when the `WWG` card requests superimposed mesh generation (2nd entry =`0`). `MeshTaly` and `MT+Cell` are available only when a mesh tally has been requested.

Command	Result
Right Margin Commands (Used in Edit, COLOR, and LABEL)	
cel	Cell labels/colors will be cell numbers.
imp	Cell labels/colors will be importances by particle type.
rho	Cell labels/colors will be atom densities.
den	Cell labels/colors will be mass densities.
vol	Cell labels/colors will be volumes (calculated or user-supplied).
fcl	Cell labels/colors will be forced collisions by particle type.
mas	Cell labels/colors will be masses.
pwt	Cell labels/colors will be photon production weights.
mat	Cell labels/colors will be material numbers (DEFAULT).
tmp	Cell labels/colors will be temperature for time index 1, tmp1.
wwn	Cell labels/colors will be weight windows for energy of time index 1, wwn1, by particle type.
ext	Cell labels/colors will be exponential transform by particle type.
pd	Cell labels/colors will be detector contribution by particle type.
dxc	Cell labels/colors will be DXTRAN contributions.
u	Cell labels/colors will be universe numbers.
lat	Cell labels/colors will be lattices.
fill	Cell labels/colors will be filling universes.
ijk	Cell labels/colors will be lattice indices.
nonu	Cell labels/colors will be fission turnoffs.
pac	Cell labels/colors will be particle activity, column.
tal	Cell colors will be mesh tallies.
PAR	Controls particle type displayed.
N	Controls number on the cell quantity. Example: WWN3:P would provide photon weight windows in the 3rd energy group and be selected by clicking WWN & N.
Bottom Margin Commands	
Enter Data	Toggled on by selecting "Click here". Allows entry of parameters per keyboard entry (e.g., ORIGIN 0. 0. 0. will locate plot origin at x, y, z = 0, 0, 0)
Redraw	Redraws the picture when it needs refreshing.
Plot>	Returns control to the command window enabling traditional plot commands to be entered.
End	Terminates the plot session.

Command	Result
Plotting Superimposed Weight-Window Mesh	
MESH off	Toggled to MESH *on* position by clicking when a mesh has been generated by WWINP card entry.
wwn..par..N	Yields weight-window particle type and number.
N	N=-1, results in no lines. N=0, sets MESH *off*. N=1, sets WW MESH.
WWMESH	Appears only if WWINP file is read in.

6.2.5 Interactive Geometry Plotting in Command-Prompt Mode

In command-prompt mode, plot requests consist of a sequence of commands terminated by a carriage return. A command consists of a keyword, usually followed by some parameters. Lines can be continued by typing an & before the carriage return, but each keyword and its associated parameters must be complete on one line. Keywords and parameters are blank-delimited with no more than 80 characters per line. Commas and equals signs are interpreted as blanks. Keywords can be shortened to any degree not resulting in ambiguity, but must be 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.

This section is a detailed description of each of the PLOT keywords and its associated parameters. These commands are typically entered after a plot> prompt or they are given in a command file for batch processing (Section 6.2.6). In the command-prompt mode, you must type only enough of the keyword so that it is unique, but as much as you type must be spelled correctly. The parameters must be typed in full as given here.

Table 6-3. PLOT Commands

Command	Description
Device-Control Commands (DEFAULT is user's terminal)	
TERM *n m*	Device type is specified by *n*. *n*=0 for a terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics metafile. TERM 0 is equivalent to putting NOTEK on MCNPX's execute line. n=1 specifies Tektronix 4010 using CGS. n=2 specifies Tektronix 4014 using CGS. n=3 specifies Tektronix 4014E using CGS. (DEFAULT) n=4115 specifies Tektronix using GKS and UNICOS. (DEFAULT) n=1 specifies Tektronix using the AIX PHIGS GKS library. (DEFAULT) Check with your vendor for the proper terminal type if you are using a GKS library. The baud rate of the terminal is specified by *m*. (DEFAULT=9600)
FILE [*aa*]	Send or don't send plots to the graphics metafile PLOTM.PS according to the value of the parameter *aa*. The graphics metafile 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 the following: If *aa* is blank, only the current plot is sent to the graphics metafile. If *aa*=ALL, the current plot and all subsequent plots are sent to the metafile until another FILE command is entered. If *aa*=NONE, the current plot is not sent to the metafile nor are any subsequent plots until another FILE command is entered.
VIEWPORT *aa*	Make the viewport rectangular or square according to the value of *aa*. 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. If *aa*=RECT, allow space beside the plot for a legend and around the plot for scales. (DEFAULT) If *aa*=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.
General Commands	
&	Continue reading commands for the current plot from the next input line. The & must be the last thing on the line.
RETURN	If PLOT was called by MCPLOT, control returns to MCPLOT. Otherwise RETURN has no effect.
MCPLOT	Call or return to the MCPLOT tally and cross-section plotter.
PAUSE [*n*]	Use with COM=*filename* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the return key is pressed.
END	Terminate execution of PLOT.†

Command	Description
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 a carriage return, 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.
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 of by a conflicting command.	
BASIS x_1 y_1 z_1 x_2 y_2 z_2	Orient the plot so that the direction (x_1 y_1 z_1) points to the right and the direction (x_2 y_2 z_2) 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.
ORIGIN v_x v_y v_z	Position the plot so that the origin, which is in the middle of the plot, is at the point (v_x, v_y, v_z). The default values are 0 0 0.
EXTENT e_h e_v	Set the scale of the plot so that the horizontal distance from the origin to either side of the plot is e_h and the vertical distance from the origin to the top or bottom is e_v. If e_v is omitted, it will be set equal to e_h. If e_v is not equal to e_h, the plot will be distorted. The default values are 100 and 100.
PX v_x	Plot a cross section of the geometry in a plane perpendicular to the x-axis at a distance v_x from the origin. This command is a shortcut equivalent of BASIS 0 1 0 0 0 1 ORIGIN v_x v_y v_z, where v_y and v_z are the current values of v_y and v_z.
PY v_y	Plot a cross section of the geometry in a plane perpendicular to the y-axis at a distance v_y from the origin.
PZ v_z	Plot a cross section of the geometry in a plane perpendicular to the z-axis at a distance v_z from the origin.

Command	Description
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. The parameters *c* and *des* are optional. 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 possible values of *des* follow, where ":<*pl*>" indicates the particle type. CEL cell names IMP:<*pl*> importances RHO atom density DEN mass density VOL volume FCL:<*pl*> forced collision MAS mass PWT photon-production weight MAT material number TMP*n* temperature (*n*=index of time) WWN*n*:<*pl*> weight-window lower bound (*n*=energy interval) EXT:<*pl*> exponential transform PD*n* detector contribution (*n*=tally number) DXC:<*pl*> DXTRAN contribution U universe LAT lattice type FILL filling universe IJK lattice indices of repeated structures/lattice geometries 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 *on*|*off*	*on* display only the macrobody surface number. (DEFAULT) *off* display the macrobody surface facet numbers.
SCALES *n*	Put scales and a grid on the plot. Scales and grids are incompatible with VIEWPORT SQUARE. If *n*=0, neither scales nor a grid. (DEFAULT) If *n*=1, scales on the edges. If *n*=2, scales on the edges and a grid on the plot.

Command	Description
MESH *n*	Controls plotting of the weight-window and weight-window-generator superimposed mesh. If *n*=0 No Lines Plot cells not outlined in black. If *n*=1 CellLine Plot geometric cells, outlined in black. If *n*=2 WW MESH Plot WW mesh (WWINP file and card WWP 4j -1 required). If *n*=3 WW+Cell Plot WW mesh + CellLine (WWINP file and card WWP 4j -1 required). If *n*=4 WWG MESH Plot WWG mesh (MESH card and card WWG J 0 required). If *n*=5 WWG+Cell Plot WWG mesh + CellLine (MESH card and card WWG J 0 required). If *n*=6 MeshTaly Plot mesh tally boundaries (RMESH, CORA, etc., required) If *n*=7 MT+Cell Plot mesh tally boundaries + CellLine The CellLine and No Lines options are always available. WW MESH and WW+Cell are available only when the WWP card calls for using a superimposed weight-window mesh (5th entry negative) and a WWINP file is provided. WWG MESH and WWG+Cell are available only when a MESH card appears in the input and when the WWG card requests superimposed mesh generation (2nd entry =0). MeshTaly and MT+Cell are available only when a mesh tally has been requested.
CONTOUR *cmin cmax* [*cstep*] [%|PCT|LIN|LOG] [OFF]	The parameters *cmin*, *cmax*, and *cstep* are the minimum, maximum, and step values for contours, respectively. The *cstep* entry is ignored and can be omitted. If either the % symbol or the PCT keyword 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 %. If the keyword LIN appears, interpret the step values as absolute values of contour levels. If the keyword LOG appears, space the contour levels logarithmically between *cmin* and *cmax*. The default values are 1e-4 1e-2 12 LOG. If the OFF keyword appears, use the following defaults: 0 100 %
COLOR *n*	Turn color on or off and set the resolution. If *n*=ON, turn color on. (DEFAULT) If *n*=OFF, turn color off. If 50≤*n*≤3000, set the color resolution to *n*. A larger value increases resolution and drawing time.
SHADE m_1=*value* m_2=*value* ... m_i=*value*	Make the cells containing problem material number m_i a particular color. Use the LABEL command to display material numbers. Parameter designates the desired color (e.g., green, blue, etc.). The command OPTIONS will list available colors if your display is a color monitor.
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 d_h d_v	Change the origin of the plot by the amount d_h in the horizontal direction and by the amount d_v 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.

Command	Description
FACTOR *f*	Enlarge the plot by the factor 1/*f*. The parameter *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 carriage return followed by a carriage return. 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.

6.2.6 Geometry Plotting in Batch Mode

Although MCNPX can be run in a batch environment without much difficulty, user interaction with the plotter is significantly reduced. If you are not using an interactive graphics terminal, use the NOTEK option on the MCNPX execution line or set TERM=0 along with other PLOT keywords when first prompted by PLOT. Every view you plot will be put in a local graphics metafile or postscript file called PLOT*n* 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 Table 6-3 for a complete explanation.) For some graphics systems, the PLOT*n*.PS file is a postscript file that can be sent to a postscript printer.

6.2.7 Sixty-Four-Color Plotting and Shading by Cell Parameters

MCNPX has 64-color plotting. Shading of geometry plots may be used for any cell parameter. MCNPX can color geometry plots by any cell quantity. Each cell can have a different color, or each repeated structure level or universe can have a different color. Logarithmic shading of importances, weight windows, and summary information is automatic. If a superimposed weight-window mesh is used, coloring also may be done by the value of the mesh weight windows.

The default shading choice is "`COLOR mat`", which colors problem cells by the program material number. This button must be clicked to get "`COLOR off`" (black and white) and then clicked again to color by whatever parameter is listed after the "`Edit`" button. For example, in the right margin, click "`cel`", which will make the "`Edit`" quantity "`cel`". Next, click "`COLOR`" so that "`COLOR cel`" is displayed; on the next plot, the color shades will be determined by program cell number.

For command-prompt plotting, enter

```
PLOT> label 0 1 rho
```

The color command then must be set such as

```
PLOT> color on
```

and the coloring will now be by `rho`, the atom density.

6.3 TALLY & CROSS-SECTION PLOTTING

6.3.1 The MCPLOT Tally and Cross-Section Plotter

MCPLOT plots tally results produced by MCNPX and cross-section data used by MCNPX. It can draw ordinary two-dimensional x-y plots, contour tally plots, and three-dimensional surface tally plots, and supports a wide variety of plot options. More than one curve can be plotted on a single x-y plot.

MCPLOT plots 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 MCNPX such as energy cutoffs, neutron cross-section temperatures, $S(\alpha,\beta)$ 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.

MCNPX can plot proton cross sections. The reaction numbers are similar to the neutron reaction numbers: all positive. The principal proton cross sections are the following: $\pm$1=total, $\pm$2=nonelastic, $\pm$3=elastic, $\pm$4=heating, and >4=various reactions. On the LA150H proton library, the only available reaction is *mt*=5 with its multiplicities, 1005, 9005, 31,005, etc. The multiplicity reaction numbers for interaction reaction *mt*=5 are 1005 for neutrons, 9005 for protons, 31,005 for deuterons, etc. To find out which reactions are available for a particular nuclide or material, enter an invalid reaction number, such as *mt*=99, and MCNPX will list the available proton reactions and the available yields, such as 1005, 32,001, and 34,002. The proton multiplicity, *mt*=9001, 9004, 9005, etc., generally is available, along with the total cross section and heating

number, *mt*=1, *mt*=4. Entering a bad nuclide, XS=12345.67H, will cause MCNPX to list the available proton nuclides.

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. After transport is finished, MCPLOT is invoked by typing a Z on the MCNPX execute line, either as a separate procedure using existing RUNTPE or MCTAL files:

MCNPX Z RMCTAL=<*mctal_filename*> or

MCNPX Z RUNTPE=<*runpte_filename*> ,

or as part of a regular uninterrupted MCNPX run. To superimpose mesh tally contours with problem geometries, initiate MCPLOT using one of the two execute lines above and then enter the geometry plotter using the PLOT command.

There are two ways to request that a plot be produced periodically during the run: use an MPLOT card (Section 5.8.6) in the INP file or use the TTY interrupt feature (Section 3.6.2). The TTY interrupt <ctrl-c>m causes MCNPX 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. No output is sent to the COMOUT file. The following commands can not be used after invoking MCPLOT with an interrupt: RMCTAL, RUNTPE, DUMP, and END. Cross-section data cannot be displayed after a TTY interrupt or by use of the MPLOT card.

Color contour plots may be created of mesh tally, radiography tally, and lattice tally results. Mesh tallies also can be plotted superimposed over problem geometries. All of these plots are done in MCNPX without the need of auxiliary post-processing codes and can be made either at the end of a calculation or while a calculation proceeds by using 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. MCTAL 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 in the execute line using the following format:

MCNPX I=*inpfile* MCTAL=*filename*

The default *filename* is a unique name based on MCTAL.

For examples of using MCPLOT, see Appendix B.

6.3.2 MCPLOT Input and Execution Line Options

To run only MCPLOT and plot tallies upon termination of the job by MCNPX, enter the following command:

```
MCNPX Z KEYWORD[=value(s)]
```

where Z invokes MCPLOT. The allowed keywords are explained in Table 6-4. Cross-section data cannot be plotted by this method.

The execute line command

```
MCNPX INP=filename IXRZ KEYWORD[=value(s)]
```

causes MCNPX to run the problem specified in *filename,* following which the prompt mcplot> appears for MCPLOT commands. Both cross-section data and tallies can be plotted using this method after the run is complete. Cross-section data cannot be plotted after a TTY interrupt or by use of the MPLOT card.

The execute line command

```
MCNPX INP=filename IXZ KEYWORD[=value(s)]
```

provides the most common way to plot cross-section data. The problem cross sections are read in, but no transport occurs. When using this method to plot cross sections, the following commands cannot be used: 3D, BAR, CONTOUR, DUMP, FREQ, HIST, PLOT, RETURN, RMCTAL, RUNTPE, SPLINE, VIEW, and WMCTAL.

Table 6-4. MCPLOT Execution Line Options

Keyword Options	Description
NOTEK	Suppress plotting at the terminal and send all plots to the graphics metafile, PLOTM. The keyword NOTEK is for production and batch situations and is used when the user's terminal has no graphics capability.
COM=*filename*	Use file *filename* as the source of plot requests. When an end-of-file (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=*filename*	Read file *filename* as the source of MCNPX tally data. The default is RUNTPE, if it exists. If the default RUNTPE file does not exist, the user will be prompted for an RMCTAL or RUNTPE command.
RMCTAL=*filename*	Read the MCTAL file, *filename*, as the source of the MCNPX tally data. The default is MCTAL, if it exists.

PLOTM=*filename*	Name the graphics metafile *filename*. The default name is PLOTM. For some systems this metafile is a standard postscript file and is named PLOTM.PS. When CGS is being used, there can be no more than six characters in *filename*. Unique names for the output file, PLOTM, will be chosen by MCNPX to avoid overwriting existing files.
COMOUT=*filename*	Write all plot requests to file *filename*. 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 file, COMOUT, will be chosen by MCNPX to avoid overwriting existing files.

Plot requests are normally entered from the keyboard of a terminal; alternatively, they 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 a carriage return not immediately preceded by an & or by a COPLOT command. Commands consist of keywords, usually followed by some parameters, either space or comma delimited.

Defaults are available for nearly everything. If MCNPX is run with Z as the execute line message, and if file RUNTPE is present with more than one energy bin in the first tally, and if a carriage return is entered in response to the MCPLOT prompt, a lin-log histogram plot of tally/MeV vs. energy, with error bars and suitable labels, will appear on the screen.

6.3.3 Plot Conventions and Command Syntax

6.3.3.1 2-D PLOT

The origin of coordinates for the MCPLOT 2-D option 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.

6.3.3.2 CONTOUR PLOT

Similarly, the origin of coordinates for MCPLOT's contour plot option 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. Extensions to the FREE and CONTOUR commands allow for shaded contour plots of tally and mesh data.

For additional examples involving contour plots see Appendix B, Section B.3.

6.3.3.3 COMMAND SYNTAX

As for the geometry plotter, each command consists of a command keyword, in most cases followed by some parameters. Keywords and parameters are entered space delimited with no more than 80 characters per line. Commas and equals signs are interpreted as spaces. A plot request can be continued onto another line by typing an `&` before the carriage return, but each command (the keyword and its parameters) must be complete on one line. Command keywords, but not parameters, can be abbreviated to any degree not resulting in ambiguity, but they 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 a dagger (†) in the list presented in Table 6-5 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-D plots only.

6.3.4 Plot Commands Grouped by Function

Table 6-5. MCPLOT Commands

Command	Description
Device-Control Commands (DEFAULT is user's terminal)	
`TERM` *n m*	Device type is specified by *n*. *n*=`0` for a terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics metafile. `TERM 0` is equivalent to putting `NOTEK` on MCNPX's execute line. `n=1` specifies Tektronix 4010 using CGS. `n=2` specifies Tektronix 4014 using CGS. `n=3` specifies Tektronix 4014E using CGS. (DEFAULT) `n=4115` specifies Tektronix using GKS and UNICOS. (DEFAULT) `n=1` specifies Tektronix using the AIX PHIGS GKS library. (DEFAULT) Check with your vendor for the proper terminal type if you are using a GKS library. The baud rate of the terminal is specified by *m*. (DEFAULT=9600)
`FILE [`*aa*`]`	Send or don't send plots to the graphics metafile PLOTM.PS according to the value of the parameter *aa*. The graphics metafile 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 the following: If *aa* is blank, only the current plot is sent to the graphics metafile. If *aa*=`ALL`, the current plot and all subsequent plots are sent to the metafile until another `FILE` command is entered. If *aa*=`NONE`, the current plot is not sent to the metafile nor are any subsequent plots until another `FILE` command is entered.
General Commands	
`&`	Continue reading commands for the current plot from the next input line. The `&` must be the last thing on the line.†

Command	Description
COPLOT	Plot a curve according to the commands entered so far and keep the plot open for co-plotting one or more additional curves. COPLOT is effective for 2-D 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 MCNPX is running histories. (DEFAULT: *n*=0)
RETURN	If MCPLOT was called by MCNPX 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.
PAUSE [*n*]	Use with COM=*filename* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the return key is pressed.
END	Terminate execution of MCPLOT.†
Inquiry Commands: When one of these commands is encountered, the requested display is made and then MCPLOT waits for the user to enter another line, which can be just a carriage return, before resuming. The same thing will happen if MCPLOT 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 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 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 co-plots, contour plots, or 3-D plots.
File Manipulation Commands	
RUNTPE *filename n*	Read dump *n* from RUNTPE file *filename*. 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 *filename*	Write the tally data in the current RUNTPE dump to MCTAL file *filename*.†
RMCTAL *filename*	Read MCTAL file *filename*.†

Command	Description
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, PLINEAR, and SPLINE.	
TALLY *n*	Define tally *n* as the current tally.† The parameter *n* is the tally designation on the F card 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 card.† The command PERT 0 will reset PERT *n*.
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. Bin normalization is not done in 3-D or contour plots.
FACTOR *a f s*	Multiply the data for axis *a* by the factor *f* and then add the term *s*.† The parameter *a* is X, Y, or Z. The parameter *s* is optional. If *s* is omitted, it is set to zero. For the initial curve of a 2-D plot, reset the axis limits (XLIMS or YLIMS) to the default values. The values given by FACTOR affects only the current curve or plot.
RESET *aa*	Reset the parameters of command *aa* to their default values.† The parameter *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.
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. The keyword BELOW has no effect on 3-D plots.
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. The values of x and y are x- and y- axis values. The maximum length of *aa* is 40 characters.
XTITLE *"aa"*	Use *aa* as the title for the x-axis. The default is the name of the variable represented by the x-axis. The maximum length of *aa* is 40 characters.

Command	Description
YTITLE "*aa*"	Use *aa* as the title for the y-axis. The default is the name of the variable represented by the y-axis. The maximum length of *aa* is 40 characters.
ZTITLE "*aa*"	Use *aa* as the title for the z-axis in 3-D plots. The default is the name of the variable represented by the z-axis. The maximum length of *aa* is 40 characters.
LABEL "*aa*"	Use *aa* as the label for the current curve.† It is printed in the legend beside a sample 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. The maximum length of *aa* is 10 characters.
Commands that Specify What is to be Plotted	
FREE *x*[*y*] [*n*X*m*] [ALL] [NOALL]	Use variable *x* (*y* blank) or variables *x* and *y* as the independent variable or variables in the plot.† Valid values for *x* and *y* are the tally bin indices F, D, U, S, M, C, E, T, I, J, and K, where I, J, and K refer to lattice or mesh indices. If only *x* is specified, 2-D plots are made. If both *x* and *y* are specified, either contour or 3-D plots are made, depending on whether 3-D is in effect. The default value of *xy* is E, and gives a 2-D plot in which the independent variable is energy. The *n*X*m* entry specifies the number of bins associated with the I and J lattice indices. (Only valid when *x*=I or *xy*=IJ.) The ALL entry specifies that the minimum and maximum contour range should be taken from all the tally bins. (Only valid when *x*=I or *xy*=IJ.) Omitting this parameter results in the default minimum and maximum contour range, which includes only those tally values contained in the specified 2-D plot. The NOALL entry specifies that the minimum and maximum contour range should be taken only from those of the FIXED command slice. (DEFAULT) The FREE command resets XTITLE, YTITLE, ZTITLE, XLIMS, YLIMS, HIST, BAR, PLINEAR, and SPLINE 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 tally bins they represent are the following: 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 I 1st lattice/mesh index J 2nd lattice/mesh index K 3rd lattice/mesh index Restriction: Only the J and K indices are allowed for the 1-D IJK plot and only the K index is allowed for a 2-D IJK contour plot.

Command	Description
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 asterisk (*) (the corresponding variable is then a free variable). If there is only one *, 2-D plots are made. If there are two, contour or 3-D 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*, the number of source histories. Allowed values of *x* include the following: 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 $f(x)*\Delta x *x^{1to8}$ vs *x*) 1c–8c 1 to 8 cumulative moments of $f(x)*x^{1to8}$ 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 removal lifetime according to the value of *i*.† If *i*= 1 k (collision) 2 k (absorption) 3 k (track) 4 prompt removal lifetime (collision) 5 prompt removal lifetime (absorption) 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 cycle skipped. Can not 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
Commands for Cross-Section Plotting	
XS *m*	Plot a cross section according to the value of *m*.† Option 1: *m*=M*n*, a material card in the INP file. Example: XS M15. The available materials will be listed if a material is requested that does not exist in the INP file. Option 2: *m*=*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.

Command	Description
MT *n*	Plot reaction *n* of material XS *m*.† The default is the total cross section. The available reaction numbers will be listed if one enters a reaction number that doesn't exist (e.g., 999)
PAR <*pl*>	Plot the data for particle type <*pl*>, where <*pl*> can be N, P, E or H of material M*n*.† The default is the source particle type for XS=M*n*. For XS=*z*, the particle type is determined from the data library type. For example, 92000.01g defines PAR=P. Must be first entry on line.
Commands that Specify the Form of 2-D Plots	
LINLIN	Use linear x-axis and linear y-axis. (DEFAULT for tally contour plots)
LINLOG	Use linear x-axis and logarithmic y-axis. (DEFAULT for all except tally contour plots)
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, *min*, upper limit, *max*, and number of subdivisions, *nsteps*, on the x- or y-axis. The parameter *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 MCNPX.
SCALES *n*	Put scales on the plots according to the value of *n*: If *n*=0, no scales on the edges and no grid. If *n*=1, scales on the edges (DEFAULT) If *n*=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.
SPLINE [*x*]	Use spline curves in the plots.† If the parameter *x* is included, rational splines of tension *x* are plotted. Otherwise Stinem and cubic splines are plotted. Rational splines are available only with the DISSPLA graphics system.
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*. If no *x* and no *y*, put the legend in its normal place. (DEFAULT) If *x*=0 and no *y*, omit the legend. If both *x* and *y* defined, for 2-D plots only, put most of the legend in its usual place, but put the part that labels the plot lines at location *x, y*, where the values of x and y are based on the units and values of the x- and y- axes.

Command	Description
Commands that Specify the Form of Contour Plots	
CONTOUR [*cmin cmax cstep*] [%|PCT|LIN|LOG] [ALL|NOALL] [LINE|NOLINE] [COLOR|NOCOLOR]	The parameters *cmin*, *cmax*, and *cstep* are the minimum, maximum, and step values for contours, respectively. If either the % symbol or the PCT keyword 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 %. If the keyword LIN appears, interpret the step values as absolute values of contour levels. If the keyword LOG appears, space the contour levels logarithmically between *cmin* and *cmax*, with *cstep* values in between. (DEFAULT option with the following values: 1e-4 1e-2 12 LOG) The ALL keyword specifies that the minimum and maximum contour range should be taken from all of the tally bins (default is to use the bins only in the current plot, or NOALL). The LINE|NOLINE option controls plotting of contour lines. The COLOR|NOCOLOR option controls shading of the contours.
† available with COPLOT	

Note: For mesh tallies, the *i*, *j*, and *k* parameters of the FREE command refer to the CORA, CORB, and CORC mesh tally dimensions.

Note: For lattice tallies, the *i*, *j*, and *k* parameters of the FREE command refer to *i*, *j*, and *k* lattice indices.

Note: For radiography tallies, the command FREE S C is used to make a contour plot of the *s*- and *t*- radiography axes.

Note: For lattice tallies that are not specified fully, the [*n*X*m*] dimensions must be provided. Mesh and radiography tallies are always specified fully, so [*n*X*m*] is never required for them.

Note: One-dimensional mesh, radiography, and lattice tallies may be specified by giving the free dimension of the FREE command and fixing the other two dimensions:

```
FREE I   FIXED  J=10   FIXED  K=12
```

7 REFERENCES

ARM73 T. W. Armstrong and K. C. Chandler, "SPAR, A FORTRAN Program for Computing Stopping Powers and Ranges for Muons, Charged Pions, and Heavy Ions," Oak Ridge National Laboratory report ORNL-4869 (May 1973).

AAR86 P. A. Aarnio, A. Fasso, H. J. Moehring, J. Ranft, and G. R. Stevenson, "FLUKA-86 users guide," CERN/TIS-RP/186 (1986).

AAR87 P. A. Aarnio, J. Lindgren, A. Fasso, J. Ranft, and G. R. Stevenson, "FLUKA-87," CERN/TIS-RP/190 (1987).

AAR90 P. A. Aarnio et al., "FLUKA89," Consiel Europeene Organisation pour La Recherche Nucleaire informal report (January 2, 1990).

ART88 E. D. Arthur, "The GNASH Preequilibrium-Statistical Model Code," Los Alamos National Laboratory report LA-UR-88-382 (February 1988).

ATC80 F. Atchison, "Spallation and Fission in Heavy Metal Nuclei under Medium Energy Proton Bombardment," in *Targets for Neutron Beam Spallation Sources*, Jul-Conf-34, Kernforschungsanlage Julich GmbH (January 1980).

BAR73 V. S. Barashenkov, A. S. Iljinov, N. M. Sobolevskii, and V. D. Toneev, "Interaction of Particles and Nuclei of High and Ultrahigh Energy with Nuclei," *Usp. Fiz. Nauk* **109,** 91 (1973) [*Sov. Phys. Usp.* **16**, 31 (1973)].

BAR81 J. Barish, T. A. Gabriel, F. S. Alsmiller, and R. G. Alsmiller, Jr., "HETFIS High-Energy Nucleon-Meson Transport Code with Fission," Oak Ridge National Laboratory Report ORNL-TM-7882 (July 1981).

BAR94 V. S. Barashenkov and A. Polanski, "Electronic Guide for Nuclear Cross Sections," *Comm. JINR* E2-94-417, Dubna (1994).

BER63 M. J. Berger, "Monte Carlo Calculation of Penetration and Diffusion of Fast Charged Particles," in *Methods in Computational Physics*, B. Alder, S. Fernbach, and M. Rotenberg, Eds., (Academic Press, New York, 1963) Vol 1, p. 135.

BER70 M. J. Berger and S. M. Seltzer, "Bremsstrahlung and Photoneutrons from Thick Target and Tantalum Targets," *Phys. Rev*. **C2**, 621 (1970).

BER63a H. W. Bertini, *Phys. Rev* **131**, 1801 (1963).

BER69 H. W. Bertini, *Phys. Rev.* **188**, 1711 (1969).

BET34 H. A. Bethe and W. Heitler, "On Stopping of Fast Particles and on the Creation of Positive Electrons," *Proc. Roy. Soc*. (London) **A146,** 83 (1934).

BEV69 Phillip R. Bevington, *Data Reduction and Error Analysis for the Physical Sciences* (McGraw-Hill Book Company, New York, NY, 1969).

BLU50 O. Blunck and S. Leisegang, "Zum Energieverlust schneller Elektronen in dunnen Schichten," *Z. Physik* **128**, 500 (1950).

BLU51 O. Blunck and R. Westphal, "Zum Energieverlust energiereicher Elektronen in dunnen Schichten," *Z. Physik* **130**, 641 (1951).

BOL85 J. W. Boldeman and M. G. Hines, *Nucl. Sci. Eng.* **91**, 114 (1985).

BRE81 D. J. Brenner, R. E. Prael, J. F. Dicello, and M. Zaider, "Improved Calculations of Energy Deposition from Fast Neutrons," in *Proceedings, Fourth Symposium on Neutron Dosimetry*, EUR-7448, Munich-Neuherberg (1981).

BRE89 D. J. Brenner and R. E. Prael, "Calculated Differential Secondary-Particle Production Cross Sections after Nonelastic Neutron Interactions with Carbon and Oxygen between 10 and 60 MeV," *Atomic and Nuclear Data Tables* **41**, 71–130 (1989).

BRI00 J. F. Briesmeister, ed., "MCNP™—A General Monte Carlo N-Particle Transport Code, Version 4C," Los Alamos National Laboratory report LA-13709-M (March 2000).

CED05 P. Cederqvist, et al., "Version Management with CVS," Version 1.11.19, Free Software Foundation, Inc. (2005).

CHA98 M. B. Chadwick, et al., "Reference Input Parameter Library: Handbook for Calculations of Nuclear Reaction Data", IAEA-TECDOC-Draft, IAEA, Vienna (March 1998).

CAR98 L. L. Carter, R. C. Little, and J. S. Hendricks, "New Probability Table Treatment in MCNP for Unresolved Resonances," 1998 Radiation Protection and Shielding Division Topical Conference on Technologies for the New Century, Sheraton Music City, Nashville, TN, Vol. II, p. 341, April 19–23, 1998.

CHA99a M. B. Chadwick, P. G. Young, S. Chiba, S. C. Frankle, G. M. Hale, H. G. Hughes, A. J. Koning, R. C. Little, R. E. MacFarlane, R. E. Prael, and L. S. Waters, "Cross Section Evaluations to 150 MeV for Accelerator-Driven Systems and Implementation in MCNPX," *Nuclear Science and Engineering* **131** (3), 293 (March 1999).

CHA99b M. B. Chadwick, P. G. Young, R. E. MacFarlane, P. Moller, G. M. Hale, R. C. Little, A. J. Koning, and S. Chiba, "LA150 Documentation of Cross Sections, Heating, and Damage: Part A (Incident Neutrons) and Part B (Incident Protons)," Los Alamos National Laboratory report LA-UR-99-1222 (1999).

CHA81 A. Chatterjee, K. H. N. Murphy, and S. K. Gupta, *Pramana* **16,** 391 (1981).

CHE76 V. A. Chechin and V. C. Ermilova, "The Ionization-Loss Distribution at Very Small Absorber Thickness," *Nucl Instr. Meth*. **136**, 551 (1976).

CHE68 K. Chen, et al., *Phys. Rev*. **166**, 949 (1968).

CLO83 P. Cloth, et al., "The KFA-Version of the High-Energy Transport Code HETC and the Generalized Evaluation Code SIMPEL," Jul-Spez-196, Kernforschungsanlage Julich GmbH (March 1983).

CLO88 P. Cloth et al., "HERMES—A Monte Carlo Program System for Beam-Materials Interaction Studies," Jul-2203, Kernforschungsanlage Julich GmbH (May 1988).

COL00 G. Collazuol, A. Ferrari, A. Guglielmi, and P. R. Sala, "Hadronic Models and Experimental Data for the Neutrino Beam Production," *Nuclear Instruments & Methods A* **449**, 609–623 (2000).

COU97 J. D. Court, "Combining the Results of Multiple LCS Runs," Los Alamos National Laboratory memorandum LANSCE-12-97-43 (May 8, 1997).

COU97a J. D. Court, "More Derivations: Combining Multiple Bins in a MCNP or LAHET Tally," Los Alamos National Laboratory memorandum LANSCE-12-97-66 (July 16, 1997).

CMU94 *The Capability Maturity Model, Guidelines for Improving the Software Process* (Carnegie Mellon University Software Engineering Institute, Addison Wesley, 1994).

CRA56 W. W. T. Crane, G. H. Higgins, and H. R. Bowman, "Average Number of Neutrons per Fission for Several Heavy-Element Nuclides," *Phys. Rev.* **101**, 1804 (1956).

DIV56 B. C. Diven, et al., "Multiplicities of Fission Neutrons," *Phys. Rev.* **101**, 1012 (1956)

DRE81 L. Dresner, "EVAP-A Fortran Program for Calculating the Evaporation of Various Particles from Excited Compound Nuclei," Oak Ridge National Laboratory report ORNL-TM-7882 (July 1981).

EGD01 H. W. Egdorf and T. L. Roberts, "Component Architectures and the Future Structure of Physics Codes," Los Alamos National Laboratory report LA-UR-01-4750 (2001).

ENS98 N. Ensslin, et al., "Application Guide to Neutron Multiplicity Counting," Los Alamos National Laboratory report LA-13422-M (November 1998).

EVA55 R. D. Evans, *The Atomic Nucleus* (Robert E. Krieger Publishing Co., 1955).

EVA98 T. M. Evans and J. S. Hendricks, "An Enhanced Geometry-Independent Mesh Weight Window Generator for MCNP," 1998 Radiation Protection and Shielding Division Topical Conference on Technologies for the New Century, Sheraton Music City, Nashville, TN, Vol. I, p. 165 (April 19–23, 1998).

FAS94a A. Fasso, A. Ferrari, J. Ranft, P. R. Sala, G. R. Stevenson, and J. M. Zazula, "FLUKA92," in *Proceedings of the Workshop on Simulating Accelerator Radiation*

Environments, SARE1, Santa Fe, New Mexico, January 11–15, 1993, A. Palounek, Ed., p 134–144 (1994), Los Alamos National Laboratory report LA-12835-C.

FAS94b A. Fasso, A. Ferrari, J. Ranft, and P. R. Sala, "FLUKA: Present Status and Future Developments," in *Proceedings of the IV International Conference on Calorimetry in High Energy Physics*, (September 19–25, 1993), A. Menzione and A. Scribano, Eds., [World Scientific, La Biodola (Elba), 1994], pp. 394–502.

FAS97 A. Fasso, A. Ferrari, J. Ranft, and P. R. Sala, "An Update about FLUKA," in "Proceedings of the 2nd Workshop on Simulating Accelerator Radiation Environments, SARE2," CERN-Geneva (October 9–11, 1995), CERN Divisional report CERN/TIS-RP/97-05 (1997), pp. 158–170.

FAV99 J. A. Favorite and K. Adams, "Tracking Charged Particles Through a Magnetic Field Using MCNPX (U)," Los Alamos National Laboratory (X-Division) research note XCI-RN(U)99-002 (February 5, 1999).

FEN06a M. L. Fensin, J. S. Hendricks, and S. Anghaie, "Enhanced Monte Carlo Linked Depletion Capabilities in MCNPX," 2006 International Congress on Advances in Nuclear Power Plants, Embedded International Topical Meeting at the 2006 ANS Annual Meeting, ICAPP '06, Reno, NV, June 4–8, 2006, Los Alamos National Laboratory report LA-UR-06-0363.

FEN06b M. L. Fensin, J. S. Hendricks, H. R. Trellue, and S. Anghaie, "Incorporation of a Predictor-Corrector Methodology and 1-Group Reaction Rate Reporting Scheme for the MCNPX Depletion Capability," ANS 2006 Annual Meeting, Albuquerque, NM, November 12–16, 2006, Los Alamos National Laboratory report LA-UR-06-3925.

FEN08 M. L. Fensin, J. S. Hendricks, and S. Anghaie, "The Enhancements and Testing of the MCNPX Depletion Capability," 2008 International Congress on Advances in Nuclear Power Plants, Embedded International Topical Meeting at the 2008 ANS Annual Meeting, ICAPP '08, Anaheim, CA, June 8–12, 2008, Los Alamos National Laboratory report: LA-UR-08-0305.

FER98 A. Ferrari and P. R. Sala, "The Physics of High-Energy Reactions," lecture given at the Workshop on Nuclear Reaction Data and Nuclear Reactors: Physics, Design and Safety, International Centre for Theoretical Physics, Miramare-Trieste, Italy, (15 April–17 May 1996), A. Gandini and G. Reffo, Eds. (World Scientific, 1998) Vol 2, pp. 424–532.

FIN06 J. P. Finch, "Vacation Matrix Method for Fission Source Convergence in Monte Carlo Criticality Calculations," PhD Dissertation, Purdue University, West Lafayette, Indiana (December 2006).

FIR96 R. B. Firestone and V. S. Shirley, *Table of Isotopes: 8th Edition* (John Wiley, New York, 1996).

FUR00 S. Furihata, "Statistical Analysis of Light Fragment Production from Medium Energy Proton-Induced Reactions," *Nucl. Instrum. Methods* **B 171** (2000), pp. 252-258; PhD thesis, Tohoku University, March 2003.

GOU40 S. Goudsmit and J. L. Saunderson, "Multiple Scattering of Electrons," *Phys. Rev.* **57**, 24 (1940).

GUD75 K. K. Gudima, G. A. Osokov, and V. D. Toneev, "Model for Pre-Equilibrium Decay of Excited Nuclei," *Yad. Fiz* **21**, 260(1975). [*Sov. J. Nucl. Phys.* **21**, 138 (1975)].

GUD83 K. K. Gudima, S. G. Mashnik, and V. D. Toneev, "Cascade-Exciton Model of Nuclear Reactions," *Nucl. Phys. A* **401**, 329 (1983).

HAL88 J. Halbleib, "Structure and Operation of the ITS Code System," in *Monte Carlo Transport of Electrons and Photons*, Theodore M. Jenkins, Walter R. Nelson, and Alessandro Rindi, eds. (Plenum Press, New York, 1988), p. 153.

HEN00a J. S. Hendricks, "Advances in MCNP4C," Radiation Protection for Our National Priorities Spokane, Washington (September 17–21, 2000) (LA-UR-00-2643).

HEN00b J. S. Hendricks, "Point-and-Click Plotting with MCNP," Radiation Protection for Our National Priorities, Spokane, Washington, September 17–21, 2000, Los Alamos National Laboratory report LA-UR-00-2642.

HEN01 J. S. Hendricks, "Superimposed Mesh Plotting in MCNP," International Meeting on Mathematical Methods for Nuclear Applications, M&C 2001, American Nuclear Society, Salt Lake City, Utah (September 9–13, 2001).

HEN02a J. S. Hendricks, G. W. McKinney, L. S. Waters, H. G. Hughes, and E. C. Snow, "New MCNPX Developments," 12th Biennial Radiation Protection and Shielding Division Topical Meeting, Santa Fe, NM, American Nuclear Society, ISBN:8-89448-667-5, ANS Order No. 700293, April 14–18, 2002, Los Alamos National Laboratory report LA-UR-02-2181.

HEN03 J. S. Hendricks, "MCNPX Model/Table Comparison," Los Alamos National Laboratory report LA-14030 (March 2003).

HEN04a J. S. Hendricks, "New Spontaneous Fission Data," Los Alamos National Laboratory internal memorandum D-5:JSH-2005-064 (December 14, 2004).

HEN04b J. S. Hendricks and G. W. McKinney, "Pulse-Height Tallies with Variance Reduction," Los Alamos National Laboratory report LA-UR-04-8431 (2004).

HEN04c J. S. Hendricks, "Monte Carlo Sampling of Fission Multiplicity," Los Alamos National Laboratory report LA-UR-04-6967 (2004).

HEN05 J. S. Hendricks and J. M. Burward-Hoy, "Monte Carlo Radiation Detector Modeling in Space Systems," Los Alamos National Laboratory report LA-UR-05-0278 (2005).

HIC56 D. A. Hicks, J. Ise, Jr., and R. V. Pyle, "Probabilities of Prompt-Neutron Emission from Spontaneous Fission," *Phys. Rev*. **101**, 1016 (1956).

HOL84 N. E. Holden and M. S. Zucker, Brookhaven National Laboratory report BNL-NCS-35513-R. IAEA Advisory Group Meeting on Neutron Standard Reference Data, Geel, Belguim, November 12–16 (1984).

HOL85 N. E. Holden and M. S. Zucker, "Prompt Neutron Multiplicity for the Transplutonium Nuclides," Brookhaven National Laboratory report BNL-NCS-36379. *Proc. Int. Conf. Nucl. Data for Basic and Applied Science*, Santa Fe, New Mexico, May 13–17 (1985).

HOW81 R. J. Howerton, "ENSL and CDRL: Evaluated nuclear Structure Libraries," Lawrence Livermore National Laboratory report UCRL-50400, Vol. 23 (February 1981).

HUG95 H. G. Hughes and L. S. Waters, "Energy Straggling Module Prototype," Los Alamos National Laboratory memorandum XTM:95-305 (U) (November 29, 1995).

HUG97 H. G. Hughes, R. E. Prael, and R. C. Little, "MCNPX—The LAHET/MCNP Code Merger," Los Alamos National Laboratory memorandum XTM-RN (U) 97-012 (April 22, 1997).

HUG98a H. G. Hughes, K. J. Adams, M. B. Chadwick, J. C. Comly, L. J. Cox, H. W. Egdorf, S. C. Frankle, F. X. Gallmeier, J. S. Hendricks, R. C. Little, R. E. MacFarlane, R. E. Prael, E. C. Snow, L. S. Waters, and P. G. Young, Jr., "Status of the MCNP™/LCS™ Merger Project," American Nuclear Society Radiation Protection and Shielding Topical Conference, Nashville, TN, April 19–23, 1998.

HUG98b H. G. Hughes, et al., "Recent Developments in MCNPX," American Nuclear Society, Topical Meeting on Nuclear Applications of Accelerator Technology, Gatlinburg, TN, September 20–23, 1998.

HUG98c H. G. Hughes, et al., "MCNPX Code Development," 4th Workshop on Simulating Accelerator Radiation Environments, Knoxville, TN, September 14, 1998.

HUG99 H. G. Hughes, et al., "MCNPX™ for Neutron-Proton Transport," International Conference on Mathematics & Computation, Reactor Physics & Environmental. Analysis in Nuclear Applications, American Nuclear Society, Madrid, Spain, September 27–30, 1999.

ICR84 **"**Stopping Powers for Electrons and Positrons," International Commission on Radiation Units and Measurements (ICRU) report **37** (October 1984).

IGN75 A. V. Ignatyuk, G. N. Smirenkin, and A. S. Tishin, *Sov. J. Nucl. Phys*. **21**, 256 (1975).

JAM06a M. R. James, G. W. McKinney, J. S. Hendricks, and M. Moyers, "Heavy-Ion Transport in MCNPX," The American Nuclear Society's 14th Biennial Topical Meeting of the Radiation Protection and Shielding Division, Carlsbad, New Mexico, USA, April 3–6, 2006.

JAM06b M. R. James, G. W. McKinney, J. S. Hendricks, and M. Moyers, "Recent enhancements in MCNPX: heavy-ion transport and the LAQGSM physics model," *Nuclear Instruments and Methods in Physics Research*, Section A, June 23, 2006, **562**(2), pp. 819-822,

JAN82 J. F. Janni, "Proton Range-Energy Tables, 1 keV–10 GeV," *Atomic Data and Nuclear Data Tables* **27**, 2/3 (1982).

KAL85 **"**PRECO-D2: Program for Calculating Preequilibrium and Direct Reaction Double Differential Cross Sections," Los Alamos National Laboratory report LA-10248-MS (1985).

KOC59 H. W. Koch and J. W. Motz, "Bremsstrahlung Cross-Section Formulas and Related Data," *Rev. Mod. Phys*. **31**, 920 (1959).

LAN44 L. Landau, "On the Energy Loss of Fast Particles by Ionization," *J. Phys. USSR* **8**, 201 (1944).

LIT00 R. C. Little, J. M. Campbell, M. B. Chadwick, S. C. Frankle, J. S. Hendricks, H. G. Hughes, R. E. MacFarlane, C. J. Werner, M. C. White, and P. G. Young, "Modern Nuclear Data for Monte Carlo Codes," MC2000: International Conference on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications, Lisbon, Portugal, October 23–26, 2000, Los Alamos National Laboratory report LA-UR-00-4979 (2000).

MAC94 R. E. MacFarlane and D. W. Muir, "The NJOY Nuclear Data Processing System version 91," Los Alamos National Laboratory report LA-12740-M (October 1994).

MAD88 D. G. Madland, "Recent Results in the Development of a Global Medium-Energy Nucleon-Nucleus Optical-Model Potential," in *Proceedings of a Specialist's Meeting on Preequilibrium Reactions,* Semmering, Austria, February 10–12, 1988, B. Strohmaier, Ed. (OECD, Paris, 1988), pp. 103–116.

MAS74 S.G. Mashnik and V.D. Toneev, "MODEX—The Program for Calculation of the Energy Spectra of Particles Emitted in the Reactions of Pre-Equilibrium and Equilibrium Statistical Decays" [in Russian], *Communication JINR* P4-8417, Dubna, 1974, 25 pp.

MAS98 S. G. Mashnik, A. J. Sierk, O. Bersillon, and T. A. Gabriel, "Cascade-Exciton Model Detailed Analysis of Proton Spallation at Energies from 10 MeV to 5 GeV," *Nucl. Instr. Meth.* **A414**, 68 (1998), Los Alamos National Laboratory report LA-UR-97-2905. (`http://t2.lanl.gov/publications/publications.html`).

MAS01 S. G. Mashnik and A. J. Sierk, "Recent Developments of the Cascade-Exciton Model of Nuclear Reactions," Los Alamos National Laboratory report LA-UR-01-5390, and International Conference on Nuclear Data for Science and Technology, Tsukuba, Japan, October 7–12 (2001).

MAS06a S. G. Mashnik, K. K. Gudima, M. I. Baznat, A. J. Sierk, R. E. Prael, and N. V. Mokhov, "CEM03.S1, CEM03.G1, LAQGSM03.S1, and LAQGSM03.G1 Versions of CEM03.01 and LAQGSM03.01 Event-Generators," Los Alamos National Laboratory report LA-UR-06-1764 (March 2006).

MAS06b S. G. Mashnik, A. J. Sierk, K. K. Gudima, M. I. Baznat, "CEM03 and LAQGSM03—new modeling tools for nuclear applications," *Journal of Physics—Conference Series*, Institute of Physics, **41**(1), pp. 340-351.

MCK00 G. W. McKinney, T. E. Booth, J. F. Briesmeister, L. J. Cox, R. A. Forster, J. S. Hendricks, R. D. Mosteller, R. E. Prael, and A. Sood, "MCNP Applications for the 21st Century," Proceedings of the 4th International Conference on Supercomputing in Nuclear Applications, Tokyo, Japan, September 4–7, 2000.

MCK02 G. W. McKinney, J. S. Hendricks, L. S. Waters, and T. H. Prettyman, "Using MCNPX for Space Applications," 12th Biennial Radiation Protection and Shielding Division Topical Meeting, Santa Fe, NM, American Nuclear Society, ISBN:8-89448-667-5, ANS Order No. 700293, April 14–18, 2002, Los Alamos National Laboratory report LA-UR-02-2179 (2002).

MOH83 H. J. Moehring, "Hadron-nucleus Inelastic Cross-sections for Use in Hadron-cascade Calculations at High Energies," CERN/TIS-RP/116 (October 1983).

MOL48 G. Moliere, "Theorie der Streuung schneller geladener Teilchen II: Mehrfachund Vielfachstreuung," *Z. Naturforsch.* **3a**, 78 (1948).

MOT29 N. F. Mott, "The Scattering of Fast Electrons by Atomic Nuclei," *Proc. Roy. Soc.* (*London*) **A125**, 425 (1929).

PEL05 D. B. Pelowitz, ed., "MCNPX™ User's Manual," Version 2.5.0, Los Alamos National Laboratory report LA-CP-05-0369 (April, 2005).

PRA88 R. E. Prael and M. Bozoian, "Adaptation of the Multistage Pre-equilibrium Model for the Monte Carlo Method (I)," Los Alamos National Laboratory report LA-UR-88-3238 (September 1998).

PRA89 R. E. Prael and H.Lichtenstein, "User Guide to LCS: The LAHET Code System," Los Alamos National Laboratory report LA-UR-89-3014, Revised (September 15, 1989). (`http://www-xdiv.lanl.gov/XCI/PROJECTS/LCS/lahet-doc.html`).

PRA94 R. E. Prael, "A Review of Physics Models in the LAHET™ Code," Los Alamos National Laboratory report LA-UR-94-1817 (1994).

PRA95 R. E. Prael and D. G. Madland, "LAHET Code System Modifications for LAHET 2.8," Los Alamos National Laboratory report LA-UR-95-3605 (September 1995).

PRA96 R. E. Prael, D. G. Madland, "A Nucleon-Nucleus Elastic Scattering Model for LAHET," in *Proceedings of the 1996 Topical Meeting on Radiation Protection and*

Shielding, April 21–25, 1996, No. Falmouth, Mass., (American Nuclear Society, 1996), pp. 251–257.

PRA98a R. E. Prael, A. Ferrari, R. K. Tripathi, and A. Polanski, "Comparison of Nucleon Cross Section Parameterization Methods for Medium and High Energies," in *Proceedings of the Fourth Workshop on Simulating Accelerator Radiation Environments (SARE4)*, September 14–16, Knoxville, TN, Tony A. Gabriel, Ed., ORNL, pp. 171–181 (1998).

PRA98b R. E. Prael, "Upgrading Physics Packages for LAHET/MCNPX," in *Proceedings of the American Nuclear Society Topical Meeting on Nuclear Applications of Accelerator Technology*, Gatlinburg, TN, Sept. 20–23, 1998.

PRA98c R. E. Prael and W. B. Wilson, "Nuclear Structure Libraries for LAHET and MCNPX," *Proceedings of the Fourth Workshop on Simulating Accelerator Radiation Environments (SARE4)*, September 14–16, Knoxville, TN, Tony A. Gabriel, Ed., ORNL, pp. 183 (1998).

PRA99 R. E. Prael, "Primary Beam Transport methods in LAHET," in *Transactions of the June ANS Meeting*, Boston, June 6–10, 1999.

PRA00a R. E. Prael, "Proposed Modification to the Charged Hadron Tracking Algorithm in MCNPX," Los Alamos National Laboratory research note X-5-RN (U) (August 23, 2000), Los Alamos National Laboratory report LA-UR-00-4027.

PRA00b R. E. Prael, "A New Nuclear Structure Library for MCNPX and LAHET3," in *Proceedings of the Fourth International Topical Meeting on Nuclear Applications of Accelerator Technology*, Washington DC, pp. 350–352, Nov. 12–15, 2000.

RAD77 Radiation Shielding Information Center, "HETC Monte Carlo High-Energy Nucleon-Meson Transport Code," Oak Ridge National Laboratory report CCC-178 (August 1977).

RAN85 J. Ranft and S. Ritter, *Z. Phys*. **C27**, 412, 569 (1985).

RIL75 M. E. Riley, C. J. MacCallum, and F. Biggs, "Theoretical Electron-Atom Elastic Scattering Cross Sections, Selected Elements, 1 keV to 256 keV," *Atom. Data and Nucl. Data Tables* **15**, 443 (1975).

RUT11 E. Rutherford, "The Scattering of a and b Particles by Matter and the Structure of the Atom," *Philos. Mag* **21**, 669 (1911).

SAN04 P. Santi, D. Beddingford, and D. Mayo, "Revised Prompt Neutron Emission Multiplicity Distributions for 236, 238-Pu," Los Alamos National Laboratory report LA-UR-04-8040 (December 2004).

SCH82 P. Schwandt et al., *Phys. Rev. C* **26,** 55 (1982).

SEL88 S. M. Seltzer, "An Overview of ETRAN Monte Carlo Methods," in *Monte Carlo Transport of Electrons and Photons*, T. M. Jenkins, W. R. Nelson, and A. Rindi, Eds. (Plenum Press, New York, 1988), p. 153.

SEL91 S. M. Seltzer, "Electron-Photon Monte Carlo Calculations: The ETRAN Code," *Appl. Radiat. Isot.* Vol. 42 (10) (1991), pp. 917–941.

SNO96 E. C. Snow, "Radiography Image Detector Patch for MCNP," private communication.

SNO98 E. C. Snow, "Mesh Tallies and Radiography Images for MCNPX," *Proceedings of the Fourth Workshop on Simulating Accelerator Radiation Environments (SARE4)*, T. A. Gabriel, ed., p. 113 (1998).

STE71 R. M. Sternheimer and R. F. Peierls, *Phys. Rev. B* **3** (11), 3681 (June 1, 1971).

SWI04 M. T. Swinhoe, J. S. Hendricks, and D. R. Mayo, "MCNPX for Neutron Multiplicity Detector Simulation," Los Alamos National Laboratory report LA-UR-04-8025 (2004).

TRI97a R. K. Tripathi, F. A. Cucinotta, and J. W. Wilson, "Universal Parameterization of Absorption Cross Sections," NASA Technical Paper 3621 (January 1997).

TRI97b R. K. Tripathi, J. W. Wilson, and F. A. Cucinotta, "New Parameterization of Neutron Absorption Cross Sections," NASA Technical Paper 3656 (June 1997).

VAV57 P. V. Vavilov, "Ionization Losses of High-Energy Heavy Particles," *Soviet Physics JETP* **5** (5), 749 (1957).

WAT02a L. S. Waters, J. S. Hendricks, H. G. Hughes, G. W. McKinney, and E. C. Snow, "Medical Applications of the MCNPX Code," 12th Biennial Radiation Protection and Shielding Division Topical Meeting, Santa Fe, NM, American Nuclear Society, ISBN:8-89448-667-5, ANS Order No. 700293, April 14–18 (2002).

WAT02b L. S. Waters, ed., "MCNPX™ User's Manual, ECI, Version 2.4.0, Los Alamos National Laboratory report LA-CP-02-408 (September, 2002).

WHI99 M. C. White, R. C. Little, and M. B. Chadwick, "Photonuclear Physics in MCNP(X)," *Proceedings of the ANS meeting on Nuclear Applications of Accelerator Technology*, Long Beach, California, November 14–18, 1999.

WHI00 M. C. White, "User Interface for Photonuclear Physics in MCNP(X)," Los Alamos National Laboratory memorandum X5-MCW-00-88(U), revised (March 21, 2001).

WIL97 W. B. Wilson, et al., "CINDER'90 code for Transmutation Calculations," *Proceedings of the International Conference on Nuclear Data for Science and Technology*, Trieste, May 19–24, 1997, Italian Physical Society, Bologna, p. 1454 (1997).

X-503 X-5 Monte Carlo Team, "MCNP—A General Monte Carlo N-Particle Transport Code, Version 5, Volume II: User's Guide," Los Alamos National Laboratory report LA-CP-03-0245 (April 24, 2003).

YAR79 Y. Yariv and Z. Fraenkel, *Phys Rev C* **20** 2227 (1979).

YAR81 Y. Yariv and Z. Fraenkel, *Phys Rev C* **24**, 488 (1981).

YOU98 P. G. Young, E. D. Arthur, and M. B. Chadwick, "Comprehensive Nuclear Model Calculations: Theory and Use of the GNASH Code," *Proceedings of the IAEA Workshop on Nuclear Reaction Data and Nuclear Reactors—Physics Design, and Safety*, Trieste, Italy, April 15–May 17, 1996.

ZUC83 M. S. Zucker and N. E. Holden, "Californium-252 and ^{238}U Nuclear Parameters of Safeguards Interest," Brookhaven National Laboratory report BNL-34804 (1983).

APPENDIX A MULTIPROCESSING

A.1 DISTRIBUTED MEMORY MULTIPROCESSING FOR THE ENTIRE ENERGY RANGE OF ALL PARTICLES

The entire MCNPX code may be run in parallel using message passing. Table physics problems (i.e., standard MCNP4C3 problems) can be run with threading and/or message passing. Fault tolerance and load balancing are available, and multiprocessing can be done across a network of heterogeneous platforms. Parallel Virtual Machine (PVM) or MPI software can be used.

The parallel message-passing capability applies to all particles for their entire energy range and for all physics models.

A.2 MPI MULTIPROCESSING

The MPI parallel communication software is supported by MCNPX. To compile MCNPX with MPI, it is necessary to use the new "MPILIB" configuration option and provide a path to the MPI header file. This may not be necessary on some systems if these header files are already in the standard include path:

```
configure --with -MPILIB[="/path/to/MPI/libraries -lmpich"]
          --with -FFLAGS="-I/path/to/MPI/include/files" --with -MPICH
```

The latter option should be specified when using the MPICH-1 product from ANL (http://www-unix.mcs.anl.gov/mpi/mpich1/). To run an MCNPX problem with MPI, simply start the MPI daemon (which typically is running already on most systems) and then start MCNPX using "MPIRUN" or "mpiexec". An example is

```
mpirun -np 4 mcnpx inp=gwm na=gwm1. ...
```

where the keyword NP is the number of processors. MPI is quite different from PVM, which required knowledge about setting certain links, environment variables, and the PVM console commands. An example of the PVM execution command is

```
mcnpx inp=gwm n=gwm1. tasks=-12 .
```

See "installation notes for building MCNPX with MPI" on the MCNPX documents page at http://mcnpx.lanl.gov/documents.html.

A.3 MPI SPEEDUP FOR CRITICALITY CALCULATIONS

Note: This new capability speeds up MPI KCODE calculations but also has some collateral consequences for sequential KCODE calculations.

Criticality calculations (KCODE source) will now run 10–1000 times faster in parallel with MPI multiprocessing. The speedup depends on the number of CPUs and the number of histories per cycle. As the number of CPUs increases above ~8 and the histories per cycle approaches ~1M, the speedup quickly increases from a factor of ~10 to above 1000 with 64 CPUs.

The speedup has been achieved by having the next-generation fission source points on each processor stay on that processor. No longer are the fission source points from all processors combined at the end of each cycle for rebroadcast in the next cycle. The considerable expense of grouping the particles together at each processor rendezvous has been eliminated.

A.3.1 DXTRAN and Detector Tracking Differences

All calculations with DXTRAN and detectors—not just KCODE or parallel calculations—generally no longer track. Answers are still correct, but these next-event estimator problems do not track unless the twenty-first entry on the `DBCN` card is set to nonzero or the default Russian roulette detector game (`DD` card) is not played. The tracking difference occurs because the default Russian roulette game no longer adjusts the roulette criteria at the two-hundredth history. The Russian roulette criteria are still set at all tally fluctuation chart intervals, *dmmp*, the fifth entry on the `PRDMP` card. The default for *dmmp* is still 1000 histories for fixed-source problems but is now *dmmp*`=1` (at the end of each cycle) for KCODE problems. Thus, a fixed-source problem that previously started playing Russian roulette on next-event estimates at history 200 now waits until history 1000.

A.3.2 User Interface Changes for Both Sequential and Parallel KCODE Problems

The new method has consequences for both sequential and parallel KCODE calculations.

- Tally fluctuation charts are printed only at the ends of KCODE cycles rather than at specific particle intervals.
- The units for the fifth entry of the `PRDMP` card are changed for KCODE calculations. The fifth entry is *dmmp*, the tally fluctuation chart print interval. For KCODE calculations, *dmmp* is now the number of cycles (DEFAULT=`1`).

- KCODE problems with DXTRAN and point detectors are still correct but may not track previous versions if the default Russian roulette game on small scores is played. The tracking difference occurs because the roulette criteria are updated in different places. DXTRAN and detectors using negative DD card entries (to have a constant Russian roulette game criteria) still track.
- Setting the twenty-first entry on the DBCN card to 1 will cause MCNPX to track MCNPX 2.5.d without the new speedup capability:

```
DBCN    20J  1  .
```

A.3.3 User Interface Changes for Parallel KCODE Problems

- The KCODE speedup is available only for negative JTASKS: TASKS=-*n x m* on the MCNPX execution line. Microtasking/load-balancing (positive JTASKS) calculations use the slower former MCNP4C communication algorithm for KCODE source updating. A warning is issued if JTASKS>0 in a KCODE calculation.
- In rare cases, a subtask may deplete its source particles. Only problem efficiency is affected, and a warning is issued.

A.3.4 Compiler and Operating System Problems for Parallel KCODE Problems

- CTRL-C and QUIT on a multiple processor MPI run in Linux do not finish writing the OUTP file before MCNPX exits. This failure appears to be an MPI error (possibly feature) in the MPI_FINALIZE call, where the last processor kills all subtasks and the master.
- CTRL-C interrupt does not function properly in Windows 2000 (probably general to all Windows). The user can attempt to quit, but MCNPX will hang and the user will be forced to kill the process through multiple CTRL-C commands.
- The Portland Group pgcc compiler (Version 4.02) will not compile the ANL mpich-1.2.5 properly on a Linux system; however, GCC 3.2.3 will work to build the MPICH libraries.

APPENDIX B MCNPX GEOMETRY AND TALLY PLOTTING

B.1 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 MCNPX or by the MCPLOT module, by other codes, or even by hand in order to send data to MCPLOT for coplotting with MCNPX tally data.

As written by MCNPX, 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 the following:

```
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 lines to describe all of the pertinent independent variables would have to be added for each table.

The form of the MCTAL file as written by MCNPX follows:

`kod, ver, probid, knod, nps, rnr` `(2A8,A19,15,I11,I15)`

- `kod` is the name of the code, MCNPX.
- `ver` is the version, 2.6.0.
- `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 If i>0, then 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.
If i<0, then i is the *number* of particle types and the next MCTAL line will list which particles are used by the tally.

j is the type of detector tally where 0=none, 1=point, 2=ring, 3=pinhole radiograph, 4=transmitted image radiograph (rectangular grid), 5=transmitted image radiograph (cylindrical grid)

List of 0/1 entries indicating which particle types are used by the tally. (40I2)
(Only present if particle type value (i) above is negative.)

Each entry, in order, represents the ordinal assigned to particles in Table 4-1. Thus, the first entry is 1 if neutrons are a tally particle and 0 if they are not; the fourth entry is 1 if there are muons and 0 if there are not, etc.

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 list next below 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 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 # of time bins, NE is the # of energy bins, ..., and NF is the # 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,I5)

- `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 removal lifetime values for each recorded KCODE cycle if `mk=0` or `5`; if `mk=19`, the whole `RKPL(19,MRKP)` array is given. (5F12.6)

B.2 RADIOGRAPHY TALLY CONTOUR PLOT EXAMPLE

Tally output may be plotted as 2-D color contours from either MCTAL or RUNTPE files. For example, a radiography tally with *s*- and *t*-axes specified on `FS` and `C` cards can be plotted with the `MCNPX Z` execute option, as illustrated below.

The following example is a radiograph of a 4-cm-radius, 1-cm-thick ^{238}U disc with an embedded 4-mm-void sphere and skew-oriented 1-cm × 1-cm × 8-mm box. The input file is

```
Radiography Tally
1 5 -25.0 -1  4 5 imp:p=1
2 0        1 -2   imp:p=1
3 0           2   imp:p=0
4 0          -4   imp:p=1
5 0          -5   imp:p=1

1 RCC     0 0 0 0 0 1 4
2 RPP   -100 100  -100 100  -100 100
4 SPH    3 0  0.5  0.4
5 BOX   -1 1 0.1  0.6 0.8 0  -0.8 0.6 0  0 0 0.8
mode p
nps     100 5
sdef    pos=0 0 -20 axs=0 0 1 rad=d1 ext=0 vec=0 0 1 dir=d2 erg=6
si1      0 0.1
sp1    -21   1
si2     -1   1
sp2    -31   1
m5     92238 1
print
prdmp    2j  1
tir5:p   0 0 10 0 0 0 -100 0 100 0
fs5    -10. 99i 10.
c5     -10. 99i 10.
```

The x-y geometry plot of this geometry is given in Figure B-1.

To get the contour plot, type the following MCNPX execution line command:

```
MCNPX Z RUNTPE=filename
```

The contour plots also may be read from a MCTAL file instead of the RUNTPE file. When the code gives you the MCPLOT prompt, enter two dimensions with the FREE command (Table 6-5); for example, S and C:

```
MCPLOT>FREE SC   .
```

Recall that the possible tally dimensions are

F	surface / cell / detector F card bin
D	total / direct or flagged bin
U	user bin
S	segment or radiography *s*-axis bin
M	multiplier bin
C	cosine or radiography *t*-axis bin
E	energy bin
T	time bin
I	1st lattice/mesh index
J	2nd lattice/mesh index
K	3rd lattice/mesh index

The results are plotted in Figure B-2. The embedded sphere and box are seen plainly in the disc.

APPENDIX B

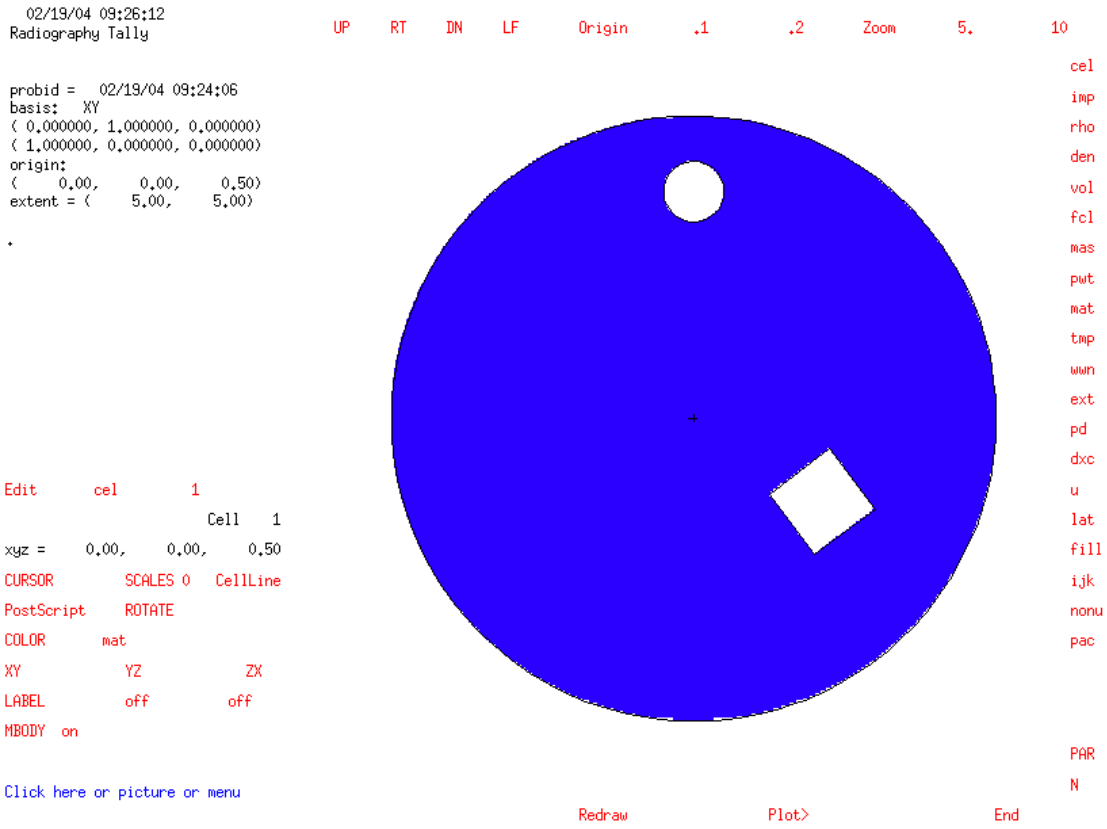


Figure B-1. Geometry plot of radiograph example.

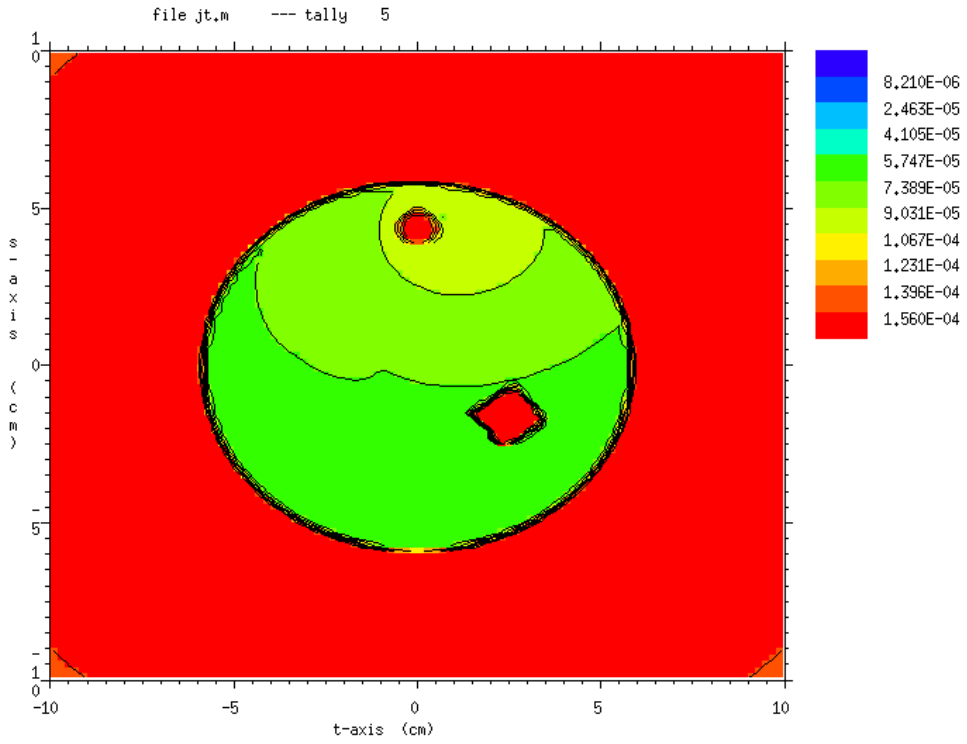


Figure B-2. Scattered photon radiographic image of ^{238}U disc.

B.3 MESH TALLY CONTOUR PLOT EXAMPLE

Mesh tallies may be plotted either in the MCNPX tally plotter (MCPLOT) from MCTAL files or superimposed over geometry plots in the geometry plotter (PLOT) from RUNTPE files.

B.3.1 MCPLOT Mesh Tally

Figure B-3 shows a mesh tally of a critical configuration of seven identical barrels of fissionable material. The mesh tally is generated from an MCTAL file in the MCPLOT tally plotter.

The input file for this problem is

```
cylinders containing critical fluid in macrobody hex lattice
1 1 -8.4      -1      u=1    imp:n=1
2 0           -2      u=1    imp:n=1
```

```
3 2 -2.7      -3 1 2  u=1    imp:n=1
4  3 -.001     3      u=1    imp:n=1
10 3 -.001    -6 lat=2 u=2   imp:n=1 fill=-2:2 -2:2 0:0
                                      2 2 2 2 2
                                      2 2 1 1 2
                                      2 1 1 1 2
                                      2 1 1 2 2
                                      2 2 2 2 2
11 0          -8             imp:n=1 fill=2
50 0           8             imp:n=0

1 rcc 0  0 0  0 12 0  5
2 rcc 0 12 0  0 8  0  5
3 rcc 0 -1 0  0 22 0  6
6 rhp 0 -1 0  0 22 0  9 0 0
8 rcc 0 -1 0  0 22 0  30

m1    1001 5.7058e-2   8016 3.2929e-2
     92238 2.0909e-3  92235 1.0889e-4
m2   13027 1
m3   7014 .8 8016 .2
c
fc14 total keff in each element
f4:n (1<10[-2:2 -2:2 0:0]<11)
fq4 f m
sd4 1 24r
f14:n   (1<10[-1 1 0])  (1<10[0 1 0])
        (1<10[-1 0 0])  (1<10[0 0 0])  (1<10[1 0 0])
        (1<10[0 -1 0])  (1<10[1 -1 0]) t
fq14 f m
sd14 1 7r
tf14 4
fm14 (-1 1 -6 -7)
print -160
prdmp 2j 1
kcode 1000 1 10 50
ksrc 0 6 0  18 6 0  -18 6 0  9 6 15  -9 6 15  9 6 -15  -9 6 -15
tmesh
 rmesh12
 cora12  -30. 99i 30.
 corb12  0. 12.
 corc12  -30. 99i 30.
endmd
```

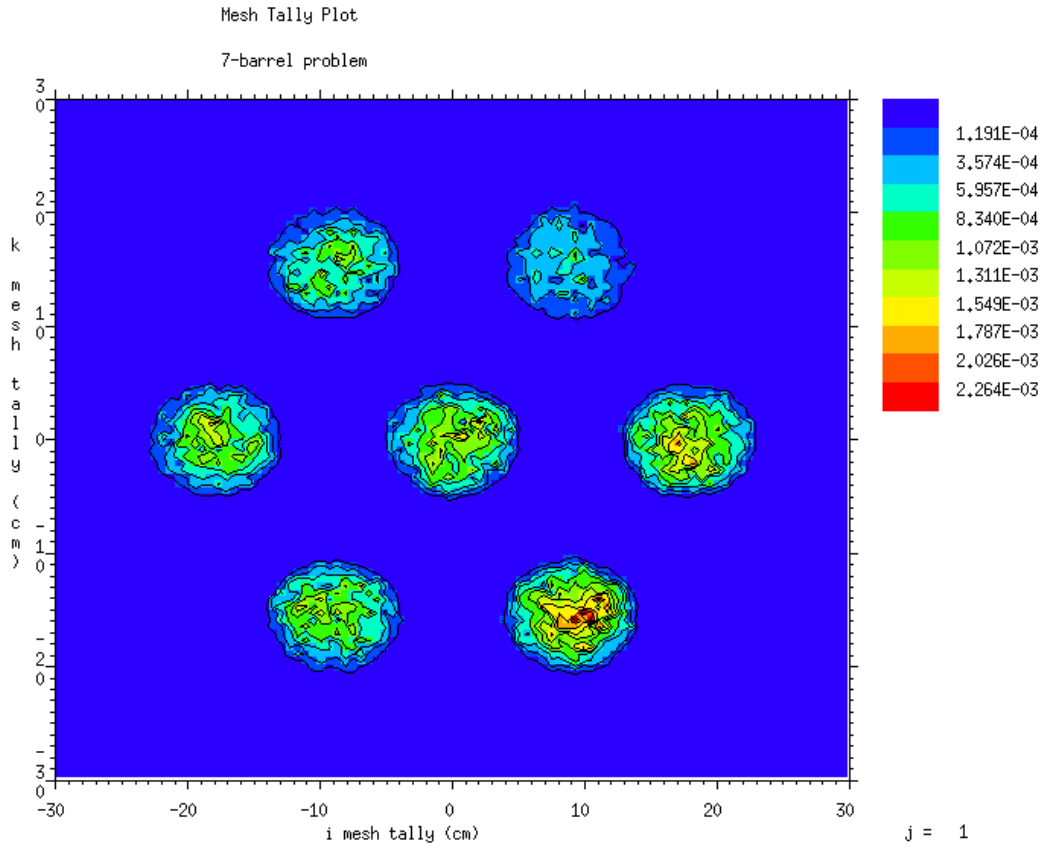


Figure B-3. Mesh tally of barrel geometry.

The plot command is

```
mcplot> tal 12 free ik   .
```

The geometry is shown in Fig. B-4.

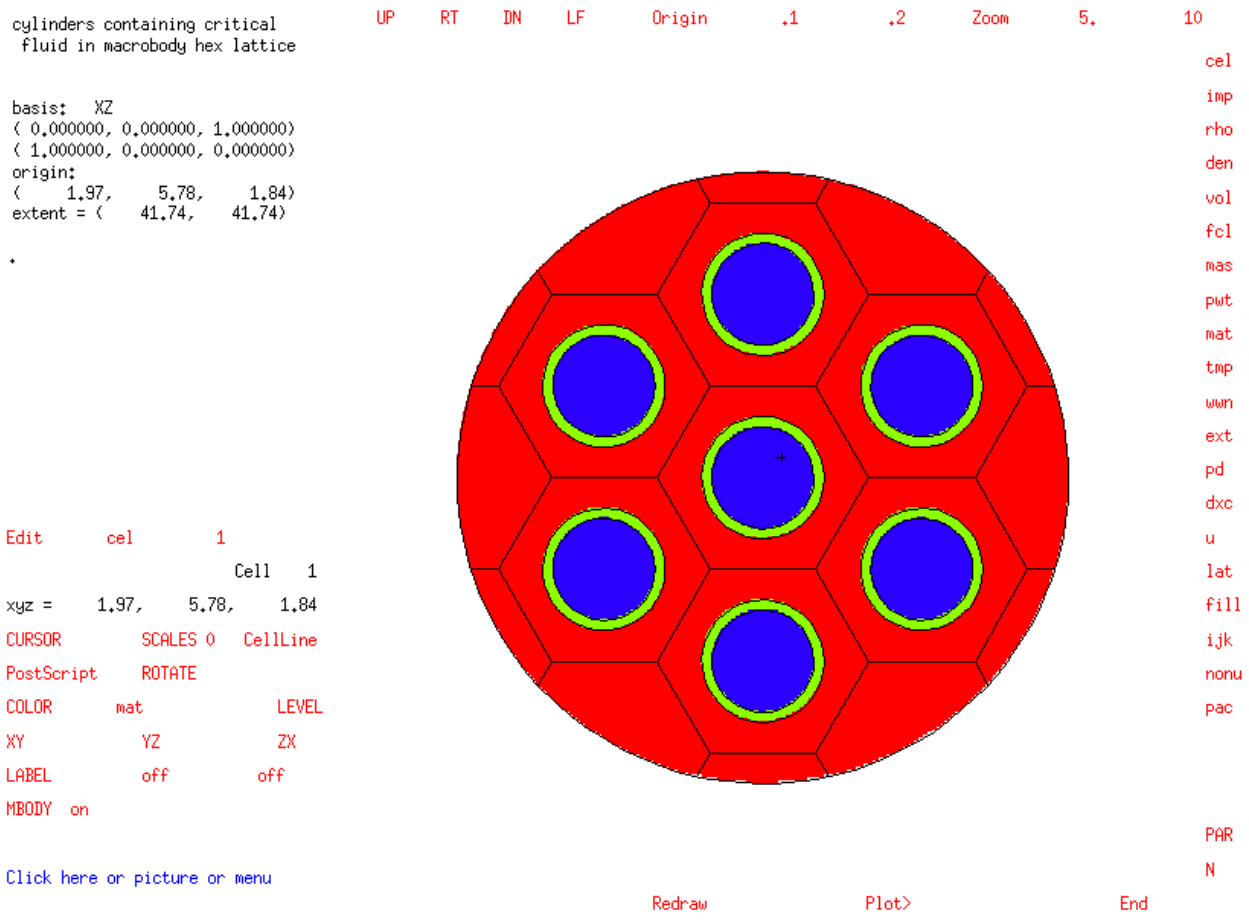


Figure B-4. Geometry of the seven-barrel problem.

B.3.2 Superimposed Geometry Plot Mesh Tally

Figure B-5 shows the mesh plot superimposed over the geometry plot. The `MCNPX Z` option is used, and the commands are

```
MCPLOT> RUNTPE=<runtpe_filename>
MCPLOT> PLOT
PLOT> py 4 ex 40 or 0 4 0 la 0 1 tal12 color on la 0 0 con 0 100 %    .
```

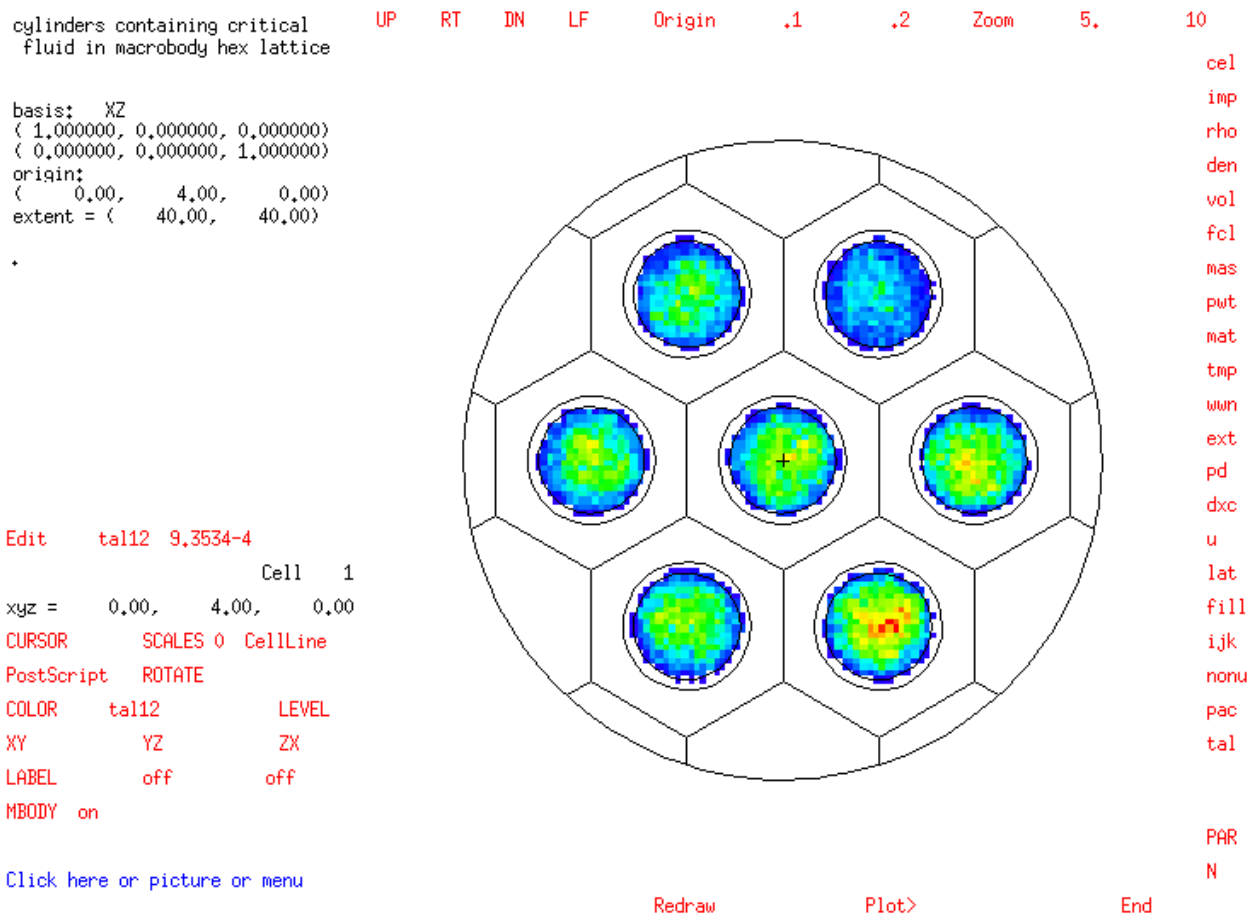


Figure B-5. Mesh plot superimposed on geometry plot.

After the PLOT command, the MCNPX interactive geometry plotter pops up. If the PLOT> button (bottom center) is clicked, then the above command after the PLOT> prompt can be entered. Alternatively, the mesh tally superimposed on the geometry can be viewed by clicking buttons of the interactive tally plot. These options are described in Section 6.1.2.3.

Each outer barrel is expected to have the same source and flux distributions and that the center barrel should have a higher value. However, the mesh tally shows that the barrels do not have the expected distribution. The asymmetric distribution is a known Monte Carlo deficiency and arises in all Monte Carlo codes, including MCNP4C, MCNP5, and MCNPX: eigenvector fluxes generally are converged falsely in eigenvalue problems of critical systems. It is evident that the mesh tally is useful in assessing such deficiencies.

During the course of a calculation, an MPLOT card in the INP file can be used to plot the mesh tallies. The plot of Fig. B-5 would be achieved with the following MPLOT card:

```
mplot freq 3000 plot ex 40 py 4 la 0 1 tal12.1 color on la 0 0
     cont 0 100 pct
```

The "freq 3000" command causes a plot to be made every 3000 histories. The "plot" command then transfers plotting from the tally plotter to the geometry plotter. The remaining commands are described in Section 6.1.2.3**.**

When a calculation is completed, the mesh tallies may be plotted as superimposed over geometries using the MCNPX Z option. Only RUNTPE files can be used; MCPLOT files cannot be used because they do not contain the geometry information. The RUNTPE file may be specified either in the execution line,

```
MCNPX  Z  RUN=<runtpe_filename>   ,
```

or the RUNTPE file may be specified in the usual way anytime when doing tally plots:

```
MCNPX     Z
mcplot>   run=<runtpe filename>   .
```

Then to get the mesh tallies, the geometry plot mode must be requested:

```
mcplot>   PLOT   .
```

At this time, the interactive geometry plotter screen will pop up and commands may be entered either interactively or in command mode by striking the PLOT> button in the bottom center of the screen.

The mesh tally boundaries also may be plotted by cycling through the CellLine options in the interactive geometry plot or by using the command mesh=6 or mesh=7 plot commands (Section 6.1.2.3).

B.3.3 Commands for Superimposed Geometry Plot Mesh Tally

To plot a mesh tally superimposed over a geometry plot, the geometry first must be specified in the usual manner. For the geometry of Fig. B-5, the plot commands are

```
PLOT> or 0 4 0 py 4 ex 40 la 0 0   .
```

The same geometry can be viewed by using the Zoom, Origin, XZ, and LABEL interactive buttons.

Next, the tally must be selected as the "Edit" quantity. In the command mode, the only method is to select the tally as the label quantity, transfer the label to the color quantity, and then turn the labels back off:

```
PLOT>   la 0 1 tal12.1 color on la 0 0   .
```

Note that only mesh tallies will be recognized. If multiple mesh tally bins exist, e.g.,

```
rmesh11:h   flux   popul   ,
```

then the number after the decimal indicates which bin. In this case, `tal11.1` refers to the "flux" mesh tally and `tal11.2` refers to the "popul" mesh tally.

Interactive plot buttons can be used to achieve the same result. First, the mesh tallies must be made the "Edit" quantity by clicking the last of the buttons in the far-right column of the screen.

Click	`tal`	(make mesh tallies the "Edit" quantity),
Click	`N`	(cycle through available mesh tally numbers), and
Click	`IP`	(cycle through mesh tally bins).

The "Edit" quantity, e.g., `tal12.1`, now has been specified. Next, change the color parameter (default = "`mat`"), by clicking COLOR twice.

Click	`COLOR`	(will change "`mat`" to "`off`"),
Click	`COLOR`	(will change "`off`" to the "Edit" quantity, "`tal12.1`"), and
Click	`Redraw`	(bottom center button—to make new picture).

Two other commands are also useful: mesh and contour.

The actual mesh tally grid can be displayed by clicking "`CellLine`" and cycling through the options to get either "`MeshTaly`" (which draws mesh tally grid lines over the plot) or "`MT+Cell`" (which draws mesh tally grid lines and cell surface lines over the plot). In the command prompt mode, this is done with

```
PLOT>  mesh = 6          (mesh tally grid lines)
```

or

```
PLOT>  mesh = 7          (mesh tally grid lines plus cell surface lines)   .
```

The contour levels can be adjusted using the contour command. No interactive button is available for this; thus, to get from interactive to command mode, either the "`Click here or picture or menu`" (bottom left of interactive screen) or "`PLOT>`" (bottom center) must be struck. The contour command is

```
CONTOUR   cmin cmax [cstep]  command   .
```

The "cmin cmax cstep" entries are the minimum, maximum, and step values for contours. Superimposed geometry mesh tally plots do not use steps: the values are shaded by 64 colors. Thus, the cstep entry is ignored and can be omitted; it is allowed only for consistency with the CONTOUR command in the tally plotter (see Section 6.1.1.2). The "cmin cmax cstep" entries are numbers and must appear together. Once a CONTOUR command is entered, subsequent CONTOUR commands use the previous "cmin cmax cstep" values; thus, only the "command" entry is required. The "command" entry may appear before cmin or after cstep or by itself. "CONTOUR" may be abbreviated simply to "CON" or "CONT". The allowable entries for "command" are

%	interpret step values as percentages. The default is 5 95 10 %;
pct	interpret step values as percentages. The default is 5 95 10 %;
lin	interpret step values as absolute values of contour levels;
log	contour levels logarithmically spaced between cmin and cmax; and
off	use default: 0 100 % .

The remaining command options for tally plots ("all", "noall", "line", "noline", "color", and "nocolor" (see Section 6.1.1.2) make no sense for geometry mesh tally plots and are disallowed. Some examples are

```
cont 0 100 pct
con 5 95 10 %
contour off
cont 1E-4 2 log
```

B.4 MCPLOT FREE COMMAND EXAMPLES

Example 1:

The following command

```
FREE  I 64x64 FIXED J=38 FIXED K=30   .
```

specifies a 1-D lattice tally plot of the cell bins, which should correspond to a lattice tally with 64 "I" index bins, 64 "J" index bins, and at least 30 "K" index bins. With the "K" index set to 30 and the "J" index to 38, the offset into the F-bins will be $29 \times 64 \times 64 + 37 \times 64 = 121{,}152$. The minimum and maximum values will be determined from the 64 "I" bin values included in the plot. If the "J" and "K" indices are not specified, their default value of 1 is assumed, which results in an offset of 0.

Example 2:

The following command

```
FREE  IJ 10x30 ALL FIXED K=60
```

specifies a 10 × 30 2-D contour plot, which should correspond to a lattice tally with 10 "I" bins, 30 "J" bins, and at least 60 "K" bins. Note that the "K" index is specified using the FIXED command, which sets the offset into the F-bins as 60 × 10 × 30 = 18,000. In this case, the contour range is taken from all of the F-bin tally values.

For additional information involving lattice tally plots see Section B.6.

B.5 PHOTONUCLEAR CROSS-SECTION PLOTS

MCNPX can plot photonuclear data in addition to the photoatomic data of MCNP.

Photoatomic reaction numbers are all negative: -1=incoherent, -2=coherent, -3=photoelectric, -4=pair production, -5=total, and -6=heating. For the MCNPX photonuclear cross-section plotting, the reaction numbers all are positive. The principal photonuclear cross sections are as follows: 1=total, 2=nonelastic, 3=elastic, 4=heating, and >4=various reactions such as 18, which is (γ,f). The photonuclear yields (multiplicities) for various secondary particles are specified by adding 1000 times the secondary particle number to the reaction number. For example, 31,001 is the total yield of deuterons (particle type D=31), 34,001 is the total yield of alphas (particle type A=34), and 1018 is the total number of neutrons (particle type N=1) from fission. To find out which reactions are available for a particular nuclide or material, enter an invalid reaction number, such as *mt*=99 and MCNPX will list the available photonuclear reactions and the available yields, such as 1018, 31,018, and 34,018. Entering a bad nuclide, XS=12345.67U, will cause MCNPX to list the available nuclides.

Figure B-6 illustrates a photonuclear cross-section plot of the total photonuclear cross section, *mt*=1, for material 11 and its constituents, carbon and lead.

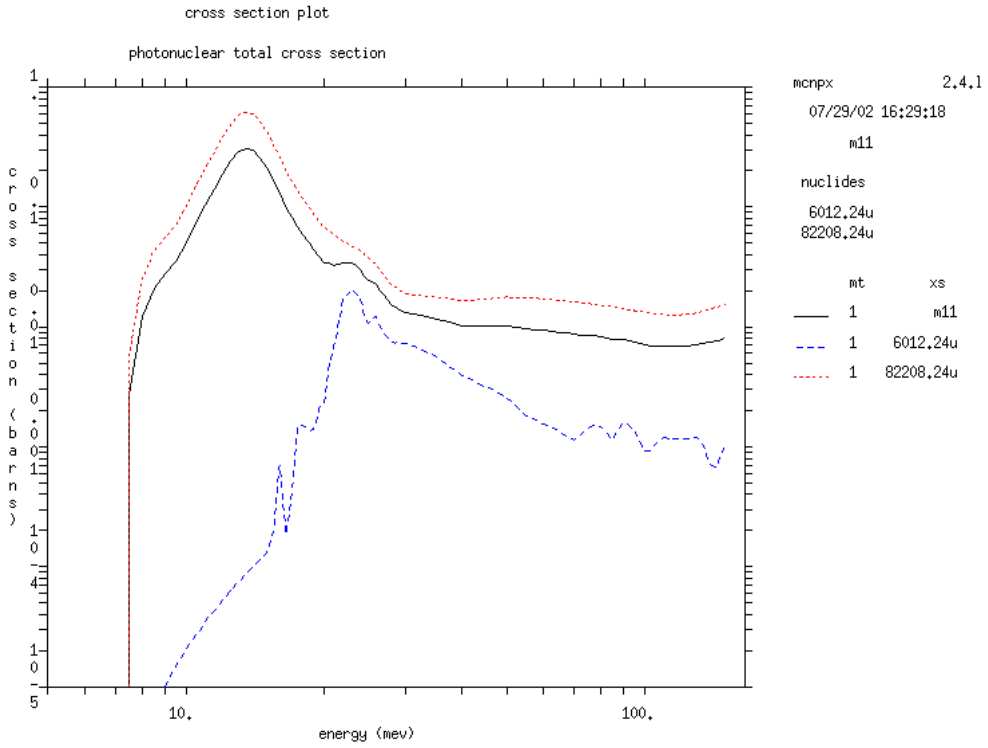


Figure B-6. Photonuclear cross-section plot.

B.6 LATTICE TALLY PLOT EXAMPLES

Lattice tallies also may be plotted as either 1-D or 2-D contour plots. An example of a lattice tally 1-D plot is

```
free i 64x64 fix j = 38 fix k = 30    .
```

This command specifies a 1-D lattice tally plot of the cell bins, which should correspond to a lattice tally with 64 "i" index bins, 64 "j" index bins, and at least 30 "k" index bins. With the "k" index set to 30 and the "j" index to 38, the offset into the f bins will be $29 \times 64 \times 64 + 37 \times 64 = 121{,}152$. The minimum and maximum values will be determined from the 64 "i" bin values included in the plot. If the "j" and "k" indices are not specified, their default value of 1 is assumed, which results in an offset of 0.

An example of a lattice tally 2-D contour plot is

```
free ij 10x30 all fix k=60    .
```

This example specifies a 10 × 30 2-D contour plot, which should correspond to a lattice tally with 10 "i" bins, 30 "j" bins, and at least 60 "k" bins. Note that the "k" index is specified using the "fix" command, which sets the offset into the f bins as 60 × 10 × 30 = 18,000. In this case, the contour range is taken from all of the f-bin tally values.

B.7 WEIGHT-WINDOW-GENERATOR SUPERIMPOSED MESH PLOTS

MCNPX can plot the WWG superimposed mesh specified on the MESH card in an input file. MCNP4C3 and previous MCNPX versions could plot only the weight-window superimposed mesh used in a problem, and a WWINP file had to be provided. In the MCNPX geometry plotter, toggle CellLine for the following options:

No Lines	Plot cells not outlined in black
CellLine	Plot geometric cells, outlined in black
WW MESH	Plot the weight-window superimposed mesh (WWINP required)
WW+Cell	Plot superimposed mesh and cells, outlined in black
WWG MESH	Plot MESH card WWG mesh
WWG+Cell	Plot WWG mesh and cells, outlined in black
MeshTaly	Plot mesh tally boundaries
MT+Cell	Plot mesh tally boundaries + CellLine

The CellLine and No Lines options are always available. WW Mesh and WW+Cell are available only when the WWP card calls for using a superimposed weight-window mesh (fifth entry negative) and a WWINP file is provided. WWG MESH and WWG+Cell are available only when a MESH card is in the input file and when the WWG requests superimposed mesh generation (WWG card second entry equals 0). In all cases, the cells may be outlined in black (CellLine, WW+Cell, WWG+Cell) or the cells simply may be colored without outlining (WW MESH, WWG MESH, No Lines).

B.7.1 Cylindrical Mesh Example

Example:

Input file: *inp10*

```
Demonstration of WWG Plot
1 1 1.0   -1  imp:p 1
2 0        1  imp:p 0

1 rcc 0 0 0  0 10 0  5
```

```
mode p
sdef sur 1.3 vec 0 1 0 dir 1 erg 100
m1 1001 2 8016 1
nps 1000
f1:p 1.2
wwg 1 0
mesh geom=cyl origin=0 -1 0  ref=0 .1 0  axs=0 1 0  vec=1 0 0
     imesh 6   iints 7  jmesh 12  jints 7   kmesh 1   kints 3
```

Com file: *com10*

```
ex 10 lab 0 0 px 0 mesh 4
pause
py 5
pause
```

Execution line:

```
mcnpx i=inp10  com=com10  ip   .
```

Or, instead of using the command file (with plot commands in command mode), the interactive plotter can be used:

```
mcnpx i=inp10 ip   ,
```

click	`CellLine`	to get `WWG+Cell`
	`label sur`	to turn off surface labels
	`XY`	to get `px=0` view (axial view, Fig. 12)
	`Zoom 10`	to get 10× magnification (click twice)
	`Origin`	click in the center of material to center picture
	`ZX`	to get `py=5` view (radial view, Fig. 13)

The above COM file or plot commands in the command mode generate the two plots shown in Figs. B-7 and B-8.

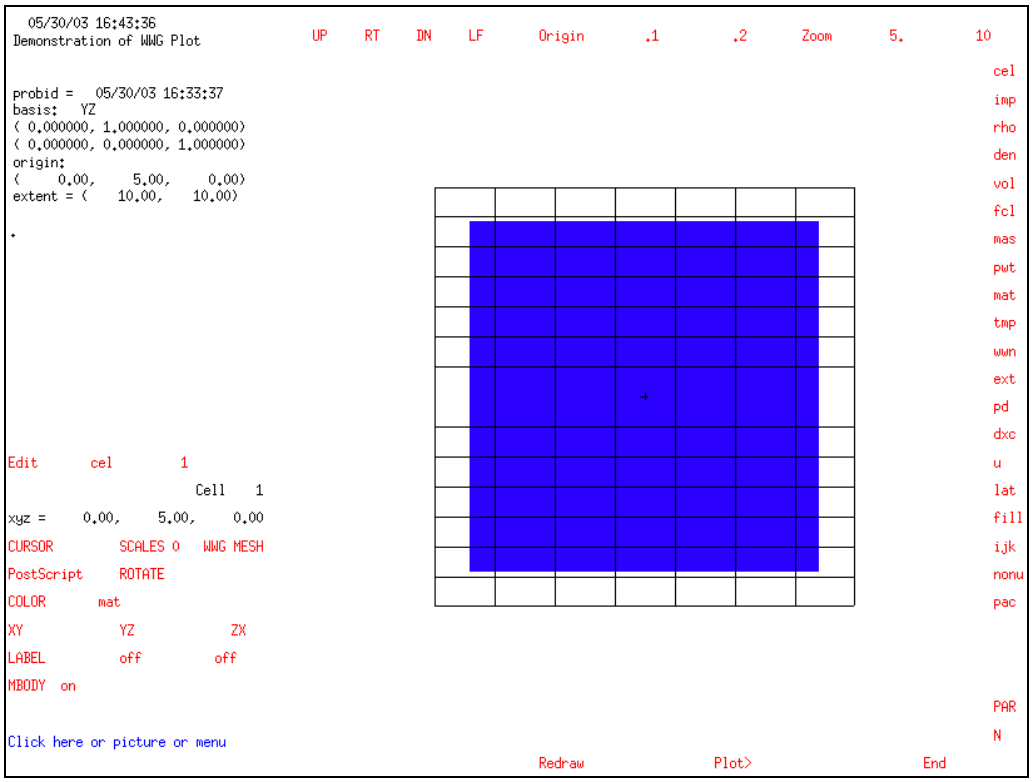


Figure B-7. WWG mesh plot, axial view.

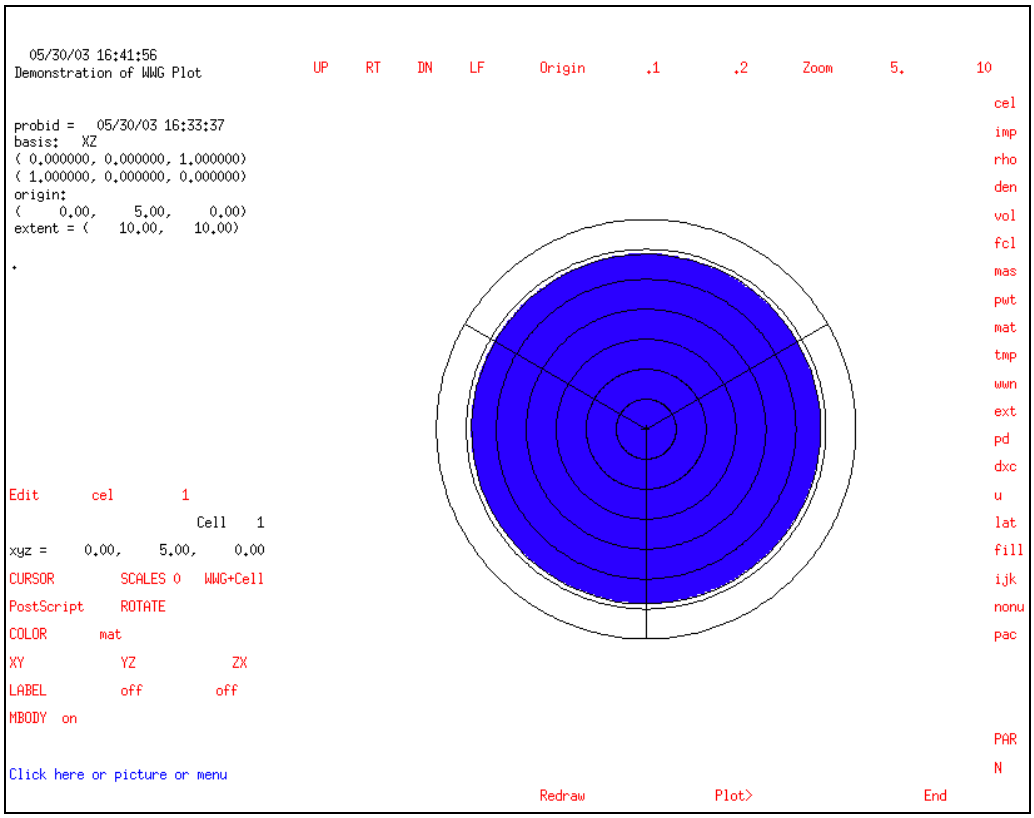


Figure B-8. WWG plot, radial view.

B.7.2 Spherical Mesh Example

The spherical mesh geometry may be thought of as an orange where the theta (θ) azimuthal angles are the bounds between slices or, alternatively, as a globe where the phi (φ) polar angles are latitude and the theta (θ) azimuthal angles are longitude. The north pole is at φ=0 degrees; the south pole is at φ=180 degrees; London is at θ=0 degrees and all the way around the globe at θ=360 degrees.

The interface for geometry plots of the spherical mesh window boundaries is the same as for cylindrical mesh boundaries. Geometry plots are colored by the input weight windows from the WWINP file by selecting `WWN` as the `COLOR` option. The weight window and weight-window generator mesh boundaries are plotted by clicking "`CellLine`" to get to the `WWG` or `WW` options. The command-prompt plot commands would be "`LA 0 1 wwn COLOR on LA 0 0`" to color by input windows. The commands "`MESH 2`" and "`MESH 4`" plot the generator mesh from the `MESH` card and weight-window mesh from the WWINP file.

Figures B-9–11 illustrate three views of a geometry divided into cells coincident with the spherical mesh, so that each color represents a specific geometry and mesh cell in each view. Figs. B-10 and B-11, drawn through the mesh sphere origin and normal and orthogonal to the polar axis, give the intuitive polar (Fig. B-10) and azimuthal (Fig. B-11) views. However, skewed, off-center plots of spherical meshes with skew axes give very non-intuitive plots as illustrated in Fig. B-9.

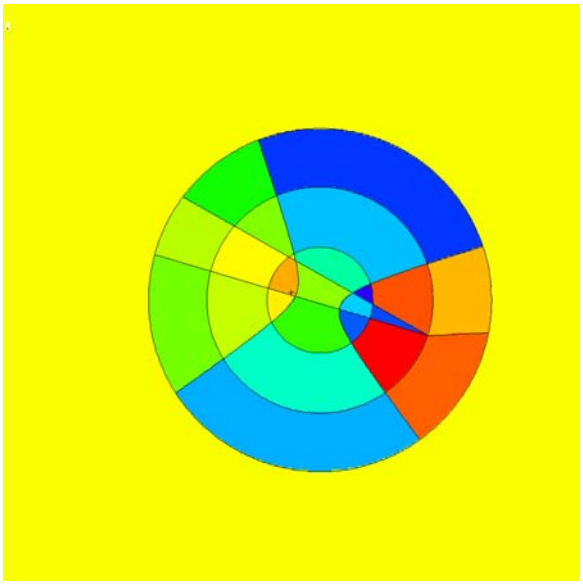


Figure B-9. The data to generate this plot view follow:

Plot view:

```
basis .84514 -.0507093 .169031 .408248 .408248 -.816497, or -3 -9 -20, ex 100.
```

Spherical mesh orientation:

```
origin 7 -9 -12, axs .4 -.5 .2, vec .1 -.2 -.7
```

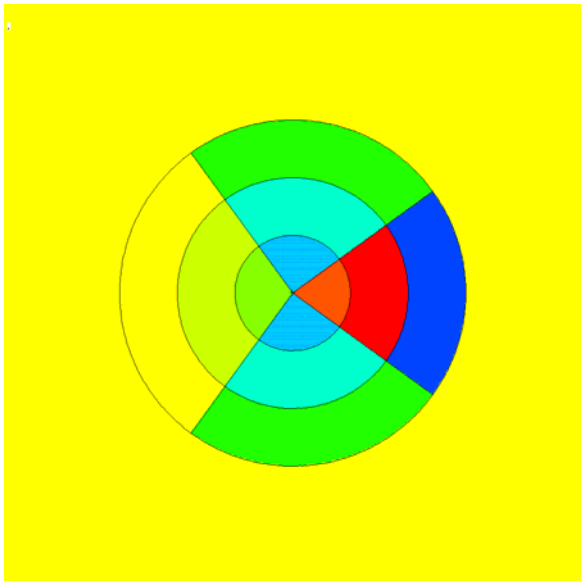


Figure B-10. Plot view orthogonal to polar axis showing polar bins JMESH = 36 and 126 degrees. The polar axis (0 degrees) is to the right and is not plotted.

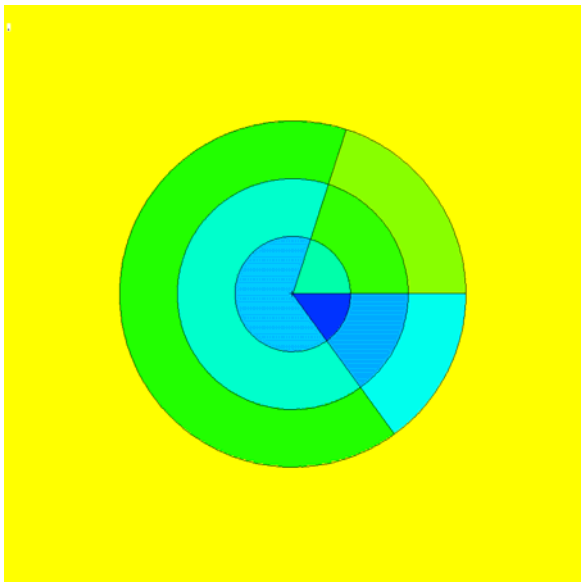


Figure B-11. View normal to polar axis at origin showing azimuthal planes at KMESH = 72, 306, and 360 degrees. The azimuthal vector, VEC, is to the right (360 degree plane)

B.8 EXAMPLE OF USE OF COPLOT

Assume all parameter-setting commands have been previously defined. The following input line will put two curves on one plot:

```
RUNTPE A COPLOT RUNTPE B
```

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`.

Next we might type the following commands:

```
XLIMS min max     TALLY 11   COPLOT RMCTAL AUX   TALLY 41 &
COPLOT RUNTPE A   TALLY 1
```

These commands change the upper and lower limits of the x-axis to *max* and *min*, respectively; define `TALLY 11` as the current tally; and plot 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.

The command

```
TALLY 24    NONORM    FILE    COPLOT    TALLY 44
```

will send a frame with two curves to the graphics metafile.

B.9 REFERENCE

ANS85 "American National Standard for Information Systems—Computer Graphics—Graphical Kernel System (GKS) Functional Description," ANSI X3.124-1985, ANSI, INC (1985).

APPENDIX C HTAPE3X FOR USE WITH MCNPX

This appendix is reprinted from "HTAPE3X for Use with MCNPX," Richard E. Prael, Los Alamos Report LA-UR-99-1992, April 16, 1999.

Abstract

HTAPE3X is a code for processing medium- and high-energy collision data written to a history file by MCNPX. In addition, it provides surface flux and current edits which supplement the standard MCNPX tallies.

C.1 THE HTAPE3X CODE

HTAPE3X is a modification of the HTAPE code from the LAHET Code System [PRA89] designed to provide analysis of the history file HISTP optionally written by MCNPX [HUG97]. It is primarily intended to provide an analysis of the outcome of collisions in the medium- and high-energy range where the interaction physics is obtained from LAHET.

However, all appropriate features have been retained, even when they duplicate existing MCNPX flux and current tallies [BRI97]. The latter features relate to editing a "surface source write (SSW)" file (default name WSSA). For experienced LAHET users, they do provide some options not available with standard MCNPX `F1` and `F2` tallies.

Note that the information written to HISTP comes only from interactions processed by the medium- and high-energy modules in MCNPX; low-energy neutron and proton (and any photon/electron) collisions which utilize MCNPX library data do not contribute to the collision information on the history file and will not contribute to edits by HTAPE3X of collision data. Surface crossing edits from data on the file WSSA will apply to all particle types and all energies.

C.2 INPUT FOR HTAPE3X

The input structure is largely unchanged from the description in reference [PRA89]. In general, energy units are MeV, time units are nanoseconds, and length units are centimeters. Note the difference in the time scale from MCNPX practice.

The input file (default name INT) for HTAPE3X has the following structure:

1. Two records of title information, 80 columns each.
2. An option control record.
3. Additional input as required by the chosen option.

Items 2 and 3 above are written as "list-directed input" [PRA89]. Repeat counts are allowed, including repeat counts for commas to take default values (i.e., "4*," expands to ",,,,"). Multiple cases may be processed; for each case the above structure applies. Slashes "/" are allowed only in the first pair of title cards unless each title card containing one or more slashes has an "S" in column 1.

The option control record defines the options to be used and the additional input information that must be specified for the problem. The structure of this record is

```
IOPT, NERG, NTIM, NTYPE, KOPT, NPARM, NFPRM, FNORM, KPLOT,
IXOUT, IRS, IMERGE, ITCONV, IRSP, ITMULT/
```

Some of the parameters in this record may optionally be preceded by a minus sign whose meaning is defined below. Thus if NTIM is specified by inserting "-3" in the option control record, it is interpreted as NTIM=3 with a minus-sign flag attached. In the discussion which follows, input control parameters are treated as positive or zero quantities, even though the flag may be present.

Table C-1. Applicability of Input Control Parameters

IOPT	NERG	NTIM	NTYPE	NPARM	NFPRM	KPLOT	IXOUT	IMERGE	ITCONV	IRSP	ITMULT
1	O	O	R	R	O	N	N	O	O	O	O
101	O	O	R	R	O	N	N	O	O	O	O
2, 102	O	O	R	R	N	N	N	O	O	O	O
3	O	O	N	0	N	0	N	N	O	N	N
103	O	O	N	R	N	0	N	N	O	N	N
5	N	N	N	0	N	0	N	N	N	N	N
105	N	N	N	R	N	0	N	N	N	N	N
8	N	N	N	0	N	0	0	N	N	N	N
108	N	N	N	R	N	0	0	N	N	N	N
9, 109	O	O	R	R	O	N	N	O	O	O	O
10, 110	O	O	R	R	N	N	N	O	O	O	O
11, 111	O	N	R	R	O	N	N	O	N	N	N
12, 112	O	N	R	R	O	N	N	O	N	N	N
13	O	O	R	O	O	N	N	O	O	O	O
14	N	N	N	O	N	N	N	N	N	N	O
114	N	N	N	R	N	N	N	N	N	N	O
15	N	N	N	O	N	O	O	N	N	N	N

IOPT	NERG	NTIM	NTYPE	NPARM	NFPRM	KPLOT	IXOUT	IMERGE	ITCONV	IRSP	ITMULT
115	N	N	N	R	N	O	O	N	N	N	N
16	O	N	N	0	N	O	N	N	N	N	N
116	O	N	N	R	N	O	N	N	N	N	N

R ≡ required, O ≡ optional, N ≡ not used. IRS is optional with any value of IOPT.

IOPT defines the editing option to be applied as defined below. For all but IOPT=13, 100 may added to the basic option type to indicate that the tally over a list of cell, surface, or material numbers will be combined in a single tally. Prefixing IOPT by a minus sign, when allowed, indicates an option-dependent modification to the tally.

NERG, when applicable, defines the number of energy bins for the tally; the maximum is 2000. The default is 0, implying that only a total over energy will be produced. If NERG is >1 and is preceded by a minus sign, the tally in each energy bin will be divided by the bin width to normalize per MeV. The total over energy will be unnormalized.

Table C-2. Applicability of Minus-Sign Flags on Input Control Parameters

IOPT	-IOPT	-NERG	-NTIM	-NTYPE	-NPARM	-NFPRM
1, 101	O	O	O	N	O	O
2, 102	O	O	O	N	O	N
3, 103	O	O	O	N	O	N
5, 105	O	N	N	N	O	N
8, 108	O	N	N	N	O	N
9, 109	O	O	O	N	O	O
10, 110	O	O	O	N	O	N
11, 111	N	O	N	N	O	O
12, 112	N	O	N	N	O	O
13	O	O	O	N	N	N
14, 114	N	N	N	N	O	N
15, 115	O	N	N	N	O	N
116	O	O	N	N	O	N

O ≡ optional; N ≡ not used.

NTIM defines the number of time bins for the tally when applicable; the maximum is 100. The default is 0, implying that only a total over time will be produced. If NTIM is >1 and is

preceded by a minus sign, the tally in each time bin will be divided by the bin width to normalize per nanosecond; the total over time will be unnormalized.

NTYPE defines the number of particle types for which the edit is to be performed for those options where it is applicable; the particle type is that of the particle causing the event, which is recorded on the history tape. The default is 0; however, some options require that a value be supplied.

KOPT defines a sub-option for tally option IOPT. The default is 0.

NPARM *usually* defines the number of cells, materials, or surfaces over which the tally is to be performed when applicable; the maximum is 400. If NPARM is preceded by a minus sign, NPARM+1 normalization divisors will be read in as described below. The default is 0; however, some options require that a value be supplied.

NFPRM, at present, is used only to define the number of cosine bin boundaries to read in for particle current tallies; the maximum is 400. If NFPRM is preceded by a minus sign, cosine bin tallies will be normalized per steradian: the total over cosine bins will remain unnormalized (i.e., angle integrated). The default is 0.

Table C-3. Particle Type Identification in HTAPE3X

Type	LAHET Usage	MCNPX Usage
0	proton	proton, $\bar{p}$
1	neutron	neutron, $\bar{n}$
2	π^+	π^+, π^-
3	π^0	π^0
4	π^-	
5	μ^+	
6	μ^-	μ^-, μ^+
7	deuteron	deuteron
8	triton	triton
9	^{3}He	^{3}He
10	alpha	alpha
11	photon	photon
12	K^+	K^+, K^-
13	K^0 long	K^0 long
14	K^0 short	K^0 short
15	K^-	

Type	LAHET Usage	MCNPX Usage
16	$\bar{p}$	
17	$\bar{n}$	
18	electron	electron, positron
19	positron	
20	neutrino	neutrino, antineutrino
21	antineutrino	

FNORM may be used to apply an overall multiplicative normalization to all bins, except for IOPT= 11, 111, 12, or 112. For these cases, FNORM multiplies the time variable (e.g., use FNORM=0.001 to convert from nanoseconds to microseconds). The default is 1.0.

KPLOT is a plot control flag; plotting is available for some options (provided it has been installed with the code using the LANL CGS and CGSHIGH Common Graphics System libraries). Using a 0 indicates that no PLOT file will be produced and is the default.

IXOUT is a flag to indicate that the tally will be written to a formatted auxiliary output file for post-processing. The details (and the filename) are option-dependent; however, a 0 indicates that no such file will be written, and is the default.

IRS is the RESOURCE option flag. A non-zero value indicates that the option will be turned on; 0 is the default (see Section C.19 below).

IMERGE is not used in HTAPE3X (see Section C.20 below).

ITCONV is the TIME CONVOLUTION option flag. A non-zero value indicates that the option will be turned on; 0 is the default (see Section C.21 below).

IRSP is the RESPONSE FUNCTION option flag. IRSP>0 indicates that the tally will be multiplied by a user-supplied response function; IRSP<0 indicates that the tally will be divided by a user-supplied response function. The default is 0. For a discussion, see Section C.22 below.

ITMULT is the TIME MULTIPLIER flag. ITMULT>0 indicates that the weights tallied will be multiplied by the event time. This option applies only when the basic option type is 1, 2, 4, 9, 10, or 13.

The standard definitions for these input variables may not apply for some options.

According to the parameters specified on the option record, the following records are required in the order specified:

- For NERG>0, a record defining NERG upper energy bin boundaries, from low to high, defined as the array ERGB(*i*), *i*=1,NERG. The first lower bin boundary is implicitly always 0.0. The definition may be done in four different ways. First, the energy boundary array may be fully entered as ERGB(*i*), *i*=1,NERG. Second, if two or more, but less than NERG, elements are given (with the record terminated by a slash), the array is completed using the spacing between energy boundaries obtained from the last two entries. Third, if only one entry is given, it is used as the first upper energy boundary and as a constant spacing between all the boundaries. Fourth, if only two entries are given with the first negative and the second positive, the second entry is used as the uppermost energy boundary, ERGB(NERG), and the first entry is interpreted as the lethargy spacing between bin boundaries. Thus the record "-0.1,800./" will specify ten equal-lethargy bins per decade from 800 MeV down.
- For NTIM>0, a record specifying NTIM upper time bin boundaries, from low to high, defined as the array TIMB(*i*), *i*=1,NTIM. The first lower time boundary is always 0.0. The same four methods that are allowed for defining the energy boundaries may also be used to define the time bin boundaries.

Table C-4. Order of HTAPE3X Input Records

(-)IOPT,…	option control record (always required)
ERGB(*i*), *i*=1, NERG	upper energy bin limits
TIMB(*i*), *i*=1, NTIM	upper time bin limits
ITIP(*i*), *i*=1, NTYPE	particle type identifiers
LPARM(*i*), *i*=1, NPARM	surface, cell, or material identifiers
FPARM(*i*), *i*=1, NFPRM	upper cosine bin boundaries
DNPARM(*i*), *i*=1, NPARM+1	normalization divisors
	original source definition record for RESOURCE option
	new source definition record for RESOURCE option
ITOPT, TWIT, TPEAK, TWIT	parameters for TIME CONVOLUTION
ERESP(*i*), *i*=1, NRESP	energy grid for RESPONSE FUNCTION
FRESP(*i*), *i*=1, NRESP-1	function values for RESPONSE FUNCTION
IRESP(*i*), *i*=1, NRESP-1	interpolation scheme for RESPONSE FUNCTION
	segment definition record or window definition record
CN(*i*), *i*=1,3	arbitrary direction vector for defining cosine binning

- For NTYPE>0, a record containing NTYPE particle types in any order, defined as the array ITIP(*i*), *i*=1,NTYPE. The contents of a surface source file WSSA are insufficient to distinguish between a particle and its antiparticle.
- For NPARM>0, a record containing NPARM *user-defined* cell, material, or surface numbers (integers), in any order, for which one wishes a tally to be made; these are defined as the array LPARM(*i*), *i*=1,NPARM. If a null record ("/") is supplied with NPARM>0, it is treated as "1,2,3,...NPARM/". (Note: A different meaning for NPARM is used for IOPT=13.)
- For NFPRM>0, a record containing NFPRM upper cosine bin boundaries, defined as the array FPARM(*i*), *i*=1,NFPRM. The first lower cosine boundary is always -1.0. If a null record is supplied, equal cosine bin boundaries from -1.0 to 1.0 will be defined by default.
- If NPARM is preceded by a minus sign, a record containing NPARM or NPARM+1 normalization divisors; these are defined in HTAPE3X as the DNPARM array. The NPARM values are in a one-to-one correspondence with the LPARM array. The last (NPARM+1) entry applies to a total over the NPARM entities where applicable; if omitted, it defaults to 1.0. Through this feature it is possible to input a list of volumes, areas, or masses, as appropriate, obtained from a MCNPX calculation. When IOPT>100, the NPARM cell, surface, or material identifiers are treated as a single entity in constructing a tally edit. In this case, the NPARM normalization divisors are summed to a single divisor. Consequently, one may supply the full list of divisors, if appropriate, or just supply one value for the common tally.
- For IRS>0, the original source definition record (in LAHET format as described in Section 2.4 of reference [PRA89]) followed by the new source definition record (also in LAHET format).
- For ITCONV≠0, a LAHET source time distribution record as described in Section 2.4 of reference [PRA89].
- For IRSP≠0, three records defining the user-supplied response function:

  ERESP(*i*), *i*=1,...,NRESP a monotonically increasing energy grid on which the value of the response function is tabulated;

  FRESP(*i*), *i*=1,...,NRESP the values of the response function at the above energies,

  IRESP(*i*), *i*=1,...,NRESP−1 interpolation scheme indicators, where IRESP(i) indicates the interpolation scheme to be used for the response function in the i^{th} energy interval.

  The length NRESP<200 is obtained from the array ERESP input (terminated by a "/"). The user must maintain the proper correspondence among the arrays (see Section C.22 below).

- Any additional input required for the particular option. For basic option types 1, 2, or 11, this may be the specification of surface segmenting. For basic option types 9, 10, or 12, it is the collimating window definition. Also, for basic option types 1, 9, 11, or 12, an arbitrary vector for angular binning may be input.

C.3 EDIT OPTION IOPT = 1 OR 101: SURFACE CURRENT

Option 1 tallies the particle current across the NPARM-designated surfaces; it is analogous to the MCNPX F1 tally. If IOPT is preceded by a minus sign, the weight binned is multiplied by the particle energy. The number of energy bins is given by NERG. The number of particle types for which surface crossing data is to be tallied is given by NTYPE and must be >0. Current will be tallied on NPARM surfaces; a total over surfaces is not performed. Any of the above particle types may be specified. Binning into NFPRM cosine bins is defined by the value of KOPT. For KOPT=0 or 5, the cosine is taken with respect to the normal to the surface at the crossing point. For KOPT=1 or 6, the cosine is taken with respect to the x-axis. For KOPT=2 or 7, the cosine is taken with respect to the y-axis. For KOPT=3 or 8, the cosine is taken with respect to the z-axis. For KOPT=4 or 9, the cosine is taken with respect to an arbitrary vector to be read in.

If KOPT= 5, 6, 7, 8, or 9, the current tallies are binned according to a slicing of each surface into NSEG+1 segments by NSEG planes. In this case, an additional record of the following form is required: "IFSEG,NSEG,FSEG(1), ... FSEG(NSEG)/". For IFSEG=1 the segmenting planes are perpendicular to the x-axis, for IFSEG=2 the y-axis, and for IFSEG=3 the z-axis. The FSEG(*i*) are the coordinates of the NSEG planes in increasing order.

Segmenting may also be accomplished by using segmenting cylinders. The input has the same format as segmenting by planes; however, IFSEG negative designates cylindrical segmenting. IFSEG=-1 indicates that the segmenting cylinders are concentric with the x-axis; IFSEG=-2 indicates that the segmenting cylinders are concentric with the y-axis; IFSEG=-3 indicates that the segmenting cylinders are concentric with the z-axis. The values of the FSEG array are the radii of nested concentric cylinders and must be in increasing order. Segmenting cylinders are concentric with an axis, not just parallel.

For KOPT=4 or 9, an additional record must be supplied with the direction cosines of the arbitrary vector with which cosine binning is to be made. The form of this record is "CN(1),CN(2),CN(3)/", where the parameters input are the direction cosines of the arbitrary vector with respect to the x-, y-, and z-axes. The vector need not be normalized.

The surface current tally represents the time-integrated current integrated over a surface area and an element of solid angle. Unless otherwise normalized, it is the weight of

particles crossing a surface within a given bin per source particle. As such, it is a dimensionless quantity.

C.4 EDIT OPTION IOPT = 2 OR 102: SURFACE FLUX

The surface flux tally is analogous to an MCNPX F2 tally. All particle types listed above may be specified. The number of energy bins is given by NERG. The number of particle types for which surface flux data is to be tallied is given by NTYPE and must be >0. NFPRM is unused. If KOPT=1, surface segmenting is performed as in option 1 above; the same input record to designate the segmenting planes or cylinders must be included as in option 1. If IOPT is preceded by a minus sign, the particle weight is multiplied by its energy before tallying.

The surface flux tally represents the time-integrated flux integrated over surface areas. Unless otherwise modified, it is a dimensionless quantity.

C.5 EDIT OPTION IOPT = 3 OR 103: PARTICLE PRODUCTION SPECTRA

Option 3 may be used to tally the spectra of particles produced in nuclear interactions. It accesses all collision records on HISTP for all particles causing collisions. If IOPT is preceded by a minus sign, the edit is performed only for events initiated by the primary (source) particles. For KOPT=0 or 1, separate edits are performed for cascade and evaporation phase production. In addition, total nucleon production from either phase is edited. For KOPT=2 or 3, only the cascade production is edited. For KOPT=4 or 5, only the evaporation phase production is edited. For KOPT=6 or 7, only the total particle production is edited. For KOPT=8 or 9, only the pre-fission-evaporation production is edited. For KOPT=10 or 11, only the post-fission-evaporation production is edited. If KOPT is even, the edit is over cell numbers; if KOPT is odd, the edit is over material numbers. If NPARM is zero, the edit is over the entire system. The parameters NTYPE and NFPRM are not used. If KPLOT=1, a plot is made of each edit table. With KOPT=0 or 1, the cascade production for neutrons and protons is simultaneously plotted (as a dotted line) with the total production.

Unless otherwise modified, tally option 3 (or 103) represents the weight of particles emitted in a given bin per source particle. As such, it is a dimensionless quantity.

C.6 EDIT OPTION IOPT = 4 OR 104: TRACK LENGTH ESTIMATE FOR NEUTRON FLUX

Option 4 is not available in this version; use a standard F4 flux tally.

C.7 EDIT OPTION IOPT = 5 OR 105: RESIDUAL MASSES AND AVERAGE EXCITATION

Option 5 provides an edit by mass number A of the calculated residual masses and the average excitation energy for each mass. Only nonelastic interactions are included. The option accesses the records on HISTP for all interacting particle types. The edit is performed for both the final residual masses and the residuals after the cascade phase. If IOPT is preceded by a minus sign, the edit is performed for events initiated by primary (source) particles only. For KOPT=0, the edit is by cell numbers; if KOPT=1, the edit is by material numbers. If NPARM=0, the edit is over the entire system. The parameters NTIM, NTYPE, and NFPRM are immaterial. KPLOT=1 will produce plots of each edit table.

Tally option 5 (or 105) represents the particle weight producing a given nuclide per source particle; as such, it is a dimensionless quantity. The mean excitation is in units of MeV.

C.8 EDIT OPTION IOPT = 6 OR 106: ENERGY DEPOSITION

Option 6 is not available in this version.

C.9 EDIT OPTION IOPT = 7: MASS AND ENERGY BALANCE

Option 7 is not available in this version.

C.10 EDIT OPTION IOPT = 8 OR 108: DETAILED RESIDUAL MASS EDIT

Option 8 provides a detailed edit of residual masses by Z and N, by Z only, by N only, and by mass number A. The option accesses the records on HISTP for all interacting particle types. If IOPT is preceded by a minus sign, the edit is performed only for events initiated by primary (source) particles. If KOPT=0 or 1, the edit is of the final residual masses, including elastic collisions. If KOPT=2 or 3, the edit is of the residuals after the cascade phase and before evaporation. If KOPT=4 or 5, the edit is of masses immediately preceding fission. If KOPT is even, the edit is by cell number; if KOPT is odd, the edit is by material number. If KPLOT=1, plots will be produced for each edit table. Parameters NERG, NTYPE, and NFPRM are unused. If IXOUT=1, an auxiliary output file appropriate for input to the CINDER program will be written; the default filename is OPT8A. Unless otherwise modified, tally units are dimensionless (weight of a residual nuclide per source particle).

An additional tabulation is produced which shows the estimated metastable state production as a fraction of the total isotopic production. As illustrated in the example here in Table C-5, a state is identified by its excitation energy and half-life; the estimated fraction of total isotope production associated with the particular metastable state is shown with the estimated relative standard deviation.

Table C-5

z	a	elev	t-half	fraction
47	110	0.11770	2.17730D+07	4.00000D-01 0.3465
47	111	0.05990	6.50000D+01	8.00000D-01 0.2001
47	116	0.08100	1.05000D+01	5.00000D-01 0.5001
48	113	0.26370	4.41500D+08	2.85714D-01 0.3195
48	115	0.17340	3.87070D+06	5.00000D-01 0.3536
48	117	0.13000	1.22400D+04	2.50000D-01 0.4331
48	119	0.14640	1.62000D+02	6.0000D-01 0.2329

C.11 EDIT OPTION IOPT = 9 OR 109: SURFACE CURRENT WITH COLLIMATING WINDOW

Option 9 is identical to option 1 except that a rectangular or circular "window" is imposed on each surface and the tally made within and without the window. The window is defined by the intersection of a rectangular or circular tube parallel to the x-, y-, or z-axis with the tally surface. A window definition record appears in place of the segmenting record of option 1. For KOPT= 0, 1, 2, 3, or 4, the window is formed by the rectangular tube; the window record has the following allowed forms:

parallel to x-axis: 1,y(min),y(max),z(min),z(max)/
parallel to y-axis: 2,z(min),z(max),x(min),x(max)/
parallel to z-axis: 3,x(min),x(max),y(min),y(max)/

For KOPT= 5, 6, 7, 8, or 9, the window is formed by a circular tube (cylinder); the window record has the following allowed forms:

parallel to x-axis: 1,y(center),z(center),radius/
parallel to y-axis: 2,z(center),x(center),radius/
parallel to z-axis: 3,x(center),y(center),radius/

C.12 EDIT OPTION IOPT = 10 OR 110: SURFACE FLUX WITH COLLIMATING WINDOW

Option 10 is identical to option 2 except that the edit is performed inside and outside a "window" defined as in option 9. Instead of the segmenting record of option 1, a window definition record appears, whose form is described in option 9. For KOPT=0, the rectangular form is used, and for KOPT=1, the circular form is used. Parameter NFPRM is unused.

C.13 EDIT OPTION IOPT = 11 OR 111: PULSE SHAPE OF SURFACE CURRENT

For each defined bin, option 11 provides an edit of the current crossing a surface in an energy and angle bin, the mean time t of crossing in the bin, the standard deviation σ of $\bar{t}$ given by $\left(\overline{t^2}-\bar{t}^2\right)^{1/2}$, the figure of merit FOM1 given by (current)/σ^2 and the figure of merit FOM2 given by (current)/σ^3.

Unless otherwise modified, the current tally is dimensionless. The units of $\bar{t}$ and σ are nanoseconds (ns), while FOM1 is in ns^{-2} and FOM2 is in ns^{-3}. The parameter FNORM is used to adjust the units of the time variable, which are nanoseconds in LAHET3, and does not modify the surface current edit. Thus, to convert from nanoseconds to microseconds, use FNORM=0.001. The bin definition is identical to option 1, including surface segmenting, except that NTIM is unused.

C.14 EDIT OPTION IOPT = 12 OR 112: PULSE SHAPE OF SURFACE CURRENT WITH WINDOW

Option 12 provides the same edits as option 11 with the same bin definition as option 9 using a collimating "window." The input is identical to option 9, with the exception that NTIM is unused.

C.15 EDIT OPTION IOPT = 13: GLOBAL EMISSION SPECTRUM

Option 13 tallies the number of particles per unit solid angle entering the external void region with direction cosine falling within a segment of solid angle; as such, it represents the angular distribution of the emitted particles at a very large distance from the

interaction region. The option uses any NCOL=4 leakage records on HISTP and all records on HISTX indiscriminately.

Surface crossing records appearing on a SSW-written file are not distinguished as to whether they correspond to an internal surface crossing or to escape into the external void. Therefore, for use with MCNPX, the original intent of this option may most easily be achieved by defining the external importance 0 (leakage) region as the exterior of a sphere containing the complete geometry; then only specifying the defining spherical surface on the SSW card that controls the contents of the surface crossing file.

Energy binning is specified by the usual methods. The number of energy bins is given by NERG. The number of particle types for which surface crossing data are to be tallied is given by NTYPE and must be >0. The polar angle bins (representing lines of latitude) are defined by entering the NFPRM cosine values in the FPARM array. Binning in the azimuthal angle ø corresponding to lines of longitude, is determined by the value of NPARM, which defines NPARM equal azimuthal angle bins from a lower bound of 0° on the first bin to an upper bound of 360° on the last bin. The value of KOPT determines the orientation used to define the angles. The allowed options are as follows:

KOPT = 1: the +z-axis defines the polar angle and ø is measured counter-clockwise from the +x-direction;

KOPT = 2: the +z-axis defines the polar angle and ø is measured counter-clockwise from the +y-direction;

KOPT = 3: the +x-axis defines the polar angle and ø is measured counter-clockwise from the +y-direction;

KOPT = 4: the +x-axis defines the polar angle and ø is measured counter-clockwise from the +z-direction;

KOPT = 5: the +y-axis defines the polar angle and ø is measured counter-clockwise from the +z-direction;

KOPT = 6: the +y-axis defines the polar angle and ø is measured counter-clockwise from the +x-direction.

A value of KOPT=0 defaults to KOPT=1. For NPARM≥1, a null record "/" must be supplied in place of the LPARM array; NPARM=0 defaults to NPARM=1, but the null record need not be supplied. If a null record is supplied for the FPARM array, NFPRM equal cosine bins from -1.0 to 1.0 are supplied.

The following is an example of the input for using option 13:

```
Title 1: Option 13 Example
Title 2: 100 Equal Solid Angle Bins
13,-10,,1,1,10,10/ ,
```

```
-0.5,800./
1/
/
/
```

In this case, the energy is binned in 10 equal lethargy intervals of half-decade width below 800 MeV and normalized per MeV. No time binning is done. Only neutrons are edited. The z-axis determines the polar angle, and the azimuthal angle is measured from the x-axis. Ten azimuthal angle bins are used, and 10 equal polar angle cosine bins are defined by taking the default. Note that the last four records could be written on one line as "`-0.5,800./1///`".

Tally option 13 may be considered as the time-integrated particle current integrated over a sphere in a void at a very large distance for the interaction region. Since it is normalized per unit solid angle, the units are dimensionless, being sr^{-1} per source particle.

C.16 EDIT OPTION IOPT = 14 OR 114: GAS PRODUCTION

Option 14 provides an edit of hydrogen and helium gas production, by isotope, by element, and total. Unless modified by `FNORM`, the units of gas production are atoms per source particle. If `KOPT=0`, the edit is by cell number; if `KOPT=1`, the edit is by material. `NERG`, `NTIM`, and `NTYPE` are unused. The estimate is made by tallying all H and He ions stopped in a cell or material, including source particles.

C.17 EDIT OPTION IOPT = 15 OR 115: ISOTOPIC COLLISION RATE

Option 15 has been added to provide a collision rate edit by target isotope. The input has the same meaning as for `IOPT=8`, with the following exceptions: `KOPT=0` or `1` tabulates all collisions; `KOPT=2` or `3` tabulates elastic scattering only; `KOPT=4` or `5` tabulates nonelastic events only. If `KOPT` is even, the edit is by cell number; if `KOPT` is odd, the edit is by material number. A CINDER removal rate input file will be produced for `IXOUT>0`. The default CINDER filename is OPT15A.

C.18 EDIT OPTION IOPT = 16 OR 116: RECOIL ENERGY AND DAMAGE ENERGY SPECTRA

Option 16 provides an edit of the spectra of total recoil energy, elastic recoil energy, total damage energy, and elastic damage energy. Also estimated are the mean weight of recoiling fragments per history, mean weight of recoil (or damage) energy per history, and the mean energy per fragment (the ratio of the previous two estimates). `NERG`

specifies the number of energy bins for the spectra; a minus sign on NERG will have the tabulation normalized per MeV (recommended to produce a true spectrum). Input variables NTIM, NTYPE, NFPRM, IXOUT, IRS, IMERGE, ITCONV, and IRSP are unused. KOPT=0 indicates tally by cell; KOPT=1 indicates tally by material. NPARM is the number of cells (or materials) to be read in for the tally. If a minus sign flag is used with IOPT (IOPT=-16), the weights tallied for the spectra will be multiplied by corresponding recoil (or damage) energy.

At any collision, the damage energy E_d is obtained from the recoil energy E_r of nucleus A_r, Z_r by the relation of Lindhard [LIN68]

$$E_d = E_r\, L\,(E_r)$$

using the formulation of Robinson [ROB71]:

Table C-6

$$k_i = \frac{0.133745 Z_r^{2/3} Z_i^{1/2}}{A_r^{3/2} A_i} \left(\frac{A_r + A_i}{2}\right)^2 \left(\frac{2}{Z_r^{2/3} + Z_i^{2/3}}\right)^{3/4}$$

$$\epsilon_i = \frac{0.03252 A_i E_r}{(A_r + A_i) Z_r Z_i (Z_r^{2/3} + Z_i^{2/3})^{1/2}}$$

$$g(\epsilon_i) = \epsilon_i + 0.40244 \epsilon_i^{3/4} + 3.4008 \epsilon_i^{1/6}$$

$$L(E_r) = \sum_{i=1}^{n} \frac{f_i}{1 + k_i g(\epsilon_i)}$$

where the summation is over the components of the material with atom fractions f_i.

C.19 THE RESOURCE OPTION

The RESOURCE option allows the user to edit the data available on a history file while altering the assumed spatial distribution of the source from that used in the original calculation. For its application, see reference [PRA89].

C.20 THE MERGE OPTION

Not used in HTAPE3X. For any tally either the HISTP file or the HISTX file is edited, but not both.

C.21 THE TIME CONVOLUTION OPTION

Assume that an initial calculation has been made with the default source time distribution (i.e., all histories start at t=0). A time-dependent tally for any of the allowed LAHET source time distributions may then be made with HTAPE3X without rerunning the transport calculation. For details, see reference [PRA89].

C.22 THE RESPONSE FUNCTION OPTION

Any non-zero value of the IRSP parameter allows the user to apply an energy-dependent response function $f(E)$, where E is the particle energy, to the current and flux tallies given by edit option types 1, 2, 4, 9, 10, and 13. The user supplies a tabulation of the function $f(E)$ by the pairs of values FRESP(i), ERESP(i) which are input as the arrays ERESP(i), i=1,...,NRESP and FRESP(i), i=1,...,NRESP described in Section C.2 above. The element IRESP(i) of the third input array then specifies an interpolation scheme for computing the response function value within the interval ERESP(i)<E≤ERESP(i+1). For IRSP>0, the interpolated response function value multiplies the tally increment; for IRSP<07 it divides the tally increment.

There are five interpolation schemes that may be specified individually for each energy interval in the response function tabulation, using the following values for IRESP(i):

1. Constant: the response function value is the value at the lower energy of the interval.
2. Linear-linear: the response function is interpolated linearly in energy.
3. Linear-log: the response function is interpolated linearly in the logarithm of the energy.
4. Log-linear: the logarithm of the response function is interpolated linearly in energy.
5. Log-log: the logarithm of the response function is interpolated linearly in the logarithm of the energy.

Any value of IRESP(i) outside the range [1,5] is treated as 1 (i.e., constant over the interval).

The energy range for the specified response function need not span all possible particle energies in the problem. If a particle energy falls below ERESP(1), then FRESP(1) is used as the value of the response function. Similarly, if a particle energy exceeds ERESP(NRESP), then FRESP(NRESP) is used as the value of the response function.

C.23 EXECUTING HTAPE3X

The default filename for the input is INT; the default filename for the output is OUTT; the default filename for the history file is HISTP; and the default filename for the surface crossing file is HISTX for input into HTAPE3X. (The latter is written by MCNPX with the default filename WSSA.) If option 8 is requested, the data file PHTLIB must be in the user's file space; if option 16 is requested, the data file BERTIN must be in the user's file space. All these filenames may be defined by file replacement on the execute line:

```
HTAPE3X INT=my_input OUTT=my_output HISTP=file1 HISTX=file2
```

C.24 REFERENCES

BRI97 J. F. Briesmeister, ed., "MCNP™—A General Monte Carlo N-Particle Transport Code," Los Alamos National Laboratory report LA-12625-M (March 1997).

HUG97 H. G. Hughes, R. E. Prael, and R. C. Little, "MCNPX—The LAHET/MCNP Code Merger," Los Alamos National Laboratory research note (X-Division) XTM-RN(U)97-012, LA-UR-97-4891 (April 1997).

LIN68 J. Lindhard, V. Nielsen, and M. Scharff, *Kgl. Dan. Vidensk. Selsk., Mat.-Fys. Medd*. **36** (10) (1968).

PRA89 R. E. Prael and H. Lichtenstein, "User Guide to LCS: The LAHET Code System," Los Alamos National Laboratory report LA-UR-89-3014 (September 1989). http://www-xdiv.lanl.gov/XCI/PROJECTS/LCS/lahet-doc.html

ROB71 M. Robinson, "The Dependence of Radiation Effects on Primary Recoil Energy," *Radiation Induced Voids in Metals*, AEC Symp. Ser. 26, p. 397, US Atomic Energy Commission (1971).

APPENDIX D USING XSEX3 WITH MCNPX

D.1 INTRODUCTION

XSEX3 is the code which analyzes a history file produced by LAHET3 or MCNPX and generates double-differential particle-production cross sections for primary beam interactions. Cross-section plots may also be generated by creating a file to be plotted by MCNPX. It is necessary to execute either code in a specific mode, described below, to achieve the desired cross-section calculation.

The execution of XSEX3 assumes that the LAHET run was made using the option `N1COL=-1`. Under this option, the incident particle interacts directly in the specified material in which the source is located without any transport; the only possible outcomes are a nuclear interaction or no interaction. The procedure may be used to calculate double-differential particle-production cross sections from any of the interaction models in the code (Bertini, ISABEL, INCL, etc.); the procedure has no meaning if such a model is not allowed for the specified particle type at the specified energy.

D.2 INPUT FOR MCNPX

Since there is no way to avoid the MCNPX geometry input, the user should define a region containing the material for which the cross sections are desired and locate the source in that region. To avoid possible error, only one material should be defined. Note: With `N1COL=-1`, MCNPX will override the source specification and construct the source as a "pencil-beam" in the +z-direction as required by XSEX3. Other MCNPX options may be used to suppress either nuclear elastic or nonelastic reactions.

1. To create a HISTP file to be edited by XSEX3, include a `HISTP` card in the INP file.
2. Define a volume parallel beam source in the +z-direction (`VEC= 0 0 1`) which is completely contained inside a cell with the material for which the cross sections are to be calculated.
3. Specify the incident particle type and kinetic energy on the `SDEF` card.
4. Use *noact*`=1` (the 8th parameter) on the `LCA` card.

The user may wish to suppress nuclear elastic scattering in the calculation by using *ielas*=0 on the LCA card. An AWTAB card may need to be supplied if the target isotope has no mass in XSDIR; the value supplied is not used and is arbitrary.

As an example, the following is a sample MCNPX input for a cross-section calculation:

```
MCNPX standard cross-section generation format for XSEX3 use.
c -------------------------------------------------------------
c 1000 MeV protons on Sn121, an isotope not in MCNPX library,
c and for which no atomic weight is specified in XSDIR.
c Minimal geometric specification for this purpose.
c -------------------------------------------------------------
c Cell - only one, spherical, radius arbitrary
c -------------------------------------------------------------
1  1  -1.0  -1
2  0         1

c -------------------------------------------------------------
c Surface - one sphere, radius arbitrary
c -------------------------------------------------------------
1  so     50.0

c -------------------------------------------------------------
c Materials
c -------------------------------------------------------------
m1     50121  1       $ not in MCNPX libraries
awtab  50121  119.864 $ need value, but arbitrary
c -------------------------------------------------------------
c Source - 0 radius beam, +z-direction, 1 GeV proton
c -------------------------------------------------------------
sdef erg = 1000 par = 9 dir = 1 pos = 0 0 0 rad = 0.0 vec = 0 0 1
c -------------------------------------------------------------
c Options - no elastic, Bertini, energy balancing
c -------------------------------------------------------------
lca   0  6j -1
lea   2j  0
c -------------------------------------------------------------
c History file - "histp" required
c -------------------------------------------------------------
histp
c -------------------------------------------------------------
c Tallies - none
c -------------------------------------------------------------
imp:h 1 0
phys:h 1000
mode h
```

```
print
nps 1000
prdmp 2j -1
```

D.3 INPUT FOR XSEX3

The input file for XSEX (default name INXS) has the following structure:

1. Two records of title information, 80 columns each;
2. An option control record (list-directed format); and
3. Additional records as required by the chosen options (list-directed format).

Multiple cases may be processed; for each case the above input structure applies. When multiple cases are processed, input quantities default to the preceding case. If the title records of the second and subsequent cases contain "/", the record must begin with a "\$".

The option control record has the structure:

nerg, nang, fnorm, kplot, imom, iyield, ltest

Table D-1. Option Control Record Parameters for XSEX3

Input Parameter	Meaning
nerg	Defines the number of energy or momentum bins for which cross sections will be calculated. For *nerg*>0, an energy (momentum) boundary record is required. For *nerg*=0, only energy-integrated cross sections will be generated. (DEFAULT=0)
nang	Defines the number of cosine bins for which cross sections will be calculated. For *nang* not equal to 0, a angular boundary record is required. For *nang*=0, only angle-integrated cross sections will be generated. Positive values of *nang* indicate cosine bin boundaries will be defined; negative values indicate angle bin boundaries (in degrees) will be specified. (DEFAULT=0)
fnorm	An overall multiplicative normalization factor to be applied to all cross sections. To convert to millibarns, use *fnorm*=1000; to obtain macroscopic cross sections, use an atom density. (DEFAULT=1.0)
kplot	A plot control flag. Any nonzero value will cause the output to be written to a file XSTAL in the format of an MCNPX MCTAL file for subsequent plotting. (See below.) (DEFAULT=0)

Input Parameter	Meaning
imom	Chooses energy or momentum to be used in cross-section definition. If *imom*=0, cross sections are tabulated by energy (MeV) and differential cross sections are calculated per unit energy (per MeV). If *imom* not equal 0, cross sections are tabulated by momentum (MeV/c) and differential cross sections are estimated per unit momentum (per MeV/c).
iyield	Not equal to 0 estimates differential yields (or multiplicities) for nonelastic and elastic reactions rather than cross sections. The integral over energy and angle for each particle type will be the multiplicity per nonelastic reaction (or unity for the elastic scattering of the incident particle if it is included in the calculation).
ltest	Not equal to 0 suppresses date and timing on the conventional output file (OUTXS). The parameter *ltest* is used to produce output for comparison during MCNPX installation and should not be used generally. (DEFAULT=0)

At most two additional records may be required, depending on the values specified for *nerg* and *nang*.

For *nerg*>0, a record is required to define *nerg* upper energy bin boundaries, from low to high, defined as the array ERGB(*i*),*i*=1,*nerg*. The first lower bin boundary is implicitly always 0.0. The definition may be done in four different ways:

1. The energy boundary array may be fully entered as ERGB(i),i=1,nerg, in increasing order.
2. If two or more, but less than *nerg*, elements are given (with the record terminated by a slash), the array is completed using the spacing between energy boundaries obtained from the last two entries.
3. If only one entry is given, it is used as the first upper energy boundary and also as a constant spacing between all the boundaries.
4. If only two entries are given with the first negative and the second positive, the second entry is used as the uppermost energy boundary, ERGB(*nerg*), and the first entry is interpreted as the lethargy spacing between bin boundaries. Thus the record "-0.1,800." will specify ten equal-lethargy bins per decade from 800 MeV down.

For *nang*>0, a record is required to define the *nang* upper cosine bin boundaries. They should be entered from low to high, with the last upper boundary equal to 1.0; the lower limit of the first bin is always -1.0. If a null record is present (only a "/"), then the range (-1, +1) is divided into *nang* equal intervals.

For *nang*<0, a record is required to define the |*nang*| lower degree bin boundaries. They should be entered from low to high, with the last lower boundary equal to 0.0; the upper limit of the first bin is always 180 degrees. If a null record is present (only a "/"), then the range (180, 0) is divided into |*nang*| equal intervals.

D.4 EXECUTING XSEX3

An input file and a history file are the only required input files. The default filename for the input is INXS, the default filename for the output is OUTXS, and the default filename for the history file is HISTP. A value of *kplot*≠0 will result in the creation of a MCTAL-format plot file, with default name XSTAL. These filenames may be changed by file replacement. The most general execute line has the following format:

```
XSEX3 INXS=... OUTXS=... HISTP=... XSTAL=...
```

D.5 PLOTTING OUTPUT FROM XSEX3

The source code for XSEX3 contains a plotting package using the LANL Common Graphics System; the latter is not generally available outside of Los Alamos National Laboratory. A new feature has been added for this release whereby a nonzero value for the input quantity *kplot* will cause the writing of a file XSTAL in the format of an MCNPX MCTAL file. Plotting of XSTAL is performed by MCNPX, using the execution option

```
mcnpx z
```

followed by the required instructions

```
rmctal xstal
nonorm
```

The latter is essential since the data are normalized in XSEX3.

Each "case" in XSEX3 is expanded in the XSTAL file for each particle type produced. The tallies are identified by the numbering scheme

100(case number) + (particle type),

the latter defined in the table below. The last in the sequence corresponds to the elastic scattering distribution of the incident particle.

When plotting XSEX3 output, the appropriate y-axis labels are "barns/MeV/steradian," barns/MeV," or "barns/steradian." If the "yield" (multiplicity) option was used in XSEX3, the appropriate y-axis labels are "particles/MeV/steradian," etc. The energy axis may be either "energy (MeV)" or "momentum (MeV/c)" according to the XSEX3 option employed.

Table D-2

Type	Particle
1	proton
2	neutron
3	pi^+
4	pi^0
5	pi^-
6	deuteron
7	triton
8	He-3
9	alpha
10	photon (prompt gamma from residual)
11	K^+
12	K (all neutrals)
13	K^-
14	antiproton
15	antineutron
16	elastic scattered projectile

An example of a COMOUT file produced when plotting XSTAL follows:

```
rmctal xstala
nonorm
tally 101 free e loglog xlims 0.1 1000. ytitle "protons/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "protons/steradian" file
tally 102 free e loglog xlims 0.1 1000. ytitle "neutrons/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "neutrons/steradian" file
tally 103 free e loglog xlims 0.1 1000. ytitle "pi+/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "pi+/steradian" file
tally 104 free e loglog xlims 0.1 1000. ytitle "pi0/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "pi0/steradian" file
tally 105 free e loglog xlims 0.1 1000. ytitle "pi-/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "pi-/steradian" file
tally 106 free e loglog xlims 0.1 1000. ytitle "deuterons/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "deuterons/steradian" file
tally 107 free e loglog xlims 0.1 1000. ytitle "tritons/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "tritons/steradian" file
tally 108 free e loglog xlims 0.1 1000. ytitle "He-3/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "He-3/steradian" file
tally 109 free e loglog xlims 0.1 1000. ytitle "alphas/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "alphas/steradian" file
```

```
tally 110 free e loglog xlims 0.1 100. ytitle "photons/MeV" file
free c linlog xlims -1.0 +1.0 ytitle "photons/steradian" file
end
```

APPENDIX E EXAMPLES

E.1 EXAMPLE 1: NEUTRON PRODUCTION FROM A SPALLATION TARGET

One of the fundamental quantities of interest in most spallation target applications is the number of neutrons produced per beam particle incident on target. For targets fed by proton accelerators, this quantity is typically denoted as "n/p". Here, we demonstrate how one goes about calculating this quantity for a simple target geometry using MCNPX.

The geometry consists of a simple right circular cylinder of lead, 10 cm in diameter by 30 cm long. A beam of 1-GeV protons is launched onto the target. The beam has a 7-cm-diameter spot size, with a parabolic spatial profile. (See Figure E-1.)

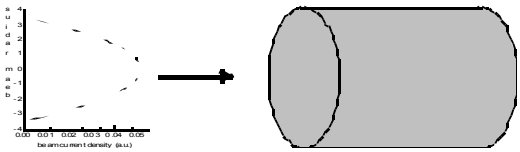


Figure E-1. Neutron production from a spallation target.

In MCNPX, net neutron production is tallied implicitly and is provided by default in the problem summary for neutrons. The problem summary shows net neutron production resulting from nuclear interactions (the component that accounts for neutron production by all particles transported using INC/Preequilibrium/Evaporation physics) and net production by (*n,xn*) reactions (neutrons created in inelastic nuclear interactions by neutrons below the transition energy, using evaluated nuclear data). Net production from nuclear interactions is given by the difference of the neutron weights in the "neutron creation" and "neutron loss" columns. A similar approach is taken to calculate net (*n,xn*) production. Net neutron production may also be calculated by realizing that the only loss mechanisms for neutrons are escape and capture. The sum of the weights in the "neutron loss" column under "escape" and "capture" is thus equal to the net neutron production. The values listed in the problem summary are "collision estimators," meaning they are tallied when a collision occurs during transport. Uncertainties are not calculated by MCNPX for these collision-estimated quantities. A reasonable upper limit on the relative uncertainty would be given by the inverse square root of the number of source particles launched.

APPENDIX E

We provide here four different variations for the calculation of net neutron production for this simple target geometry. In the "base case," we transport protons, neutrons, and charged pions. The transition energy between LAHET physics and neutron transport using tabular nuclear data is set to the default (`-1`), which means that "mix and match" (Section 5.3.3) will be turned on and the ENDF/B-VI.6 neutron libraries are used. All protons are transported using LAHET physics. Nucleon and pion interactions simulated by LAHET physics use the Bertini intranuclear cascade model. Variations from this base case are outlined in Table E-1 below. For each case, 20,000 source protons were transported.

Table E-1. Neutron Problem Summaries

Case	INC Model	Particles transported	Neutron transition energy (MeV)	Proton transition energy (MeV)
base	**Bertini**	**N H /**	**n/a**	**n/a**
1	**Bertini**	**N H / D T S A**	**n/a**	**n/a**
2	**ISABEL**	**N H /**	**n/a**	**n/a**
3	**CEM**	**N H /**	**n/a**	**n/a**
4	**INCL**	**N H /**	**n/a**	**n/a**

For the sake of brevity, we reproduce here just the neutron problem summaries from the MCNPX output decks.

Base Case

```
sample problem: spallation target
c     neutron production with Bertini physics
c     EJ Pitcher, 1 Nov 99
c     MR James, 31 Oct 2007
c
c     --- cell cards ---
c
c     Pb target
     1 1 -11.4   1 -2 -3
c     bounding sphere
     2 0         (-1:2:3) -4
c     outside universe
     3 0         4

c     --- surface cards ---
c
     1   pz  0.0
     2   pz 30.0
     3   cz  5.0
```

```
     4   so 90.0

c      --- material cards ---
c
c      Material #1: Pb without Pb-204
m1     82206 0.255 82207 0.221 82208 0.524 nlib=.66c hlib=.24h
c
c      --- data cards ---
mode        n  h /
imp:n,h,/   1 1r 0
phys:n    1000. j   j
phys:h    1000. j   j
lca          j  j   j
nps       20000
prdmp        j  -30  j  1
c
c     --- source definition ---
c     1-GeV proton beam, 7-cm-diam, parabolic spatial profile
sdef   sur 1 erg 1000. dir 1 vec 0. 0. 1. rad d1 pos 0. 0. 0. par 9
si1  a   0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
         1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7
         2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5
sp1      0.00000 0.09992 0.19935 0.29780 0.39478 0.48980 0.58237
         0.67200 0.75820 0.84049 0.91837 0.99135 1.05894 1.12065
         1.17600 1.22449 1.26563 1.29894 1.32392 1.34008 1.34694
         1.34400 1.33078 1.30678 1.27151 1.22449 1.16522 1.09322
         1.00800 0.90906 0.79592 0.66808 0.52506 0.36637 0.19151
         0.00000
```

For the base case, the neutron problem summary follows:

sample problem: spallation target probid = 10/30/07 11:31:34

neutron creation	tracks	weight (per source particle)	energy (per source particle)	neutron loss	tracks	weight (per source particle)	energy (per source particle)
source	0	0.	0.	escape	364341	1.8201E+01	2.1900E+02
nucl. interaction	307817	1.5391E+01	3.1854E+02	energy cutoff	0	0.	0.
particle decay	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	0.	0.	weight cutoff	0	0.	0.
energy importance	0	0.	0.	energy 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.	9.8178E+00
photonuclear	0	0.	0.	capture	0	1.4132E-02	7.6061E-02
(n,xn)	78140	3.9032E+00	1.8858E+01	loss to (n,xn)	25209	1.2588E+00	4.9005E+01
prompt fission	0	0.	0.	loss to fission	0	0.	0.
delayed fission	0	0.	0.	nucl. interaction	3657	1.8285E-01	6.1401E+01
				particle decay	0	0.	0.
tabular boundary	0	0.	0.	tabular boundary	0	0.	0.
tabular sampling	7250	3.6250E-01	1.9059E+00				
total	393207	1.9657E+01	3.3930E+02	total	393207	1.9657E+01	3.3930E+02

```
 number of neutrons banked                 367998       average time of (shakes)             cutoffs
 neutron tracks per source particle    1.9660E+01         escape           5.7601E+00          tco   1.0000E+34
 neutron collisions per source particle 2.7673E+01        capture          4.5556E-01          eco   0.0000E+00
 total neutron collisions                  553453         capture or escape 5.7560E+00         wc1  -5.0000E-01
 net multiplication            0.0000E+00 0.0000         any termination   5.3344E+00         wc2  -2.5000E-01
```

The two methods for calculating total neutron production give the following results:

net nuclear interactions + net (*n,xn*) + tabular sampling:

(15.391 - 0.1829) + (3.9032 - 1.2588) + 0.3625 = 18.215 n/p

escapes + captures:

18.201 + 0.014132 = 18.215 n/p

Both methods give the same answer. Since "escapes + captures" is easier to calculate, this is the method typically used. A reasonable upper limit on the relative uncertainty of n/p is ($20{,}000^{-1/2}$) ~0.7%.

Case 1

In the first variation, we transport not only nucleons (denoted by the symbols `N` and `H` on the `MODE` card) and charged pions (`/`), but also light ions (deuterons, tritons, ^{3}He, and alphas, denoted by `D`, `T`, `S`, and `A`, respectively). The only differences between the two input decks are the following two cards:

Base Case:
```
MODE        N  H /
IMP:N,H,/  1 1R 0
```

Case 1:
```
MODE        N  H / D T S A
IMP:N,H,/,D,T,S,A   1 1R 0
```

Note that nuclear interactions by light ions are simulated using the ISABEL INC model. The problem summary for this case is shown below:

```
     sample problem: spallation target                                    probid =   10/30/07 11:49:18

 neutron creation       tracks   weight       energy          neutron loss           tracks   weight       energy
                                 (per source particle)                                      (per source particle)

 source                      0    0.           0.              escape              366229    1.8295E+01    2.1797E+02
 nucl. interaction      309414    1.5471E+01   3.1914E+02      energy cutoff            0    0.            0.
 particle decay              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    0.           0.              weight cutoff            0    0.            0.
 energy importance           0    0.           0.              energy 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.            9.8066E+00
 photonuclear                0    0.           0.              capture                  0    1.4317E-02    7.6812E-02
 (n,xn)                  78886    3.9405E+00   1.9279E+01      loss to (n,xn)       25427    1.2697E+00    4.9547E+01
 prompt fission              0    0.           0.              loss to fission          0    0.            0.
 delayed fission             0    0.           0.              nucl. interaction     3759    1.8795E-01    6.2861E+01
                                                               particle decay           0    0.            0.
 tabular boundary            1    5.0000E-05   7.4566E-03      tabular boundary         1    5.0000E-05    7.4566E-03
 tabular sampling         7115    3.5575E-01   1.8470E+00
     total               395416    1.9767E+01   3.4027E+02          total           395416    1.9767E+01    3.4027E+02
```

```
 number of neutrons banked                 369989       average time of (shakes)             cutoffs
 neutron tracks per source particle    1.9771E+01         escape           5.7398E+00          tco   1.0000E+34
 neutron collisions per source particle 2.7872E+01        capture          4.6829E-01          eco   0.0000E+00
 total neutron collisions                  557431         capture or escape 5.7357E+00         wc1  -5.0000E-01
 net multiplication            0.0000E+00 0.0000         any termination   5.3133E+00         wc2  -2.5000E-01
```

Net neutron production for this case is 18.309 n/p, or 0.5% above the base case value. Examination of the net nuclear interactions and net (*n,xn*) figures show very similar results to the base case. The implication of this result is that we need not concern ourselves with light ion transport if the quantity with which we are concerned is related solely to neutrons, as neutron production by light ions is small when we start with a proton beam.

Case 2

In the second variation, we replace the Bertini INC model used in the base case for the simulation of nucleon and pion interactions with nuclei by the ISABEL INC model (in this example, both INC models utilize the same GCCI level-density model). We invoke the ISABEL INC model by including in the input deck the following card:

Base Case:	`LCA  J J J`
Case 2:	`LCA  J J 2`

This changes the value of the variable *`iexisa`* (third value on the `LCA` card) from its default value of 1 to 2. The neutron problem summary for this case follows:

```
     sample problem: spallation target                                    probid =   10/30/07 11:58:15

neutron creation       tracks   weight        energy          neutron loss          tracks   weight        energy
                                (per source particle)                                       (per source particle)

source                      0    0.            0.            escape              351437    1.7556E+01    2.2173E+02
nucl. interaction      294554    1.4728E+01    3.2360E+02    energy cutoff            0    0.            0.
particle decay              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    0.            0.            weight cutoff            0    0.            0.
energy importance           0    0.            0.            energy 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.            9.2619E+00
photonuclear                0    0.            0.            capture                  0    1.3867E-02    7.4376E-02
(n,xn)                  78013    3.8969E+00    1.8914E+01    loss to (n,xn)       24990    1.2479E+00    4.9221E+01
prompt fission              0    0.            0.            loss to fission          0    0.            0.
delayed fission             0    0.            0.            nucl. interaction     3812    1.9060E-01    6.4269E+01
                                                             particle decay           0    0.            0.
tabular boundary            0    0.            0.            tabular boundary         0    0.            0.
tabular sampling         7672    3.8360E-01    2.0437E+00
    total               380239    1.9008E+01    3.4455E+02        total           380239    1.9008E+01    3.4455E+02

  number of neutrons banked                 355249       average time of (shakes)             cutoffs
  neutron tracks per source particle    1.9012E+01         escape           5.7589E+00          tco   1.0000E+34
  neutron collisions per source particle 2.6739E+01        capture          4.8810E-01          eco   0.0000E+00
  total neutron collisions                  534777         capture or escape 5.7548E+00         wc1  -5.0000E-01
  net multiplication            0.0000E+00 0.0000         any termination   5.3199E+00         wc2  -2.5000E-01
```

Note the net neutron production calculated with the ISABEL INC model is 17.570 n/p, which is 3.5% below the value predicted by the Bertini INC model. This is consistent with

other studies that reveal slightly lower neutron production resulting from ISABEL as compared to Bertini.

Case 3

In this variation, we use the CEM model for neutron, protons and pions. CEM is turned on by setting the 9th entry of the `LCA` card to `1`:

```
Base Case:    LCA   J  J  J
Case 3:       LCA   8J 1
```

Note that CEM, unkike the other INC models in the code, has its own evaporation model (GEM). Therefore, the pre-equilibrium (MPM) model and evaporation model settings have no effect when CEM is specified.

The neutron summary table for this case is shown below:

```
     sample problem: spallation target                                  probid =   10/30/07 12:40:42

 neutron creation       tracks   weight       energy           neutron loss          tracks   weight       energy
                                 (per source particle)                                       (per source particle)

 source                      0    0.           0.               escape             382821    1.9124E+01    2.1568E+02
 nucl. interaction      331976    1.6599E+01   3.2155E+02       energy cutoff           0    0.            0.
 particle decay              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    0.           0.               weight cutoff           0    0.            0.
 energy importance           0    0.           0.               energy 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.            1.1687E+01
 photonuclear                0    0.           0.               capture                 0    1.4850E-02    8.3446E-02
 (n,xn)                  75130    3.7524E+00   1.6630E+01       loss to (n,xn)      25401    1.2683E+00    4.4639E+01
 prompt fission              0    0.           0.               loss to fission         0    0.            0.
 delayed fission             0    0.           0.               nucl. interaction    3625    1.8125E-01    6.7289E+01
                                                                 particle decay          0    0.            0.
 tabular boundary            1    5.0000E-05   7.4726E-03       tabular boundary        1    5.0000E-05    7.4726E-03
 tabular sampling         4741    2.3705E-01   1.1995E+00
     total               411848    2.0588E+01   3.3939E+02           total           411848    2.0588E+01    3.3939E+02

   number of neutrons banked                  386447       average time of (shakes)             cutoffs
   neutron tracks per source particle     2.0592E+01         escape            5.4389E+00         tco   1.0000E+34
   neutron collisions per source particle 2.9144E+01         capture           4.3054E-01         eco   0.0000E+00
   total neutron collisions                   582874         capture or escape 5.4350E+00         wc1  -5.0000E-01
   net multiplication              0.0000E+00 0.0000         any termination   5.0529E+00         wc2  -2.5000E-01
```

Note the net neutron production calculated with the CEM model is 19.139 n/p, which is 5.1% above the value predicted by the Bertini INC model.

Case 4

In the final variation from the base case we use the INCL model coupled with the ABLA evaporation mode:

```
Base Case:    LCA     J J J
Case 4:       LCA     8J  2
```

Note: The ABLA evaporation model is automatically chosen when INCL is specified.

The neutron problem summary for this case is shown below:

```
     sample problem: spallation target                                  probid =   10/30/07 12:48:41

neutron creation       tracks   weight        energy          neutron loss          tracks   weight        energy
                                (per source particle)                                       (per source particle)

source                      0    0.            0.              escape              335209    1.6746E+01    2.2548E+02
nucl. interaction      274416    1.3721E+01    3.2427E+02      energy cutoff            0    0.            0.
particle decay              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    0.            0.              weight cutoff            0    0.            0.
energy importance           0    0.            0.              energy 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.            9.3519E+00
photonuclear                0    0.            0.              capture                  0    1.2728E-02    6.8055E-02
(n,xn)                  81574    4.0754E+00    2.1016E+01      loss to (n,xn)       25346    1.2659E+00    5.2944E+01
prompt fission              0    0.            0.              loss to fission          0    0.            0.
delayed fission             0    0.            0.              nucl. interaction     3705    1.8525E-01    5.9496E+01
                                                               particle decay           0    0.            0.
tabular boundary            3    1.5000E-04    2.2488E-02      tabular boundary         3    1.5000E-04    2.2488E-02
tabular sampling         8270    4.1350E-01    2.0471E+00
    total              364263    1.8210E+01    3.4736E+02          total           364263    1.8210E+01    3.4736E+02

  number of neutrons banked                338917       average time of (shakes)              cutoffs
  neutron tracks per source particle    1.8213E+01        escape            5.4190E+00          tco   1.0000E+34
  neutron collisions per source particle 2.5282E+01       capture           4.6701E-01          eco   0.0000E+00
  total neutron collisions                 505634         capture or escape 5.4152E+00          wc1  -5.0000E-01
  net multiplication             0.0000E+00 0.0000        any termination   4.9843E+00          wc2  -2.5000E-01
```

Net neutron production for this case is 16.759 n/p, 8% less than the base case value.

Summary

Results compiled for each case of this example are shown in Table E-2. Runtimes were obtained using MCNPX 2.6.0 on a 3.2 GHz PC running Windows XP. Note the runtime for the case where the ISABEL INC model is used is about 10% greater than the base case using the Bertini model. Case 2 also runs slower because more particles are tracked and the light ion interactions are provided by the ISABEL model. The CEM model runs comparably to Bertini in this case. The INCL model has a significant speed penalty, almost a factor of 10.

Table E-2. Results Compiled for Summary Cases

Case	Variation from base case	Runtime (minutes)	n/p
base	**n/a**	**3.69**	**18.215**
1	**light ion transport & nuclear interaction**	**4.28**	**18.309**
2	**ISABEL INC for nucleons and pions**	**4.02**	**17.570**

3	**CEM INC for nucleons and pions**	**3.72**	**19.139**
4	**INCL INC for nucleons and pions; ABLA evaporation model**	**35.89**	**16.759**

This example demonstrates how to calculate neutron production from a spallation target. When the quantity of interest depends only on neutrons and one starts with a proton beam, there is no need to transport any particles other than protons, neutrons, and charged pions, as neutron production by other particles is negligible compared to production by these three particle types[7]. Use of the various physics model options, such as the ISABEL, CEM, and INCL modules, within MCNPX is encouraged—this provides the user with the ability to test the sensitivity of the quantity of interest to the different physics models. If significant differences are observed, the user should evaluate which physics model is most appropriate for his or her particular application. For example, total neutron production from actinide targets is known to be more accurate if the multi-step preequilibrium model (MPM) is turned off, which is not the default setting.

E.2 EXAMPLE 2: BEAM SOURCES

An additional feature has been added through the specification of a general transformation on the SDEF card in one of two forms; TR=*n* or TR=D*n*. In either case a general transformation is applied to a source particle *after* its coordinates and direction cosines have been determined using the other parameters on the SDEF card. Particle coordinates are modified by both rotation and translation; direction cosines are modified by rotation only. This allows the user to rotate the direction of the beam or move the entire beam of particles in space. The TR=D*n* card is particularly powerful because it allows the specification of more than one beam at a time.

An example of specifying a Gaussian beam follows:

```
Title
c Cell cards
.
.
.
ccc  0     -nnn     $ cookie cutter cell

c Surface Cards
.
.
.
nnn  SQ   a^-2  b^-2  0  0  0  0  -c^2  0  0  0    $ cookie cutter surface
```

[7] All particles should be included for energy deposition calculations, as discussed in Section 5.6.1.1.

```
c Control Cards
SDEF     DIR=1  VEC=0 0 1  X=D1 Y=D2 Z=0  CCC=ccc  TR=n
SP1      -41  fx  0
SP2      -41  fy  0
TRn       x0 y0 z0   cosϕ -sinϕ 0   sinϕ cosϕ 0   0 0 1
```

The SDEF card sets up an initial beam of particles traveling along the z-axis (DIR=1, VEC=0 0 1). Information on the x- and y-coordinates of particle position is detailed in the two SP cards. (On the SDEF card, the specifications X=D1 and Y=D2 indicate that MCNPX must look for distributions 1 and 2, here given by source probability distributions, SP1 and SP2.) The z-coordinate is left unchanged (Z=0).

Because there is no PAR option in this example, the particle generated by this source will be the one with the lowest IPT number in Table 4-1 (i.e., neutron).

The SP cards have three entries. The first entry is -41, which indicates sampling is to be done from a built-in Gaussian distribution. (Note: Although the function -41 is a Gaussian only in time in MCNP, the function has been modified to handle a Gaussian in position for MCNPX.) This position Gaussian distribution has the following density function:

$$p(x',y') = \left(\exp - \frac{1}{2}\left(\left(\frac{x'}{a}\right)^2 + \left(\frac{y'}{b}\right)^2 \right) \right) \Big/ \left(2\pi ab \left(1 - \exp \frac{\left(-c^2\right)}{2} \right) \right)$$

The parameters a and b are the standard deviations of the Gaussian in x and y.

The second entry (f_x or f_y) on the SP cards is the full-width at half-maximum (FWHM) of the Gaussian in either the x- or y-direction. These must be computed from a and b by the user as follows:

$$\mathrm{f_x} = (8\ln 2)^{\frac{1}{2}}\,\mathrm{a} = 2.35482\mathrm{a}$$

$$\mathrm{f_y} = (8\ln 2)^{\frac{1}{2}}\,\mathrm{b} = 2.35482\mathrm{b}$$

The third entry on the SP cards represents the centroid of the Gaussian in either the x- or y-direction. We recommend that the user input 0 here, and handle any transformations of the source with a TR card as described below. Using a non-zero value will interfere with the rejection function as specified by the "cookie cutter" option.

Note, that in print table 10 in the MCNPX output file, the definitions of a, b, and c are different from those discussed above; however, FWHM will be the same as the 3rd entry on the SP cards. The parameter 'a' in Table 10 differs from the parameter 'a'

above by a factor of the square root of two. This is a legacy item from the conversion of the -41 function from time to space, and will be corrected in a future version.

The user generally does not want the beam Gaussian to extend infinitely in x and y, therefore a cookie cutter option has been included to keep the distribution to a reasonable size. CCC=*ccc* tells MCNPX to look at the card labeled *ccc* (*ccc* is a user-specified cell number) to define the cutoff volume. The first entry on the *ccc* card is 0, which indicates a void cell. The second number, -*nnn* (*nnn* again is a user specified number), indicates a surface card within which to accept particles. In the example, this is a SQ surface (a 2-sheet hyperboloid) that is defined as follows:

$$\left(\frac{x'}{a}\right)^2 + \left(\frac{y'}{b}\right)^2 \le c^2$$

Any particle generated within this cell is accepted; any outside of the cell is rejected. Any well defined surface may be selected, and it is common to use a simple cylinder to represent the extent of a beampipe.

In this example, a source is generated in an (x',y')-coordinate system with the distribution centered at the origin and the particles traveling in the z′-direction. The particle coordinates can be modified to an (x,y)-coordinate system by translation and rotation according to the following equations, where $0 \le \phi_L \le \pi$:

$$x = x' \sin\phi_L - y' \cos\phi_L + x_0$$
$$y = x's \cos\phi_L + y' \sin\phi_L + y_0$$

Thus the angle ϕ_L is the angle of rotation of the major axis of the source distribution from the positive y-direction in the laboratory coordinate system. If $\cos\phi_L = 0.0$, the angle is 90° and the major axis lies along the x-axis. The TR*n* card in the example above implements this rotation matrix, however the user is warned that ϕ_L in the TR*n* card is equal to $\phi_L - \frac{\pi}{2}$.

E.3 DEFINING MULTIPLE BEAMS

The opportunity to specify a probability distribution of transformations on the SDEF card allows the formation of multiple beams which differ only in orientation and intensity. This feature may have applications in radiography or in the distribution of point sources of arbitrary intensity.

The use of a distribution of transformations is invoked by specifying TR=D*n* on the SDEF card. The cards SI, SP, and, optionally, SB are used as specified for the SSR card, which is discussed in Section 5.5.6.

SI*n* L i_1 ... i_k
SP*n* *option* p_1 ... p_k
SB*n* *option* b_1 ... b_k

The L option on the SI card is required; new input checking has been implemented to ensure this usage for both the SDEF and SSR applications. The "*option*" on the SP and SB cards may be blank, D, or C. The values i_1 ... i_k identify *k* transformations which must be supplied. The content of the SP and SB cards then follows the general MCNPX rules.

The following example shows a case of three intersecting Gaussian parallel beams, each defined with the parameters *a*=0.2 cm, *b*=0.1 cm and *c*=2 in the notation previously discussed. For each, the beam is normal to the plane of definition.

Beam 1 is centered at (0,0,-2). The major axis of the beam distribution is along the x-axis. The beam is emitted in the +z-direction and has relative intensity 1.

Beam 2 is centered at (-2,0,0). The major axis of the beam distribution is along the y-axis. The beam is emitted in the +x-direction and has relative intensity 2.

Beam 3 is centered at (0,-2,0). The major axis of the beam distribution is along the line defined by x=z. The beam is emitted in the +y-direction and has relative intensity 3.

The card SB*n* is used to provide equal sampling from each of the three beams, independent of the relative intensities. The input cards are as follows:

```
Title
c Cell cards
.
.
.
999  0       -999 $ cookie cutter cell

c Surface Cards
.
.
.
999  SQ   25 100 0 0 0 0 -4 0 0 0     $ cookie cutter surface

c Control Cards
SDEF    DIR=1  VEC=0 0 1  X=D1  Y=D2  Z=0  CCC=999  TR=D3
SP1     -41 .4709640
SP2     -41.23584820
SI3    L 1 2 3
SP3      1 2 3
```

```
SB3      1 1 1
TR1      0  0 -2 1     0 0     0     1  0     0 0 1
TR2     -2  0  0 0     1 0     0     0  1     1 0 0
TR3      0 -2  0 0.707 0 0.707 0.707 0 -0.707 0 1 0
```

E.4 LIGHT ION RECOIL (RECL)

MCNPX can produce and track ions created by elastic recoil from neutrons or protons. Neutrons and protons undergoing elastic scatter with light nuclei (H, D, T, ^{3}He, and ^{4}He) can create ions (protons, deuterons, tritons, ^{3}He, and α) that are banked for subsequent transport.

Figure E-2 shows the energy-angle production of alphas created from 15-MeV neutrons striking ^{4}He. Note that in the forward bin, cosine $0.8<\mu<1$, the α energy goes up to the theoretical maximum of 9.6 MeV. The theoretical maxima in the other cosine bins (0.8, 0.6, 0.4, and 0.2) are 6.144, 3.456, 1.536, and 0.384.

The input file for this example is as follows.

```
Test of light ion recoil
1  1 1e-5 -1
2  0       1

1 so 1.e-5

mode n a
imp:n,a 1 0
phys:n 6j 1
sdef erg=15
print -161 -162
tmp1 1e-20 0
fcl:n 1 0
m1 2004 .2
cut:a j 0
nps 1000000
f51:a 1
e51 .1 100log 20
c51 -.8 8i 1 t
fq51 e c
```

The plot commands to produce Fig. E-2 are presented in the following plot command file.

```
rmct lir.m tal 51 xlim .1 15 loglog &
title 1 "Light Ion Recoil: 15 MeV Neutrons on 4He" &
title 2 "Alpha Energy vs Cosine" &
fix c 11 label 1 "cos total" cop fix c 6 label 2 "cos -1-.2" &
cop fix c 7 label 3 "cos .2-.4" cop fix c 8 label 4 "cos .4-.6" &
cop fix c 9 label 5 "cos .6-.8" cop fix c 10 label 6 "cos .8-1."
```

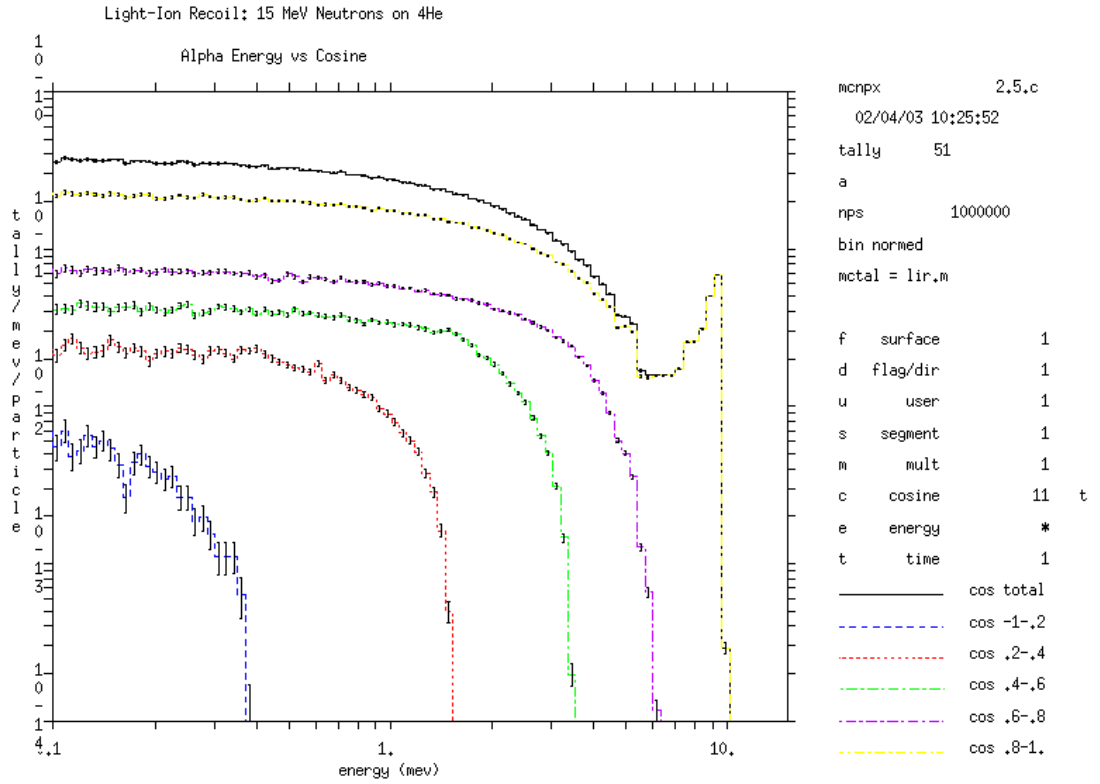


Figure E-2. Light ion recoil.

E.5 MIX-AND-MATCH NUCLIDE REPLACEMENT

Consider a neutron problem with deuterium and tritium. The available deuterium library goes up to 150 MeV, but the tritium library goes up to only 20 MeV. Previously, either neutron physics models above 20 MeV (neglecting the deuterium table data up to 150 MeV) or nuclear data tables below 150 MeV (using the 20-MeV tritium data throughout the entire 20- to 150-MeV range) had to be used. With the mix-and-match capability, deuterium uses tables up to 150 MeV and uses physics models above 150 MeV; tritium uses data tables up to 20 MeV and uses physics models above 20 MeV.

Figure E-3 shows an example of the energy-matching capability. The 100-MeV neutrons are incident on an 8.433-cm-long, 3.932-cm-radius BGO crystal. The crystal contains 21% bismuth, 16% germanium, and 63% oxygen. Assume no germanium libraries are available. The solid line represents flux in the crystal with the full mix-and-match

capability, which uses all libraries up to their energy limits and physics models above those limits and for germanium. The dashed-line calculation uses the old method of substituting arsenic for the missing germanium library, using the libraries up to 20 MeV and using physics models above. The dotted line uses bismuth and oxygen libraries up to their limits of 150 MeV; the arsenic library is used up to its limit of 20 MeV, and then the 20-MeV data are used from 20 to 150 MeV; above 150 MeV, physics models are used for all three nuclides. This last option is least desirable but often was used in past code versions to take advantage of the 150-MeV libraries, even though many data libraries go only to 20 MeV.

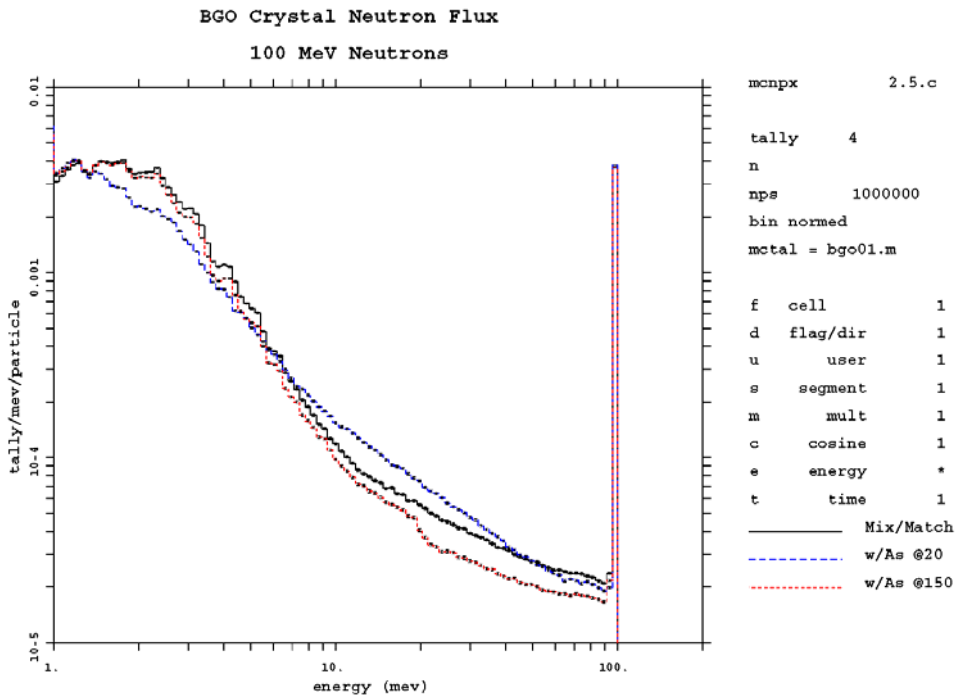


Figure E-3. Comparison of different germanium library and model options.

E.6 INLINE GENERATION OF DOUBLE DIFFERENTIAL CROSS SECTIONS AND RESIDUAL NUCLEI

The double differential cross sections and distributions of residual nuclei for a single nuclear interaction thus may be calculated directly in MCNPX. Tallying of the residual nuclei is discussed in the `FT8 RES` tally description (see Section 5.6.17). Tallying of the differential cross section can be done with standard `F1` surface tallies, as shown in the

following example. The input file models a 1.2-GeV proton source having a single collision with ^{208}Pb.

```
Test of p(1.2GeV)+Pb(208)
1 1 -11. -1 imp:h 1
2 0        1 imp:h 0

1 so .01

mode h n
sdef par h erg=1200 vec 0 0 1 dir 1
m1 82208 1
phys:h 1300 j 0
phys:n 1300 3j 0
nps 10000
fc1  *** neutron angle spectra tally ***
f1:n  1
ft1  frv 0 0 1
fq1 e c
*c1 167.5 9i 17.5 0 T
e1 1 50log 1300 T
lca   2 1 1 23 1 1 0 -2 0
```

The differential cross section for neutron production is tallied in the `F1` current tally with energy and time bins. This tally is simply the neutrons that are created from the single proton collision with lead and then escape. These data may be plotted with MCNPX using the tally plotter and then following execute line command

```
MCNPX     Z   ,
```

where the command file, COM91, is

```
rmctal=mctl91
file all loglog xlim 1 1300 ylim 1e-6 1 &
fix c 13 cop fix c 1 cop fix c 6 cop fix c 12
```

In Fig. E-4, the first line (solid black) is the energy spectrum over all angles, the second (blue dashed) is the 180° output, the third (red dotted) is the 90° output, and the fourth (green broken) is the 0° output.

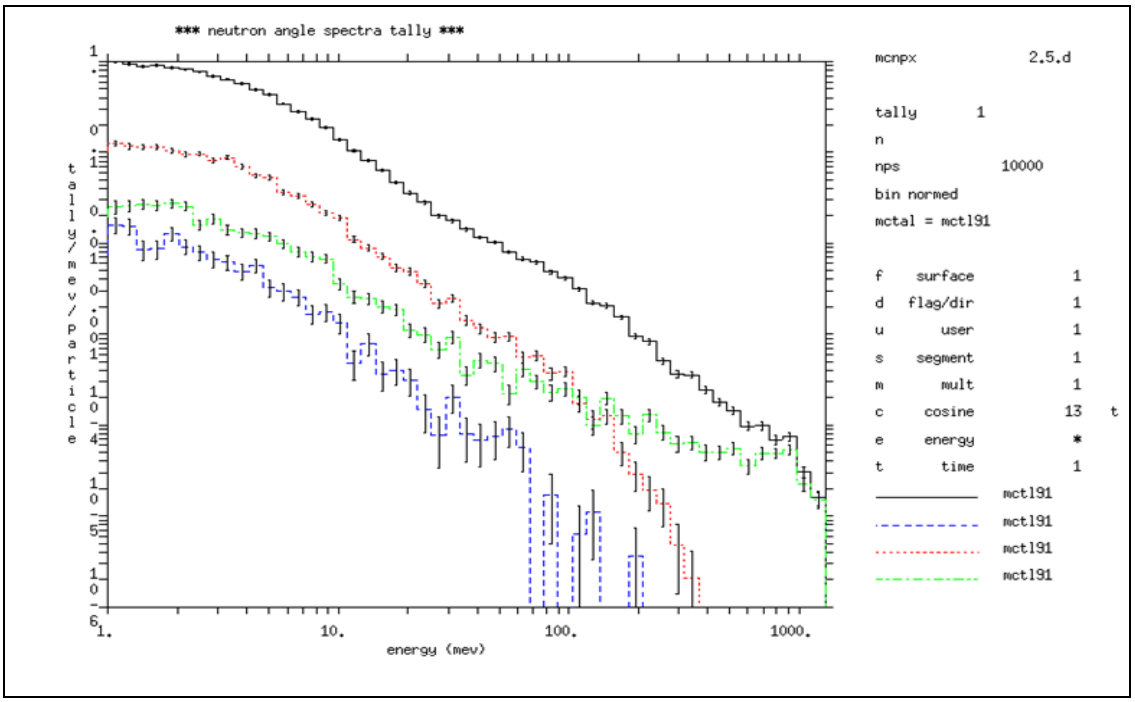


Figure E-4. Differential cross sections at all angles, 180°, 90°, 0°, for 1.3-GeV protons on $^{208}_{82}Pb$.

E.7 FISSION MULTIPLICITY OUTPUT

Multiplicity and moments are printed in `print table 117` for both spontaneous and spontaneous plus induced fissions.

spontaneous fission source multiplicity and moments. print table 117

	by number			by weight			
	fission fissions	multiplicity neutrons	fraction	fission fissions	multiplicity neutrons	fraction	error
nu = 0	697	0	6.97000E-02	3.24005E-02	0.00000E+00	6.97000E-02	0.0373
nu = 1	2295	2295	2.29500E-01	1.06685E-01	1.06685E-01	2.29500E-01	0.0197
nu = 2	3261	6522	3.26100E-01	1.51590E-01	3.03180E-01	3.26100E-01	0.0161
nu = 3	2518	7554	2.51800E-01	1.17051E-01	3.51153E-01	2.51800E-01	0.0187
nu = 4	1025	4100	1.02500E-01	4.76478E-02	1.90591E-01	1.02500E-01	0.0305
nu = 5	183	915	1.83000E-02	8.50688E-03	4.25344E-02	1.83000E-02	0.0736
nu = 6	21	126	2.10000E-03	9.76199E-04	5.85720E-03	2.10000E-03	0.2181
total	10000	21512	1.00000E+00	4.64857E-01	1.00000E+00	1.00000E+00	0.0073

```
  factorial moments            by number              by weight

          nu                2.15120E+00 0.0054      2.15120E+00 0.0054
      nu(nu-1)/2!           1.91100E+00 0.0116      1.91100E+00 0.0116
   nu(nu-1)(nu-2)/3!        8.86800E-01 0.0219      8.86800E-01 0.0219
nu(nu-1) .... (nu-3)/4!     2.25500E-01 0.0439      2.25500E-01 0.0439
nu(nu-1) .... (nu-4)/5!     3.09000E-02 0.0987      3.09000E-02 0.0987
nu(nu-1) .... (nu-5)/6!     2.10000E-03 0.2180      2.10000E-03 0.2180


spontaneous and induced fission multiplicity and moments.              print table 117

       ------ by number -----------  ---------------- by weight ----------------------
              fission  multiplicity                    fission   multiplicity
      fissions neutrons    fraction      fissions      neutrons      fraction    error

nu =  0    700      0   6.90949E-02   3.25400E-02   0.00000E+00   6.90949E-02   0.0372
nu =  1   2301   2301   2.27125E-01   1.06964E-01   1.06964E-01   2.27125E-01   0.0197
nu =  2   3286   6572   3.24351E-01   1.52752E-01   3.05504E-01   3.24351E-01   0.0161
nu =  3   2558   7674   2.52492E-01   1.18910E-01   3.56731E-01   2.52492E-01   0.0186
nu =  4   1059   4236   1.04531E-01   4.92283E-02   1.96913E-01   1.04531E-01   0.0300
nu =  5    205   1025   2.02349E-02   9.52956E-03   4.76478E-02   2.02349E-02   0.0695
nu =  6     22    132   2.17155E-03   1.02269E-03   6.13611E-03   2.17155E-03   0.2131

  total  10131  21940   1.00000E+00   4.70946E-01   1.01990E+00   1.00000E+00   0.0072


  factorial moments            by number              by weight

          nu                2.16563E+00 0.0054      2.16563E+00 0.0054
      nu(nu-1)/2!           1.94393E+00 0.0115      1.94393E+00 0.0115
   nu(nu-1)(nu-2)/3!        9.16395E-01 0.0216      9.16395E-01 0.0216
nu(nu-1) .... (nu-3)/4!     2.38279E-01 0.0426      2.38279E-01 0.0426
nu(nu-1) .... (nu-4)/5!     3.32642E-02 0.0932      3.32642E-02 0.0932
nu(nu-1) .... (nu-5)/6!     2.17155E-03 0.2130      2.17155E-03 0.2130
```

In the above problem, there were 10000 source histories; all were spontaneous fissions. There were 21512 spontaneous fission neutrons produced. The number of source particles and the source weight listed in the problem summary table for neutrons is also 21512 and 2.1512E+00. Also, from the problem summary table for neutrons, there were 131 induced fissions, producing 428 fission neutrons.

In the second `print table 117`, there are 10000+131=10131 fissions. There are 21512+428=21940 fission neutrons. For nu=0, the multiplicity fraction is 700/10131=0.0690949. The total multiplicity fraction always sums to 1. By-weight

fissions sum to 10131/21512=0.470946. By-weight fission neutrons sum to 21940/21512=1.01990.

The by-weight multiplicity fractions are the same as the by-number multiplicity fractions because analog capture is used in this problem and the entire source is spontaneous fission.

If `SDEF PAR=-SF` is used, the tallies, summary information, and some entries in `print table 117` are normalized by source history. By-weight fissions is 10131/10000 =1.01310 instead of 0.470946. By-weight fission neutrons is 2.19400 instead of 1.01990. The by-weight multiplicity fractions are divided by the total fission weight, 10131.0, to sum to unity.

The first moment is
nu = 21940/10131=2.16563.

The second moment is
(2×1/2!×3286+3×2/2!×2558+4×3/2!×1059+5×4/2!×205+6×5/2!×22)/10131=1.94393.

The third moment is
(3×2×1/3!×2558+4×3×2/3!×1059+5×4×3/3!×205+6×5×4/3!×22)/10131=0.916395.

The fourth moment is
(4×3×2×1/4!×1059+5×4×3×2/4!×205+6×5×4×3/4!×22)/10131=0.238279.

The fifth moment is
(5×4×3×2×1/5!×205+6×5×4×3×2/5!× 2)/10131=0.0332642.

The sixth moment is
6×5×4×3×2×1/6!×22/10131=0.00217155.

E.8 CAPTURE TALLIES

E.8.1 Interpreting Capture Tally Output

The `FT8 CAP` coincidence capture tally option produces both a standard tally, which is generally unreadable, and a coincidence capture table, `print table 118`. An example is provided to help in the interpretation of this table:

```
neutron captures, moments & multiplicity distributions. tally 8         print table 118

 cell:    999

 neutron captures on 3he
                     captures      captures    multiplicity fractions
        histories   by number     by weight    by number    by weight   error
```

```
captures =  0     700       0   0.00000E+00  7.00000E-02  3.25400E-02  0.0364
captures =  1    2285    2285   1.06220E-01  2.28500E-01  1.06220E-01  0.0184
captures =  2    3223    6446   2.99647E-01  3.22300E-01  1.49823E-01  0.0145
captures =  3    2489    7467   3.47109E-01  2.48900E-01  1.15703E-01  0.0174
captures =  4    1022    4088   1.90033E-01  1.02200E-01  4.75084E-02  0.0296
captures =  5     209    1045   4.85775E-02  2.09000E-02  9.71551E-03  0.0684
captures =  6      51     306   1.42246E-02  5.10000E-03  2.37077E-03  0.1397
captures =  7      12      84   3.90480E-03  1.20000E-03  5.57828E-04  0.2885
captures >  7       9      73   3.39345E-03  9.00000E-04  4.18371E-04  0.3332

   total        10000   21794   1.01311E+00  1.00000E+00  4.64857E-01  0.0056

     factorial moments              by number               by weight

           3he                 2.17940E+00 0.0056      1.01311E+00 0.0056
      3he(3he-1)/2!            2.01890E+00 0.0128      9.38499E-01 0.0128
   3he(3he-1)(3he-2)/3!        1.06390E+00 0.0291      4.94561E-01 0.0291
3he(3he-1) .... (3he-3)/4!     3.93800E-01 0.0744      1.83061E-01 0.0744
3he(3he-1) .... (3he-4)/5!     1.34100E-01 0.1636      6.23373E-02 0.1636
3he(3he-1) .... (3he-5)/6!     4.43000E-02 0.2666      2.05932E-02 0.2666
3he(3he-1) .... (3he-6)/7!     1.12000E-02 0.3808      5.20640E-03 0.3808
3he(3he-1) .... (3he-7)/8!     1.70000E-03 0.5548      7.90257E-04 0.5548
```

The capture tally input for this problem was

```
F8:n      999                  input F8 card
FT8 CAP    -8    -8    2003    input FT8 CAP card
```

Note that the line "`captures > 7 9 73`" indicates that nine histories had eight or more neutrons captured. This implies that 8 histories had 8×8=64 neutrons captured and 1 history had 1×9 neutrons captured, for a total of 73 neutrons captured. The table of captures evidently was too short, and the problem should have been run with `FT8 CAP -9 -9` or even more captures and moments. Not specifying enough capture rows affects only the captures >7 lines and the error estimate on the totals capture line; all other information is correct as if more captures and moments were listed.

As an interpretation of the neutron captures on the 3he table, Column 1 is the number of histories according to the number of captures by the designated material (2003=3he) in the designated cell (999). This number sums to the total number of source histories for the problem, nps=10000.

Column 2 is the number of captures by 2003 in cell 999=21794. Because analog capture is the default for `F8` tallies, the total weight captured is also 21794.

Column 3 is the total weight captured divided by the tally normalization. For `SDEF PAR=-SF`, the tally normalization is the number of source histories = number of spontaneous fissions = 10000. For `SDEF PAR=-SF`, column 3 would be 21794.0/10000=

2.17940. In this problem, SDEF PAR=SF, and the tally normalization is the source particles = spontaneous fission neutrons = 21512. Thus, captures by weight are 21794.0/21512=1.01311.

Column 4 is the multiplicity fraction by number, which is Column 1 divided by the number of source histories. The total is always 1.00000.

Column 5 is the multiplicity fraction by weight, which is the weight of histories undergoing capture divided by the tally normalization. For SDEF PAR=-SF, this fraction would be 10000.0/10000=1.00000. In this problem, SDEF PAR=SF and the multiplicity fraction by weight is 10000.0/21512=0.464857.

The interpretation of the factorial moments table now follows.

The first moment by number is the number of captures divided by the number of source histories=21794/10000=2.17940.

The first moment by weight is the total weight of capture divided by the tally normalization. For SDEF PAR=-SF, this moment would be 21794.0/10000=21794.0. In this problem, SDEF PAR=SF and the first moment by weight is 21794.0/21512=1.01311.

The second moment is N × (N-1)/2, where N is the number of captures. In this problem,

N	N × (N-1)/2		histories		product
1	0	×	2285	=	0
2	1	×	3223	=	3223
3	3	×	2489	=	7467
4	6	×	1022	=	6132
5	10	×	209	=	2090
6	15	×	51	=	765
7	21	×	12	=	252
8	28	×	8	=	224
9	36	×	1	=	36
sum				=	20189

and the second moment by number is divided by the number of histories,

20189 / 10000 = 2.01890 .

Because of analog capture, the second moment weight is 20189.0. The second moment by weight is divided by the tally normalization. For SDEF PAR=-SF, this moment would be 20189.0/10000=2.01890, which is the same as the second moment by number. In this problem, SDEF PAR=SF, and the second moment by weight is

20189.0 / 21512 = 0.938499 .

The seventh moment is

$7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1/7!$	=	1	×	12	=	12
$8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2/7!$	=	8	×	8	=	64
$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3/7!$	=	36	×	1	=	36
sum					=	112

thus, 112/10000=0.0112 .

The eighth moment is

$8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1/8!$	=	1	×	8	=	8
$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2/8!$	=	9	×	1	=	9
sum					=	17

thus, 17/10000=0.0017 .

And the ninth moment is

$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1/9!$	=	1	×	1	=	1

thus, 1/10000=0.0001 .

E.8.2 FT8 Capture Tallies with Time Gating

The coincidence capture tally optionally allows specification of predelay and gate width [SWI04] with the "GATE" keyword on the FT8 card. The "GATE" keyword may appear anywhere after the "CAP" keyword and is part of the "CAP" command. Immediately following, the "GATE" keyword must be the predelay time and the total gate width, both in units of shakes (1.0e-8 s).

The addition of the predelay and time gate width changes the capture tally scoring. When a neutron is captured at time t_0 in the specified cell by the specified nuclide (22 and ^{3}He = 2003 in all three tallies below), the gate is "turned on." If the predelay is t_1 and the gate width is t_2, then all captures between $t_0 + t_1$ and $t_0 + t_1 + t_2$ are counted. For a history with no captures, no events are scored. With one capture, 0 events are scored. With two captures, the first turns on the time gate are at time t_0 and scores 0; the second will score one event if it is captured between $t_0 + t_1$ and $t_0 + t_1 + t_2$ or score another 0 if outside the gate.

Other entries after the "CAP" keyword may be placed in any order, as shown in the following examples. The negative entries change the allowed number of captures and moments (defaults 21 and 12 are changed to 40 and 40 in F78 below). The list of capture nuclides (^{3}He = 2003 in all three tallies below) also may be placed anywhere after "CAP."

Examples for three capture tallies now follow. The capture tally without gating (F18) is shown for reference. An infinite gate (F38) results in a very different print table 118: the number of captures is the same, but the moments are offset by one. A finite gate (F78) has fewer captures, as expected.

Example 1: Capture Tally without Gate

Input:

```
f18:n 22
ft18 cap 2003
```

Output:

```
1 neutron captures, moments and multiplicity distributions.  tally  18              print table 118

 weight normalization by source histories =          20000

 cell:    22

 neutron captures on 3he
                       captures    captures       multiplicity fractions
           histories  by number   by weight     by number     by weight    error

 captures =  0  13448       0    0.00000E+00   6.72400E-01   6.72400E-01   0.0049
 captures =  1   5550    5550    2.77500E-01   2.77500E-01   2.77500E-01   0.0114
 captures =  2    588    1176    5.88000E-02   2.94000E-02   2.94000E-02   0.0406
 captures =  3    238     714    3.57000E-02   1.19000E-02   1.19000E-02   0.0644
 captures =  4     94     376    1.88000E-02   4.70000E-03   4.70000E-03   0.1029
 captures =  5     40     200    1.00000E-02   2.00000E-03   2.00000E-03   0.1580
 captures =  6     26     156    7.80000E-03   1.30000E-03   1.30000E-03   0.1960
 captures =  7      8      56    2.80000E-03   4.00000E-04   4.00000E-04   0.3535
 captures =  8      5      40    2.00000E-03   2.50000E-04   2.50000E-04   0.4472
 captures =  9      1       9    4.50000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 12      1      12    6.00000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 16      1      16    8.00000E-04   5.00000E-05   5.00000E-05   1.0000

    total       20000    8305    4.15250E-01   1.00000E+00   1.00000E+00   0.0128

      factorial moments              by number              by weight

            3he                4.15250E-01 0.0128     4.15250E-01 0.0128
       3he(3he-1)/2!           1.59300E-01 0.0651     1.59300E-01 0.0651
    3he(3he-1)(3he-2)/3!       1.47900E-01 0.2165     1.47900E-01 0.2165
  3he(3he-1) .... (3he-3)/4!   1.87750E-01 0.5063     1.87750E-01 0.5063
  3he(3he-1) .... (3he-4)/5!   2.96500E-01 0.7493     2.96500E-01 0.7493
  3he(3he-1) .... (3he-5)/6!   4.61900E-01 0.8727     4.61900E-01 0.8727
  3he(3he-1) .... (3he-6)/7!   6.15800E-01 0.9311     6.15800E-01 0.9311
  3he(3he-1) .... (3he-7)/8!   6.68950E-01 0.9626     6.68950E-01 0.9626
  3he(3he-1) .... (3he-8)/9!   5.83050E-01 0.9812     5.83050E-01 0.9812
  3he(3he-1) .... (3he-9)/10!  4.03700E-01 0.9918     4.03700E-01 0.9918
  3he(3he-1) .... (3he-10)/11! 2.19000E-01 0.9972     2.19000E-01 0.9972
  3he(3he-1) .... (3he-11)/12! 9.10500E-02 0.9994     9.10500E-02 0.9994
```

Example 2: Infinite Gate

Input:

```
f38:n 22
ft38 cap 2003 gate 0 1e11
```

Output:

```
1 neutron captures, moments and multiplicity distributions.  tally  38              print table 118

 weight normalization by source histories =          20000

 cell:    22

 neutron captures on 3he

 time gate:  predelay =  0.0000E+00     gate width =  1.0000E+11

     pulses         occurrences  occurrences          pulse fraction
    in gate histogram by number    by weight     by number     by weight    error

 captures =  0   6552       0    0.00000E+00   3.27600E-01   3.27600E-01   0.0101
 captures =  1   1002    1002    5.01000E-02   5.01000E-02   5.01000E-02   0.0308
 captures =  2    414     828    4.14000E-02   2.07000E-02   2.07000E-02   0.0486
 captures =  3    176     528    2.64000E-02   8.80000E-03   8.80000E-03   0.0750
 captures =  4     82     328    1.64000E-02   4.10000E-03   4.10000E-03   0.1102
 captures =  5     42     210    1.05000E-02   2.10000E-03   2.10000E-03   0.1541
 captures =  6     16      96    4.80000E-03   8.00000E-04   8.00000E-04   0.2499
 captures =  7      8      56    2.80000E-03   4.00000E-04   4.00000E-04   0.3535
 captures =  8      3      24    1.20000E-03   1.50000E-04   1.50000E-04   0.5773
 captures =  9      2      18    9.00000E-04   1.00000E-04   1.00000E-04   0.7071
 captures = 10      2      20    1.00000E-03   1.00000E-04   1.00000E-04   0.7071
 captures = 11      2      22    1.10000E-03   1.00000E-04   1.00000E-04   0.7071
 captures = 12      1      12    6.00000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 13      1      13    6.50000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 14      1      14    7.00000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 15      1      15    7.50000E-04   5.00000E-05   5.00000E-05   1.0000

    total        8305    3186    1.59300E-01   4.15250E-01   4.15250E-01   0.0291

      factorial moments              by number              by weight

             n                1.59300E-01 0.0651      1.59300E-01 0.0648
          n(n-1)/2!           1.47900E-01 0.2165      1.47900E-01 0.2165
        n(n-1)(n-2)/3!        1.87750E-01 0.5063      1.87750E-01 0.5062
    n(n-1)(n-2) ... (n-3)/4!  2.96500E-01 0.7493      2.96500E-01 0.7492
    n(n-1)(n-2) ... (n-4)/5!  4.61900E-01 0.8727      4.61900E-01 0.8726
    n(n-1)(n-2) ... (n-5)/6!  6.15800E-01 0.9311      6.15800E-01 0.9311
    n(n-1)(n-2) ... (n-6)/7!  6.68950E-01 0.9626      6.68950E-01 0.9626
    n(n-1)(n-2) ... (n-7)/8!  5.83050E-01 0.9812      5.83050E-01 0.9812
    n(n-1)(n-2) ... (n-8)/9!  4.03700E-01 0.9918      4.03700E-01 0.9918
    n(n-1)(n-2) ... (n-9)/10! 2.19000E-01 0.9972      2.19000E-01 0.9972
    n(n-1)(n-2) ... (n-10)/11! 9.10500E-02 0.9994     9.10500E-02 0.9994
    n(n-1)(n-2) ... (n-11)/12! 2.80000E-02 1.0000     2.80000E-02 1.0000
```

Example 3: Finite Gate

Input:

```
f78:n 22
ft78 cap gate .5 .4 -40 -40 2003
```

Output:

```
1 neutron captures, moments and multiplicity distributions.  tally  78              print table 118

 weight normalization by source histories =          20000

 cell:    22

 neutron captures on 3he

 time gate:  predelay =  5.0000E-01     gate width =  4.0000E-01

     pulses         occurrences  occurrences           pulse fraction
    in gate histogram by number    by weight     by number     by weight    error

 captures =  0   7837      0     0.00000E+00   3.91850E-01   3.91850E-01   0.0118
 captures =  1    394     394    1.97000E-02   1.97000E-02   1.97000E-02   0.0666
 captures =  2     67     134    6.70000E-03   3.35000E-03   3.35000E-03   0.1542
 captures =  3      6      18    9.00000E-04   3.00000E-04   3.00000E-04   0.4082
 captures =  4      1       4    2.00000E-04   5.00000E-05   5.00000E-05   1.0000

  total          8305     550    2.75000E-02   4.15250E-01   4.15250E-01   0.0624

     factorial moments              by number               by weight

              n                2.75000E-02 0.0717      2.75000E-02 0.0716
          n(n-1)/2!            4.55000E-03 0.1654      4.55000E-03 0.1654
        n(n-1)(n-2)/3!         5.00000E-04 0.4690      5.00000E-04 0.4690
    n(n-1)(n-2) ... (n-3)/4!   5.00000E-05 1.0000      5.00000E-05 1.0000
```

Scratch space is needed to save capture times during the course of a history. The times are stored temporarily in the capture and moment bins of the tally. If sufficient bins are unavailable, then the number of allowed captures and moments must be increased using the negative entries after the "CAP" keyword. The message "*** warning *** dimension overflow. Some pulses not counted." is put in print table 118 if the space needs to be increased.

E.9 RESIDUAL NUCLEI TALLY: FT8 RES

The following input file models a 1.2-GeV proton source having a single collision with ^{208}Pb.

```
Test of p(1.2GeV)+Pb(208)
1 1 -11. -1 imp:h 1
2 0        1 imp:h 0

1 so .01

mode h n
sdef par h erg=1200 vec 0 0 1 dir 1
m1 82208 1
phys:h 1300 j 0
phys:n 1300 3j 0
nps 10000
f8:h 1
ft8 res 1 99
fq8 u e
lca   2 1 1 23 1 1 0 -2 0
```

These data are plotted in Fig. E-5, with MCNPX using the tally plotter and the execute line command

```
MCNPX Z   ,
```

where the command file, COM91, is

```
rmctal=mctl91
tally 8 free u xlim 81189 8120 ylim .0001 .01   .
```

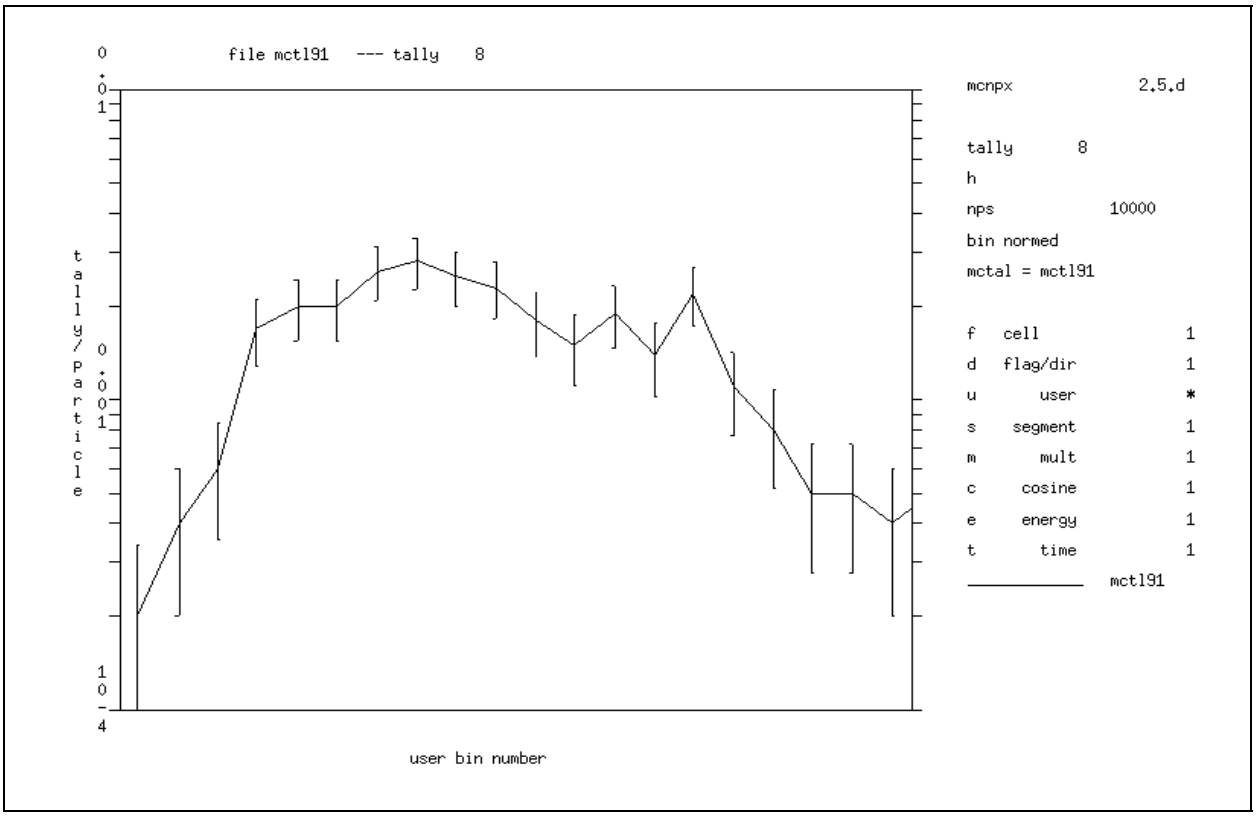


Figure E-5. Residuals for 81Tl isotopes 189 to 201 from 1.3-GeV protons on $^{208}_{82}$Pb .

E.10 BURNING MULTIPLE MATERIALS IN A REPEATED STRUCTURE WITH SPECIFIED CONCENTRATION CHANGES

In the following example, a 4×4 fuel pin array (created using repeated structures) is burned while material concentration changes are made at various time steps. Portions of the input and output files are provided below to illustrate various BURN card features;:

```
burn example
1   1  6.87812e-2  -1          u=2  imp:n=1 vol=192.287 $ fuel
3   2  4.5854e-2    1 -2       u=2  imp:n=1 vol=66.43   $ clad
4   3  7.1594e-2    2          u=2  imp:n=1 vol=370.82  $ water
6   4  6.87812e-2  -1          u=3  imp:n=1 vol=192.287 $ fuel
7   5  4.5854e-2    1 -2       u=3  imp:n=1 vol=66.43   $ clad
8   6  7.1594e-2       2       u=3  imp:n=1 vol=370.82  $ water
10  0              -3  4 -5  6 u=1  imp:n=1 lat=1 fill=0:1 0:1 0:0
                                    2 3 2 3
...
```

```
...
BURN  TIME=50,10,500
      MAT=1 4
      POWER=1.0
      PFRAC=1.0 0 0.2
      OMIT= 1,8,6014,7016,8018,9018,90234,91232,95240,95244
            4,8,6014,7016,8018,9018,90234,91232,95240,95244
      BOPT= 1.0, -4
      AFMIN= 1e-32
      MATVOL= 384.57 384.57
      MATMOD= 2
              1
                1  -4  1  94238 1e-6
              2
                2  -1  2  94238 1e-6  94241 1e-6
                   -4  1  94238 1e-6
...
```

A 4×4 lattice contains universes 2 and 3, which are both repeated twice in the lattice. Universe 2 comprises cells 1, 3, and 4, where cell 1 contains material 1; universe 3 comprises cells 6, 7, and 8, where cell 6 contains material 4. The MAT keyword specifies that both materials 1 and 4 will be burned. The combination of the TIME, POWER and PFRAC keywords specify that these materials will be burned first for 50 days at 100% of 1 MW, then decayed for 10 days, and then finally burned for 500 days at 20% of 1 MW.

The BOPT keyword specifies that the following options will be invoked: the Q-value multiplier will be set to a value of 1.0, only Tier 1 fission products will be included, the output will be ordered by ZAID and printed at the end of each KCODE run, and only tabular transport cross sections will be used. Because tabular transport cross sections do not exist for every isotope that is generated, an OMIT card is required to omit these isotopes from the transport process. The transmutation of these isotopes is accounted for by sending a 63-group flux from MCNPX to be matched to a 63-group cross-section set within CINDER90. These are energy integrated to determine a total collision rate. The OMIT card in the example omits eight isotopes from material 1 and eight isotopes from material 4. The AFMIN card states that only isotopes possessing an atom fraction below 1e-32 will be omitted from the transport calculation.

Because repeated structures exist in the example, a MATVOL keyword is required to calculate the track-length-estimated reaction rates in each repeated structure. Because material 1 and 4 are repeated twice and each material possesses a volume of 192.287 cm^3, MATVOL keyword entries of 384.57 (192.287×2) were required for each material being burned.

A MATMOD keyword is used to manually change the concentration of certain isotopes at specified time steps. In this example, manual isotope concentration changes are to be completed at two time steps. At time step 1, material 4 will have the atom density of isotope 94238 changed to 1e-6 atoms/b-cm. At time step 2, the atom densities of isotopes 94238 and 94241 in material 1 both will be revised to 1e-6 atoms/b-cm. Also in step 2, the atom density of isotope 94238 in material 4 will be set to 1e-6 atoms/b-cm.

Print table 210 contains the burnup summary table:

```
1burnup summary table by material                                        print table 210


 neutronics and burnup data

 step  duration     time      power      keff      flux     ave. nu  ave. q     burnup     source
        (days)     (days)     (MW)                                              (GWd/MTU)  (nts/sec)
   0  0.000E+00  0.000E+00  1.000E+00  1.54021  7.715E+14    2.452   200.979  0.000E+00  7.616E+16
   1  5.000E+01  5.000E+01  1.000E+00  1.50987  7.945E+14    2.473   201.411  7.183E+00  7.664E+16
   2  1.000E+01  6.000E+01  0.000E+00  1.51150  0.000E+00    2.474   201.448  7.183E+00  0.000E+00
   3  5.000E+02  5.600E+02  2.000E-01  1.43413  1.699E+14    2.510   202.199  2.155E+01  1.550E+16
...
```

The burnup summary table contains information regarding the entire burn system. Each time step is listed with the corresponding time duration and actual specified time. Next listed is the power for used for the flux normalization, k_{eff}, energy integrated system averaged flux, system averaged neutrons per fission and recoverable energy per fission, and burnup. Finally, the production rate is listed in the source column.

Since both materials 1 and 4 were burned in the example, individual burn material burnup information is also available. The available information includes: time step, time duration, actual time, fission power fraction, and individual material burnup:

```
Individual Material Burnup

 Material #:    1

 step  duration     time    power fraction    burnup
        (days)     (days)                    (GWd/MTU)
   0  0.000E+00  0.000E+00    5.015E-01      0.000E+00
   1  5.000E+01  5.000E+01    5.016E-01      7.205E+00
   2  1.000E+01  6.000E+01    5.002E-01      7.205E+00
   3  5.000E+02  5.600E+02    5.002E-01      2.158E+01

 Material #:    4

 step  duration     time    power fraction    burnup
        (days)     (days)                    (GWd/MTU)
   0  0.000E+00  0.000E+00    4.985E-01      0.000E+00
   1  5.000E+01  5.000E+01    4.984E-01      7.161E+00
   2  1.000E+01  6.000E+01    4.998E-01      7.161E+00
   3  5.000E+02  5.600E+02    4.998E-01      2.152E+01
...
```

The fission power fraction is calculated by taking the ratio of the fission power in a particular material to the sum of all burn materials. Fission power fractions are only related to fissions in burn materials.

$$power\ fraction = \frac{\left(\Phi\Sigma_f VQ\right)_i}{\sum_i \left(\Phi\Sigma_f VQ\right)_i}$$

The individual material burnup is calculated by

$$Burnup = Burnup_{previous\ step} + \frac{Power\ Level \times Power\ Fraction \times Time \times PFRAC}{MTU}$$

The time-dependant isotope buildup/depletion is listed after the burnup summary information. The isotope buildup/depletion for each individual material is given at each time step. The information is further subdivided into actinide and nonactinide categories:

```
nuclide data are sorted by increasing zaid for material   1 volume  3.8457E+02 (cm**3)

 actinide inventory for material   1 at end of step  0, time 0.000E+00 (days), power 1.000E+00 (MW)

  no. zaid      mass      activity   spec.act.  atom den.  atom fr.   mass fr.
                (gm)        (Ci)     (Ci/gm)    (a/b-cm)
   1  90231  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   2  90232  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   3  90233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   4  91233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   5  92234  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   6  92235  3.441E+02  0.000E+00  0.000E+00  2.293E-03  1.000E-01  9.886E-02
...
...
 actinide inventory for material   1 at end of step  1, time 5.000E+01 (days), power 1.000E+00 (MW)

  no. zaid      mass      activity   spec.act.  atom den.  atom fr.   mass fr.
                (gm)        (Ci)     (Ci/gm)    (a/b-cm)
   1  90231  1.286E-09  6.837E-04  5.315E+05  8.718E-15  3.832E-13  3.723E-13
   2  90232  2.394E-08  2.625E-15  1.097E-07  1.616E-13  7.100E-12  6.929E-12
   3  90233  1.235E-13  4.468E-06  3.618E+07  8.298E-19  3.647E-17  3.574E-17
   4  91233  1.345E-09  2.792E-05  2.075E+04  9.039E-15  3.973E-13  3.894E-13
...
```

At the end of each subdivision is an accumulation total of the isotope information for that subdivision. Atom and weight fractions calculations are based on the fractions of that specific subdivision.

```
...
     totals  3.455E+03  2.584E+05  7.479E+01  2.275E-02  1.000E+00  1.000E+00
...
...
 nonactinide inventory for material 1 at end of step  0, time 0.000E+00 (days), power 1.000E+00 (MW)

  no.  zaid     mass      activity   spec.act.  atom den.  atom fr.   mass fr.
                (gm)        (Ci)      (Ci/gm)   (a/b-cm)
   1   6012  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   2   6013  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   3   7014  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   4   7015  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   5   8016  4.684E+02  0.000E+00  0.000E+00  4.585E-02  1.000E+00  1.000E+00
...
```

After isotope information for each individual material is given, `print table 220` lists the total build/up of all actinides and nonactinides from all materials combined at each of the time steps.

```
...
1burnup summary table summed over all materials                                    print table 220

 nuclides with atom fractions below 1.000E-32 for a material are zeroed and deleted from print
tables after t=0

 nuclide data are sorted by increasing zaid summed over all materials volume  7.6914E+02 (cm**3)

 actinide inventory for sum of materials at end of step  0, time 0.000E+00 (days), power 1.000E+00
(MW)

  no.  zaid      mass     activity   spec.act.  atom den.   atom fr.   mass fr.
                (gm)        (Ci)      (Ci/gm)   (a/b-cm)
   1  90231  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   2  90232  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   3  90233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   4  91233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   5  92234  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   6  92235  6.883E+02  0.000E+00  0.000E+00  4.585E-03  1.000E-01  9.886E-02
...
```

E.11 REFERENCES

SWI04 M. T. Swinhoe, J. S. Hendricks, and D. R. Mayo, "MCNPX for Neutron Multiplicity Detector Simulation," Los Alamos National Laboratory report LA-UR-04-8025 (2004).

APPENDIX F DATA TABLE FORMATS

MCNPX has two *types* and ten *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, tables, and the basic data table formats are described in this appendix in the following sections:

F.1 DATA TYPES AND CLASSES

MCNPX reads ten *classes* of data from two *types* of data *tables*. A description of the two types of data tables follows:

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 than Type-2 tables. Few installations use Type-1 tables in MCNPX directly. Most generate Type-2 tables from Type-1 tables using the MAKXS code. (See Section F.9.)

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 and PC Windows platforms. Type-2 tables are used most because they are more compact and faster to read than Type-1 tables.

Data tables exist for ten *classes* of data: continuous-energy neutron, discrete-reaction neutron, continuous-energy photoatomic interaction, continuous-energy electron interaction, continuous-energy photonuclear interaction, neutron dosimetry, $S(\alpha,\beta)$ thermal, neutron multigroup, photoatomic multigroup, and continuous-energy proton. A

user should think of a data table as an entity that contains evaluation-dependent information about one of the ten *classes* of data for a specific target isotope, isomer, element, or material. For how the data are used in MCNPX, a user does not need to know whether a particular table is in Type-1 or Type-2 format. For any 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; MCNPX could read exclusively from individual data tables not in libraries.

F.2 XSDIR—DATA DIRECTORY FILE

MCNPX 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 sequential 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 following form:

DATAPATH=*datapath*

where the word DATAPATH (case insensitive) must start in columns 1–5. The equals 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 the following:

1. the current working directory,
2. the directory specified by the DATAPATH variable on the MCNPX execution line,
3. the directory specified by the DATAPATH variable in the INP file message block,
4. the DATAPATH environmental variable,
5. the DATAPATH provided in the XSDIR file,
6. the DATAPATH hardwired in the MCNPX source at complilation.

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 charged-particle stopping powers. If the atomic weight ratio is missing for any nuclide requested on an M (material) 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 7–11-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:

1.	Name of the Table	character*10
2.	Atomic Weight Ratio	real
3.	Filename	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 for the letter C, discrete-reaction neutron tables by D, dosimetry tables by Y, $S(\alpha,\beta)$ 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, multigroup photon tables by G, and continuous-energy proton tables by H. For the $S(\alpha,\beta)$ tables, the first six 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 the MCNPX theory manual (not yet released). This entry is used only for neutron tables.
3. Filename. The filename 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. This character word "`ptable`" indicates a continuous-energy neutron nuclide has unresolved resonance range probability tables.

F.3 DATA TABLES

The remainder of this appendix is designed for the user who wishes to know a great deal about how data are stored in data tables and in MCNPX. First we describe how to find a specific table on a Type-1 or Type-2 library. Then we document the detailed format of the various blocks of information for each *class* of data.

Three arrays are associated with each data table. The `NXS` array contains various counters and flags. The `JXS` array contains pointers. The `XSS` array contains all of the data. These arrays are the same regardless of the *type* of a specific table. The arrays are manipulated internally by MCNPX. Within a data table, the counter and pointer arrays are dimensioned to `NXS(16)` and `JXS(32)`. In MCNPX the same arrays are dimensioned to `NXS(16,IEX)` and `JXS(32,IEX)`, where `IEX` is the index of the particular table in the problem. There is no limit to the number of tables or their size other than available space on a particular computing platform.

To locate data for a specific table (external to MCNPX) it is necessary to extract several parameters associated with that table from the directory file XSDIR. The filename obviously indicates the name of the library in which the table is stored. Other important parameters from the viewpoint of this appendix are file type (`NTY`), address (`IRN`), table length (`ITL`), and number of entries per record (`NER`).

F.3.1 Locating Data on a Type-1 Table

Because Type-1 tables are 80-character card-image files, the XSDIR address IRN is the line number of the first record, i.e., the beginning of the table. The first 12 records (lines) contain miscellaneous information as well as the NXS and JXS arrays. The format follows:

Relative Address	Absolute Address	Contents	Format
1	IRN	HZ,AW(0),TZ,HD	A10,2E12.0,1X,A10
2	IRN+1	HK,HM	A70,A10
3–6	IRN+2	(IZ(I),AW(I),I=1,16)	4(I7,F11.0)
7–8	IRN+6	(NXS(I),I=1,16)	8I9
9–12	IRN+8	(JXS(I),I=1,32)	8I9

The variables are defined in Table F-1–Table F-3 for neutron, photon, dosimetry, and $S(\alpha,\beta)$ thermal libraries. These variables are defined in Table F-32 and Table F-33 for multigroup data.

The XSS array immediately follows the JXS array. All data from the XSS array are read into MCNPX with a 4E20.0 format. (When Type-1 tables are created, floating-point numbers are written in 1PE20.12 format and integers are written in I20 format.) The length of the XSS array is given by the table length, ITL, in the directory (also by NXS(1) in the table itself). The number of records required for the XSS array is (ITL+3)/4. A Type-1 library is shown in Figure F-1.

Figure F-1. Layout of a Type-1 library.

Starting Address (Line Number)	Number of Records	Contents
IRN1=1	12	misc. including NXS_1, JXS_1
IRN1+12	(ITL1+3)/4	XSS_1
IRN2	12	misc. including NXS_2, JXS_2
IRN2+12	(ITL2+3)/4	XSS_2
. . .	. . .	. . .
IRN_n	12	misc. including NXS_n, JXS_n
IRN_n+*12*	(ITL*n*+3)/4	XSS_n

IRN_i, ITL_i are the addresses and table lengths from XSDIR
n = number of tables contained on library

APPENDIX F

Table F-1. Definition of the NXS Array

NTY	1 or 2 Continuous-Energy or Discrete-Reaction Neutron	3 Dosimetry	4 Thermal	5 Continuous-Energy Photon
NXS(1)	Length of second block of data	Length of second block of data	Length of second block of data	Length of second block of data
NXS(2)	ZA=1000*Z+A	ZA=1000*Z+A	IDPNI=inelastic scattering mode	Z
NXS(3)	NES=number of energies		NIL=inelastic dimensioning parameter	NES=number of energies
NXS(4)	NTR=number of reactions excluding elastic	NTR=number of reactions	NIEB=number of inelastic exiting energies	NFLO=length of the fluorescence data divided by 4
NXS(5)	NR=number of reactions having secondary neutrons excluding elastic		IDPNC=elastic scattering mode	
NXS(6)	NTRP=number of photon production reactions		NCL=elastic dimensioning parameter	
NXS(7)			IFENG=secondary energy mode	
NXS(8)	NPCR=number of delayed neutron precursor families			
.....				
.....				
.....				
NXS(15)	NT=number of PIKMT reactions			
NXS(16)	0 = normal photon production −1 = do not produce photons			
Note that many variables are not used, allowing for expansion in the future.				

Table F-2. Definition of the JXS Array

NTY	1 or 2 Continuous-Energy or Discrete-Reaction Neutron	3 Dosimetry	4 Thermal	5 Continuous-Energy Photon
JXS(1)	ESZ=location of energy table	LONE=location of first word of table	ITIE=location of inelastic energy table	ESZG=location of energy table
JXS(2)	NU=location of fission nu data		ITIX=location of inelastic cross sections	JINC=location of incoherent form factors
JXS(3)	MTR=location of MT array	MTR=location of MT array	ITXE=location of inelastic energy/angle distributions	JCOH=location of coherent form factors
JXS(4)	LQR=location of Q-value array		ITCE=location of elastic energy table	JFLO=location of fluorescence data
JXS(5)	TYR=location of reaction type array		ITCX=location of elastic cross sections	LHNM=location of heating numbers
JXS(6)	LSIG=location of table of cross-section locators	LSIG=location of table of cross-section locators	ITCA=location of elastic angular distributions	
JXS(7)	SIG=location of cross sections	SIGD=location of cross sections		
JXS(8)	LAND=location of table of angular distribution locators			
JXS(9)	AND=location of angular distributions			
JXS(10)	LDLW=location of table of energy distribution locators			
JXS(11)	DLW=location of energy distributions			

NTY	1 or 2 Continuous-Energy or Discrete-Reaction Neutron	3 Dosimetry	4 Thermal	5 Continuous-Energy Photon
JXS(12)	GPD=location of photon production data			
JXS(13)	MTRP=location of photon production MT array			
JXS(14)	LSIGP=location of table of photon production cross-section locators			
JXS(15)	SIGP=location of photon production cross sections			
JXS(16)	LANDP=location of table of photon production angular distribution locators			
JXS(17)	ANDP=location of photon production angular distributions			
JXS(18)	LDLWP=location of table of photon production energy distribution locators			
JXS(19)	DLWP=location of photon production energy distributions			
JXS(20)	YP=location of table of yield multipliers			
JXS(21)	FIS=location of total fission cross section			
JXS(22)	END=location of last word of this table	END=location of last word of this table		
JXS(23)	LUNR=location of probability tables			

NTY	1 or 2 Continuous-Energy or Discrete-Reaction Neutron	3 Dosimetry	4 Thermal	5 Continuous-Energy Photon
JXS(24)	DNU=location of delayed nubar data			
JXS(25)	BDD=location of basic delayed data (λ's, probabilities)			
JXS(26)	DNEDL=location of table of energy distribution locators			
JXS(27)	DNED=location of energy distributions			
.....				
JXS(32)				
Note that many variables are not used, allowing for easy expansion in the future.				
All pointers in the JXS array refer to locations in the XSS array.				
JXS(1) always points to the first entry in the second block of data.				

Table F-3. Definition of Miscellaneous Variables on Data Tables

HZ—10 character name (ZAID) of table. The form of HZ is

ZZZAAA.abC	continuous-energy neutron
ZZZAAA.abD	discrete-reaction neutron
ZZZAAA.abY	dosimetry
XXXXXX.abT	thermal $S(\alpha,\beta)$
ZZZ000.abP	continuous-energy photon
ZZZ000.abM	neutron multigroup
ZZZ000.abG	photon multigroup
ZZZ000.abU	photonuclear
ZZZ000.abE	continuous-energy electron
ZZZ000.abH	proton

where ZZZ is the atomic number

AAA is the mass number

XXXXXX for thermal data is a Hollerith name or abbreviation of the material

nn is the evaluation identifier

AW(0)—atomic weight ratio; the atomic weight divided by the mass of a neutron

TZ—temperature at which the data were processed (in MeV)

HD—10-character date when data were processed

HK—70-character comment

HM—10-character MAT identifier

(IZ(I),AW(I),I=1,16)—16 pairs of ZZZAAAs and atomic weight ratios. In the past these were needed for photon tables but are now ignored. The IZ entries are still needed for thermal tables to indicate for which isotope(s) the scattering data are appropriate.

F.3.2 Locating Data on a Type-2 Table

A standard unformatted file consists of many records, each with NER entries, where NER is the number of entries per record defined on XSDIR. A Type-2 data table consists of one record that contains pointers, counters, and character information, followed by one or more records containing the XSS array.

The information contained in the first record for each table is the same as that contained in the first twelve lines of a Type-1 table described above. The variables, in order, are HZ, AW(0), TZ, HD, HK, HM, (IZ(I),AW(I),I=1,16), (NXS(I),I=1,16), (JXS(I),I=1,32). The variables are defined in Table F-1 through Table F-3. The variables HZ, HD, and HM are 10-character variables and HK is a 70-character variable. Floating-point variables may be double precision in some cases. The number of words contained in this "package" of information is therefore different for different computing systems. The remainder of the first record is empty. The next NREC records (NREC≥1) contain the XSS data array, with NREC=(ITL+NER~1)/NER, where ITL is the table length. A Type-2 library is shown in Figure F-2.

Figure F-2. Layout of a Type-2 library.

Address	Contents	
IRN_1 = 1	misc. including NXS_1, JXS_1	
2	XSS_1	$NER < ITL_1 \leq 2*NER$
3	XSS_1 (cont)	
IRN_2 = 4	misc. including NXS_2, JXS_2	
5	XSS_2	$ITL_2 \leq NER$
⋮	⋮	⋮
IRN_n = MAX−3	misc. including NXS_n, JXS_n	
MAX−2	XSS_n	
MAX−1	XSS_n (cont)	$2*NER < ITL_n \leq 3*NER$
MAX	XSS_n (cont)	
(Records per table are examples only)		

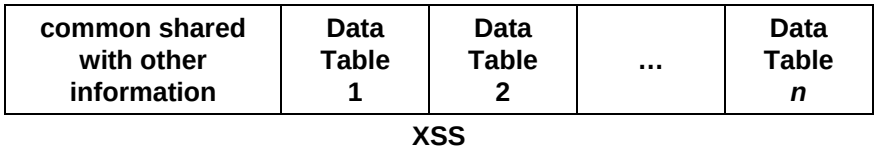
n = number of tables contained on library
MAX = number of records contained on library
IRN_i, ITL_i, NER are the addresses, table lengths, and entries per record from XSDIR

F.3.3 Locating Data Tables in MCNPX

The NXS and JXS arrays exist in MCNPX for each data table. The information contained in the (two-dimensional) arrays in MCNPX mirrors the information contained in NXS and JXS (one-dimensional) on the individual tables. The current dimensions are NXS(16) and JXS(32) on the data tables and NXS(16,•) and JXS(32,•) in MCNPX, where • indicates variable dimensioning. In the code, the arrays are usually referenced as NXS(I,IEX) and JXS(I,IEX), where IEX is the index to a particular table.

The data from all cross-section tables used in an MCNPX problem are in the XSS array, a part of dynamically allocated common. The data from the first table appear first, followed by the data from the second table, etc., as shown in **Error! Reference source not found.**. The pointers in the JXS array indicate absolute locations in the XSS array.

Figure F-3. Diagram of data storage in MCNPX.



XSS

The definitions of the variables in the NXS and JXS arrays (Table F-1 and Table F-2) are the same in MCNPX as on a data table with one exception. For discrete-reaction neutron tables, NXS(16,IEX) is used in MCNPX as an indicator of whether discrete tables in a problem have cross sections tabulated on identical energy grids. Although the definitions of the variables are the same, the contents are generally not. Pointers in the JXS array are pointing to locations in the MCNPX internal XSS array that are different from the locations in the data table XSS array. Flags in the NXS array will generally retain the same value in MCNPX. Counters in the NXS array may retain the same value, primarily depending on the degree to which MCNPX is able to expunge data for a particular problem.

F.3.4 Individual Data Blocks

Several blocks of data exist for every cross-section table. The format of an individual block is essentially the same in MCNPX as on a data table. In either case, the absolute location of a data block in the XSS array is determined by pointers in the JXS array. The specific data blocks available for a particular table are a function of the *class* of data. We next describe the detailed format of individual data blocks for each *class* of data.

F.4 DATA BLOCKS FOR CONTINUOUS/DISCRETE NEUTRON TRANSPORT TABLES

The format of individual data blocks found on neutron transport tables is identical for continuous-energy (NTY=1) and discrete-reaction (NTY=2) tables. Therefore, the format for both are described in this section. All data blocks are now listed with a brief description of their contents and the table numbers in which their formats are detailed.

**Note: In the tables that follow these descriptions, it is understood that NXS(I) or JXS(I) really means NXS(I,IEX) or JXS(I,IEX) when locating data blocks in MCNPX.

1. ESZ Block—contains the main energy grid for the table and the total, absorption, and elastic cross sections as well as the average heating numbers. The ESZ Block always exists. See Table F-4.
2. NU Block—contains prompt, delayed and/or total $\bar{\nu}$ as a function of incident neutron energy. The NU Block exists only for fissionable isotopes (that is, if JXS(2)≠0). See Table F-5.
3. MTR Block—contains list of ENDF/B MT numbers for all neutron reactions other than elastic scattering. The MTR Block exists for all isotopes that have reactions other than elastic scattering (that is, all isotopes with NXS(4)≠0). See Table F-6.

4. LQR Block—contains list of kinematic Q-values for all neutron reactions other than elastic scattering. The LQR Block exists if NXS(4)≠0. See Table F-7.
5. TYR Block—contains information about the type of reaction for all neutron reactions other than elastic scattering. Information for each reaction includes the number of secondary neutrons and whether secondary neutron angular distributions are in the laboratory or center-of-mass system. The TYR Block exists if NXS(4)≠0. See Table F-8.
6. LSIG Block—contains list of cross-section locators for all neutron reactions other than elastic scattering. The LSIG Block exists if NXS(4)≠0. See Table F-9.
7. SIG Block—contains cross sections for all reactions other than elastic scattering. The SIG Block exists if NXS(4)≠0. See Table F-10.
8. LAND Block—contains list of angular-distribution locators for all reactions producing secondary neutrons. The LAND Block always exists. See Table F-11.
9. AND Block—contains angular distributions for all reactions producing secondary neutrons. The AND Block always exists. See Table F-12.
10. LDLW Block—contains list of energy distribution locators for all reactions producing secondary neutrons except for elastic scattering. The LDLW Block exists if NXS(5)≠0. See Table F-13.
11. DLW Block—contains energy distributions for all reactions producing secondary neutrons except for elastic scattering. The DLW Block exists if NXS(5)≠0. See Table F-14.
12. GPD—contains the total photon production cross section tabulated on the ESZ energy grid and a 30×20 matrix of secondary photon energies. The GPD Block exists only for those older evaluations that provide coupled neutron/photon information (that is, if JXS(12)≠0). See Table F-15.
13. MTRP Block—contains list of MT numbers for all photon production reactions. (We will use the term "photon production reaction" for any information describing a specific neutron-in photon-out reaction.) The MTRP Block exists if NXS(6)≠0. See Table F-6.
14. LSIGP Block—contains list of cross-section locators for all photon production reactions. The LSIGP Block exists if NXS(6)≠0. See Table F-9.
15. SIGP Block—contains cross sections for all photon production reactions. The SIGP Block exists if NXS(6)≠0. See Table F-16.
16. LANDP Block—contains list of angular-distribution locators for all photon production reactions. The LANDP Block exists if NXS(6)≠0. See Table F-17.

17. ANDP Block—contains photon angular distributions for all photon production reactions. The ANDP Block exists if NXS(6)≠0. See Table F-18.
18. LDLWP Block—contains list of energy-distribution locators for all photon production reactions. The LDLWP Block exists if NXS(6)≠0. See Table F-13.
19. DLWP Block—contains photon energy distributions for all photon production reactions. The DLWP Block exists if NXS(6)≠0. See Table F-14.
20. YP Block—contains list of MT identifiers of neutron reaction cross sections required as photon production yield multipliers. The YP Block exists if NXS(6)≠0. See Table F-19.
21. FIS Block—contains the total fission cross section tabulated on the ESZ energy grid. The FIS Block exists if JXS(21)≠0. See Table F-20.
22. UNR Block—contains the unresolved resonance range probability tables. The UNR block exists if JXS(23)≠0. See Table F-21.

Table F-4. ESZ Block

Location in XSS	Parameter	Description
JXS(1)	E(I),I=1,NXS(3)	Energies
JXS(1)+NXS(3)	σ_t(I),I=1,NXS(3)	Total cross sections
JXS(1)+2*NXS(3)	σ_a(I),I=1,NXS(3)	Total absorption cross sections
JXS(1)+3*NXS(3)	σ_{el}(I),I=1,NXS(3)	Elastic cross sections
JXS(1)+4*NXS(3)	H_{ave}(I),I=1,NXS(3)	Average heating numbers

Table F-5. NU Block

There are four possibilities for the NU Block:		
1. JXS(2)=0	no NU Block	
2. XSS(JXS(2))>0	Either prompt $\bar{\nu}$ or total $\bar{\nu}$ is given. The NU array begins at location XSS(KNU) where KNU=JXS(2).	
3. XSS(JXS(2))<0	Both prompt $\bar{\nu}$ and total $\bar{\nu}$ are given. The prompt NU Array begins at XSS(KNU) where KNU=JXS(2)+1; the total NU array begins at XSS(KNU), where KNU=JXS(2)+ABS(XSS(JXS(2)))+1.	
4. JXS(24)>0	Delayed $\bar{\nu}$ is given. The $\bar{\nu}$ array begins at XSS(KNU) where KNU=JXS(24). Delayed $\bar{\nu}$ data must be given in form b described below.	

The NU array has two forms if it exists:		
a) Polynomial function form of NU array		
Location in XSS	**Parameter**	**Description**
KNU	LNU=1	Polynomial function flag
KNU+1	NC	Number of coefficients
KNU+2	C(I),I=1,NC $\bar{\nu}(E) = \sum_{I=1}^{NC} C(I) * E^{I-1}$, E in MeV	Coefficients
b) Tabular data form of NU array		
Location in XSS	**Parameter**	**Description**
KNU	LNU=2	Tabular data flag
KNU+1	NR	Number of interpolation regions
KNU+2	NBT(I),I=1,NR	ENDF interpolation parameters
KNU+2+NR	INT(I),I=1,NR	If NR=0, NBT and INT are omitted and linear-linear interpolation is used.
KNU+2+2*NR	NE	Number of energies
KNU+3+2*NR	E(I),I=1,NE	Tabular energy points
KNU+3+2*NR+NE	$\bar{\nu}$ (I),I=1,NE	Corresponding values of $\bar{\nu}$
If delayed $\bar{\nu}$ data exist, the precursor distribution format is given below. The energy distribution for delayed fission neutrons is given by data that follows the format in Table F-13 and Table F-14, where LED=JXS(26) and LDIS=JXS(27).		
JXS(25)	DEC_1	Decay constant for this group
JXS(25)+1	NR	Number of interpolation regions
JXS(25)+2	NBT(I),I=1,NR	ENDF interpolation parameters
JXS(25)+2+NR	INT(I),I=1,NR	If NR=0, NBT and INT are omitted and linear-linear interpolation is used.
JXS(25)+2+2*NR	NE	Number of energies
JXS(25)+3+2*NR	E(I),I=1,NE	Tabular energy points
JXS(25)+3+2*NR+NE	P(I),I=1,NE	Corresponding probabilities
JXS(25)+3+2*NR+2NE	DEC_2	Decay constant for this group

Table F-6. MTR, MTRP Blocks

Location in XSS	Parameter	Description
LMT	MT_1	First ENDF reaction available
LMT+1	MT_2	Second ENDF reaction available

Location in XSS	Parameter	Description
. . .	. . .	. . .
LMT+NMT−1 where LMT=JXS(3) for MTR Block LMT=JXS(13) for MTRP Block NMT=NXS(4) for MTR Block NMT=NXS(6) for MTRP Block	MT_{NMT}	Last ENDF reaction available

Note: For MTR Block: MT_1, MT_2, … are standard ENDF MT numbers, that is, MT=16=(n,2n); MT=17=(n,3n); etc.

For MTRP Block: The MT values are somewhat arbitrary. To understand the scheme used for numbering the photon production MTs, it is necessary to realize that in ENDF/B format, more than one photon can be produced by a particular neutron reaction that is itself specified by a single MT. Each of these photons is produced with an individual energy-dependent cross section. For example, MT 102 (radiative capture) might be responsible for 40 photons, each with its own cross section, angular distribution, and energy distribution. We need 40 photon MTs to represent the data; the MTs are numbered 102001, 102002, …, 102040. Therefore, if ENDF/B MT "N" is responsible for "M" photons, we shall number the photon MTs 1000∗N+1, 1000∗N+2, …, 1000*N+M.

Table F-7. LQR Block

Location in XSS	Parameter	Description
JXS(4)	Q_1	Q-value of reaction MT_1
JXS(4)+1	Q_2	Q-value of reaction MT_2
. . .	. . .	. . .
JXS(4)+NXS(4)−1	$Q_{NXS(4)}$	Q-value of reaction $MT_{NXS(4)}$

Note: The MT*s* are given in the MTR Block.

Table F-8. TYR Block

Location in XSS	Parameter	Description
JXS(5)	TY_1	Neutron release for reaction MT_1
JXS(5)+1	TY_2	Neutron release for reaction MT_2
. . .	. . .	. . .

Location in XSS	Parameter	Description
JXS(5)+NXS(4)−1	$TY_{NXS(4)}$	Neutron release for reaction $MT_{NXS(4)}$

Note: The possible values of TY_i are ±1, ±2, ±3, ±4, 19, 0, and integers greater than 100 in absolute value. The sign indicates the system for scattering: negative=CM system; positive=LAB system. Thus if TY_i=+3, three neutrons are released for reaction MT_i and the data on the cross-section tables used to determine the exiting neutrons' angles are given in the LAB system.

TY_i=19 indicates fission. The number of secondary neutrons released is determined from the fission $\bar{\nu}$ data found in the NU Block.

TY_i=0 indicates absorption (ENDF reactions MT>100); no neutrons are released.

$|TY_i|$>100 signifies reactions other than fission that have energy-dependent neutron multiplicities. The number of secondary neutrons released is determined from the yield data found in the DLW Block. The MT_is are given in the MTR Block.

Table F-9. LSIG, LSIGP Blocks

Location in XSS	Parameter	Description
LXS	$LOCA_1$=1	Loc. of cross sections for reaction MT_1
LXS+1	$LOCA_2$	Loc. of cross sections for reaction MT_2
. . .	. . .	. . .
LXS+NMT−1 where LXS=JXS(6) for LSIG Block LXS=JXS(14) for LSIGP Block NMT=NXS(4) for LSIG Block NMT=NXS(6) for LSIGP Block	$LOCA_{NMT}$	Loc. of cross sections for reaction MT_{NMT}

Note: All locators are relative to JXS(7) for LSIG or JXS(15) for LSIGP. The MT_is are given in the MTR Block for LSIG or the MTRP Block for LSIGP. LOCA-*i* values must be monotonically increasing or data will be overwritten in subroutine EXPUNG.

Table F-10. SIG Block

Location in XSS	Description
JXS(7)+LOCA1−1	Cross-section array* for reaction MT_1
JXS(7)+LOCA2−1	Cross-section array* for reaction MT_2
. . .	. . .
JXS(7)+LOCANXS(4)−1	Cross-section array* for reaction $MT_{NXS(4)}$

*The i^{th} array has the form:

Location in XSS	Parameter	Description
JXS(7)+$LOCA_i$−1	IE_i	Energy grid index for reaction MT_i
JXS(7)+$LOCA_i$	NE_i	Number of consecutive entries for MT_i
JXS(7)+$LOCA_i$+1	σ_i[E(K)],K=IE_i, IE_i+NE_i-1	Cross sections for reaction MT_i

Note: The values of $LOCA_i$ are given in the LSIG Block. The energy grid E(K) is given in the ESZ Block. The energy grid index IE_i corresponds to the first energy in the grid at which a cross section is given. The MT_is are defined in the MTR Block.

Table F-11. LAND Block

Location in XSS	Parameter	Description Loc. of angular dist. data for …
JXS(8)	$LOCB_1$=1	elastic scattering
JXS(8)+1	$LOCB_2$	reaction MT_1
. . .	. . .	. . .
JXS(8)+NXS(5)	$LOCB_{NXS(5)+1}$	reaction $MT_{NXS(5)}$

Note: All locators ($LOCB_i$) are relative to JXS(9). If $LOCB_i$=0, no angular distribution data are given for this reaction, and isotropic scattering is assumed in either the LAB or CM system. Choice of LAB or CM system depends upon value for this reaction in the TYR Block. The MT_is are given in the MTR Block.

If $LOCB_i$=-1, no angular distribution data are given for this reaction in the AND Block. Angular distribution data are specified through LAW_i=44 in the DLW Block.

The $LOCB_i$ locators must be monotonically increasing or data will be overwritten in subroutine EXPUNG.

Table F-12. AND Block

Location in XSS	Description
JXS(9)+$LOCB_1$−1	Angular distribution array* for elastic scattering
JXS(9)+$LOCB_2$−1	Angular distribution array* for reaction MT_1
. . .	. . .
JXS(9)+$LOCB_{NXS(5)+1}$−1	Angular distribution array* for reaction $MT_{NXS(5)}$

Note: The values of $LOCB_i$ are given in the LAND Block. If $LOCB_i$=0, no angular distribution array is given and scattering is isotropic in either the LAB or CM system. Choice of LAB or CM system depends on value in the TYR Block. The MTs are given in the MTR Block.

*The i^{th} array has the form:

Location in XSS	Parameter	Description
JXS(9)+LOCB$_i$-1	NE	Number of energies at which angular distributions are tabulated.
JXS(9)+LOCB$_i$	E(J),J=1,NE	Energy grid
JXS(9)+LOCB$_i$+NE	LC(J),J=1,NE	Location of tables* associated with energies E(J)
	If LC(J) is positive, it points to 32 equiprobable bin distribution. If LC(J) is negative, it points to a tabular angular distribution. If LC(J)=0=isotropic and no further information is needed.	

*The j^{th} array for a 32 equiprobable bin distribution has the form:

Location in XSS	Parameter	Description
JXS(9)+|LC(J)|-1	P(1,K),K=1,33	32 equiprobable cosine bins for scattering at energy E(1)

*The j^{th} array for a tabular angular distribution has the form:

Location in XSS	Parameter	Description
JXS(9)+|LC(J)|-1 is now defined to be:		
LDAT(K+1)	JJ	Interpolation flag: 0=histogram 1=lin-lin
LDAT(K+2)	NP	Number of points in the distribution
LDAT(K+3)	CSOUT(I),I=1,NP	Cosine scattering angular grid
LDAT(K+3+NP)	PDF(I),I=1,NP	Probability density function
LDAT(K+3+2*NP)	CDF(I),I=1,NP	Cumulative density function

Note: All values of LC(J) are relative to JXS(9). If LC(J)=0, no table is given for energy E(J) and scattering is isotropic in the coordinate system indicated by entry in the TYR Block.

Table F-13. LDLW, LDLWP Block

Location in XSS	Parameter	Description
LED	$LOCC_1$	Loc. of energy distribution data for reaction MT_1 or group 1 if delayed neutron
LED+1	$LOCC_2$	Loc. of energy distribution data for reaction MT_2 or group 2 if delayed neutron
. . .	. . .	. . .

Location in XSS	Parameter	Description
LED+NMT−1	$LOCC_{NMT}$	Loc. of energy distribution data for reaction MT_{NMT} or group NMT if delayed neutron
where LED=JXS(10) for LDLW Block LED=JXS(18) for LDLWP Block LED=JXS(26) for delayed neutron		NMT=NXS(5) for LDLW Block NMT=NXS(6) for LDLWP Block NMT=NXS(8) for delayed neutrons

Note: All locators are relative to JXS(11) for LDLW or JXS(19) for LDLWP. The MT_is are given in the MTR Block for LDLW or MTRP Block for LDLWP. The $LOCC_i$ locators must be monotonically increasing or data will be overwritten in subroutine EXPUNG. For delayed neutrons, the $LOCC_i$ values are relative to JXS(27).

Table F-14. DLW, DLWP Block

Location in XSS	Description
$JED+LOCC_1-1$	Energy distribution array* for reaction MT_1
$JED+LOCC_2-1$	Energy distribution array* for reaction MT_2
. . .	. . .
$JED+LOCC_{NMT}-1$ where JED=JXS(11) for DLW JED=JXS(19) for DLWP NMT=NXS(5) for DLW NMT=NXS(6) for DLWP	Energy distribution array* for reaction MT_{NMT}

Note: Values of $LOCC_i$ are given in the LDLW and LDLWP Blocks. Values of MT_i are given in the MTR and MTRP Blocks.

*The i^{th} array has the form:

Location in XSS	Parameter	Description
$LDIS+LOCC_i-1$	LNW_1	Location of next law. If LNW_i=0, then law LAW_1 is used regardless of other circumstances.
$LDIS+LOCC_i$	LAW_1	Name of this law
$LDIS+LOCC_i+1$	$IDAT_1$	Location of data for this law relative to LDIS
$LDIS+LOCC_i+2$	NR	Number of interpolation regions to define law applicability regime
$LDIS+LOCC_i+3$	NBT(I),I=1,NR	ENDF interpolation parameters.
$LDIS+LOCC_i+3+NR$	INT(I),I=1,NR	If NR=0, NBT and INT are omitted and linear-linear interpolation is used.
$LDIS+LOCC_i+3+2*NR$	NE	Number of energies
$LDIS+LOCC_i+4+2*NR$	E(I),I=NE	Tabular energy points

Location in XSS	Parameter	Description
LDIS+LOCC$_i$+4+2*NR+NE	P(I),I=1,NE	Probability of law validity. If the particle energy E is E<E(1), then P(E)=P(1). If E>E(NE), then P(E)=P(NE). If more than 1 law is given, then LAW$_1$ is used only if ξ<P(E) where ξ is a random number between 0 and 1.
LDIS+IDAT$_1$-1	LDAT(I),I=1,L**	Law data array for LAW$_1$. The length L of the law data array LDAT is determined from parameters within LDAT. The various law data arrays LDAT for each law LAW$_i$ are given in the following tables.
LDIS+LNW$_1$-1	LNW$_2$	Location of next law
LDIS+LNW$_1$	LAW$_2$	Name of this law
LDIS+LNW$_1$+1	IDAT$_2$	Location of data for this law
. . .	. . .	. . .
Where LDIS=JXS(11) for DLW LDIS=JXS(19) for DLWP LDIS=JXS(27) for delayed neutrons		

Note: The locators LOCC$_i$ are defined in the LDLW Block or the LDLWP Block. All locators (LNW$_i$, IDAT$_i$) are relative to LDIS.

**We now define the format of the LDAT array for each law. Laws 2 and 4 are used to describe the spectra of secondary photons from neutron collisions. All laws except for Law 2 are used to describe the spectra of scattered neutrons. In the following tables we provide relative locations of data in the LDAT array rather than absolute locations in the XSS array. The preceding table defines the starting location of the LDAT array within the XSS array.

a. LAW$_i$=1 Tabular Equiprobable Energy Bins (From ENDF Law 1)

Location	Parameter	Description
LDAT(1) LDAT(2) LDAT(2+NR)	NR NBT(I),I=1,NR INT(I),I=1,NR	Interpolation scheme between tables of E_{out}. If NR=0 or if INT(I) ±1 (histogram), linear-linear interpolation is used
LDAT(2+2*NR) LDAT(3+2*NR)	NE E_{in}(I),I=1,NE	Number of incident energies tabulated List of incident energies for which E_{out} is tabulated
LDAT(3+2*NR+NE)	NET	Number of outgoing energies in each E_{out} table
LDAT(4+2*NR+NE)	E_{out_1}(I),I=1,NET E_{out_2} (I),I=1,NET $E_{out_{NE}}$ (I),I=1,NET	E_{out} tables are NET boundaries of NET-1 equally likely energy intervals. Linear-linear interpolation is used between intervals

b. LAW$_i$=2 Discrete Photon Energy

Location	Parameter	Description
LDAT(1)	LP	Indicator of whether the photon is a primary or nonprimary photon
LDAT(2)	EG	Photon energy (if LP=0 or LP=1), or Binding energy (if LP=2)
If LP=0 or LP=1, the photon energy is EG		
If LP=2, the photon energy is EG+(AWR)/(AWR+1)∗EN, where AWR is the atomic weight ratio and EN is the neutron energy		

c. LAW$_i$=3 Level Scattering (From ENDF Law 3)

$$\mathrm{LDAT}(1) = \left(\frac{A+1}{A}\right)|Q|$$

$$\mathrm{LDAT}(2) = \left(\frac{A}{A+1}\right)^2$$

$$E_{out}^{CM} = \mathrm{LDAT}(2) * \left(E - \mathrm{LDAT}(1)\right)$$

where

E_{out}^{CM} = outgoing center-of-mass energy
Q = Q-value
E = incident energy
A = atomic weight ratio

The outgoing neutron energy in the laboratory system, E_{out}^{LAB}, is

$$E_{out}^{LAB} = E_{out}^{CM} + \left\{E + 2\mu_{cm}(A+1)\left(EE_{out}^{CM}\right)^{1/2}\right\} / (A+1)^2 \quad ,$$

where μ_{cm} = cosine of the center-of-mass scattering angle.

d. LAW$_i$=4 Continuous Tabular Distribution (From ENDF Law 1)

Location	Parameter	Description
LDAT(1) LDAT(2) LDAT(2+NR)	NR NBT(I),I=1,NR INT(I),I=1,NR	Number of interpolation regions ENDF interpolation parameters. If NR=0, NBT and INT are omitted and linear-linear interpolation is used.
LDAT(2+2*NR)	NE	Number of energies at which distributions are tabulated
LDAT(3+2*NR) LDAT(3+2*NR+NE)	E(I),I=1,NE L(I),I=1,NE	Incident neutron energies Locations of distributions (relative to JXS(11) or JXS(19))
Data for E(1) (let K=3+2∗NR+2∗NE):		
LDAT(K)	INTT	Combination of the number of discrete photon lines, ND, and the interpolation scheme for subsequent data, INTT=1 histogram distribution INTT=2 linear-linear distribution
LDAT(K+1)	NP	Number of points in the distribution
LDAT(K+2)	EOUT(I),I=1,NP	Outgoing energy grid
LDAT(K+2+NP)	PDF(I),I=1,NP	Probability density function
LDAT(K+2+2*NP)	CDF(I),I=1,NP	Cumulative density function
Data for E(2):		
. . .	. . .	. . .
If the value of LDAT(K) is INTT′>10, then INTT′=(ND∗10) + INTT where INTT is the interpolation scheme and the first ND values of NP points describe discrete photon lines. The remaining NP – ND values describe a continuous distribution. In this way the distribution may be discrete, continuous, or a discrete distribution superimposed upon a continuous background.		

e. LAW$_i$=5 General Evaporation Spectrum (From ENDF Law 5)

Location	Parameter		Description
LDAT(1)	NR	}	Interpolation scheme between T values
LDAT(2)	NBT(I),I=1,NR	}	
LDAT(2+NR)	INT(I),I=1,NR	}	
LDAT(2+2*NR)	NE		Number of incident energies tabulated
LDAT(3+2*NR)	E(I),I=1,NE		Incident energy table

Location	Parameter	Description
LDAT(3+2*NR+NE)	T(I),I=1,NE	Tabulated function of incident energies
LDAT(3+2*NR+2*NE)	NET	Number of X values tabulated
LDAT(4+2*NR+2*NE)	X(I),I=1,NET	Tabulated probabilistic function
E_{out} = X(ξ)*T(E), where X(ξ) is a randomly sampled table of X values, and E is the incident energy.		

f. LAW$_i$=7 Simple Maxwell Fission Spectrum (From ENDF Law 7)

Location	Parameter	Description
LDAT(1)	NR	Interpolation scheme between T values
LDAT(2)	NBT(I),I=1,NR	
LDAT(2+NR)	INT(I),I=1,NR	
LDAT(2+2*NR)	NE	Number of incident energies tabulated
LDAT(3+2*NR)	E(I),I=1,NE	Incident energy table
LDAT(3+2*NR+NE)	T(I),I=1,NE	Tabulated T values
LDAT(3+2*NR+2*NE)	U	Restriction energy

$$f\left(E \to E_{out}\right) = C\sqrt{E_{out}}\, e^{-E_{out}/T(E)}$$

with restriction $0 \le E_{out} \le E - U$

$$C = T^{-3/2}\left[\frac{\sqrt{\pi}}{2} erf\left(\sqrt{\left(E-U\right)/T}\right) + -\sqrt{\left(E-U\right)/T}\, e^{-(E-U)/T}\right]^{-1}$$

g. LAW$_i$=9 Evaporation Spectrum (From ENDF Law 9)

Location	Parameter	Description
LDAT(1)	NR	Interpolation scheme between T values
LDAT(2)	NBT(I),I=1,NR	
LDAT(2+NR)	INT(I),I=1,NR	
LDAT(2+2*NR)	NE	Number of incident energies tabulated
LDAT(3+2*NR)	E(I),I=1,NE	Incident energy table
LDAT(3+2*NR+NE)	T(I),I=1,NE	Tabulated T values
LDAT(3+2*NR+2*NE)	U	Restriction energy

$$f\left(E \to E_{out}\right) = CE_{out}e^{-E_{out}/T(E)}$$

with restriction $0 \le E_{out} \le E - U$

$$C = T^{-2}\left[1 - e^{(E-U)/T}\left(1 + \left(E-U\right)/T\right)\right]^{-1}$$

h. LAW$_i$=11 Energy-Dependent Watt Spectrum (From ENDF Law 11)

Location	Parameter	Description
LDAT(1)	NR_a	Interpolation scheme between *a* values
LDAT(2)	$NBT_a(I),I=1,NR_a$	
LDAT(2+NR_a)	$INT_a(I),I=1,NR_a$	
LDAT(2+2*NR_a)	NE_a	Number of incident energies tabulated for *a*(E_{in}) table
LDAT(3+2*NR_a)	$E_a(I),I=1,NE_a$	Incident energy table
LDAT(3+2*NR_a+NE_a)	$a(I),I=1,NE_a$	Tabulated *a* values
Let L=3+2*(NR_a+NE_a)		
LDAT(L)	NR_b	Interpolation scheme between *b* values
LDAT(L+1)	$NBT_b(I),I=1,NR_b$	
LDAT(L+1+NR_b)	$INT_b(I),I=1,NR_b$	
LDAT(L+1+2*NR_b)	NE_b	Number of incident energies tabulated for *b*(E_{in}) table
LDAT(L+2+2*NR_b)	$E_b(I),I=1,NE_b$	Incident energy table
LDAT(L+2+2*NR_b+NE_b)	$b(I),I=1,NE_b$	Tabulated *b* values

$$f\left(E \to E_{out}\right) = C_o \exp\left[-E_{out}/a(E)\right]\sinh\left[b(E)E_{out}\right]^{1/2}$$

with restriction $0 \le E_{out} \le E - U$.

This law is sampled by the rejection scheme in LA-5061-MS (R11, p. 45).

i. LAW$_i$=22 Tabular Linear Functions (from UK Law 2)

Location in XSS	Parameter	Description
LDAT(1)	NR	Interpolation parameters that are not used by MCNPX (histogram interpolation is assumed)
LDAT(2)	NBT(I),I=1,NR	
LDAT(2+NR)	INT(I),I=1,NR	

Location in XSS	Parameter	Description
LDAT(2+2*NR)	NE	Number of incident energies tabulated
LDAT(3+2*NR)	E_{in}(I),I=1,NE	List of incident energies for E_{out} tables
LDAT(3+2*NR+NE)	LOCE(I),I=1,NE	Locators of E_{out} tables (relative to JXS(11))
Data for E_{in}(1) (Let L=3+2*NR+2*NE):		If $E_{in}(I)_i$ and E < E_{in}(I+1) and ξ is a random number [0,1] then if $\sum_{k=1}^{k=K} P_I(K) < \xi \le \sum_{k=1}^{k=K} P_1(K)$ $E_{out} = C_I(K) * (E - T_I(K))$
LDAT(L)	NF_1	
LDAT(L+1)	P_1(K),K=1,NF_1	
LDAT(L+1+NF_1) LDAT(L+1+2*NF_1)	T_1(K),K=1,NF_1 C_1(K),K=1,NF_1	
Data for E_{in}(2):		
. . .	. . .	

j. LAW$_i$=24 (From UK Law 6)

Location in XSS	Parameter	Description
LDAT(1)	NR	Interpolation parameters that are not used
LDAT(2)	NBT(I),I=1,NR	by MCNPX
LDAT(2+NR)	INT(I),I=1,NR	(histogram interpolation is assumed)
LDAT(2+2*NR)	NE	Number of incident energies
LDAT(3+2*NR)	E_{in}(I),I=1,NE	List of incident energies for which T is tabulated
LDAT(3+2*NR+NE)	NET	Number of outgoing values in each table
LDAT(4+2*NR+NE)	T_1(I),I=1,NET T_2(I),I=1,NET . . . T_{NE}(I),I=1,NET	Tables are NET boundaries of NET-1 equally likely intervals. Linear-linear interpolation is used between intervals.
E_{out} = T_K(I)*E where T_K(I) is sampled from the above tables E is the incident neutron energy		

k. LAW$_i$=44 Kalbach-87 Formalism (From ENDF File 6 Law 1, LANG=2)

Location	Parameter	Description
LDAT(1)	NR	Number of interpolation regions
LDAT(2)	NBT(I),I=1,NR	ENDF interpolation parameters. If NR=0, NBT and INT are omitted and linear-linear interpolation is used.
LDAT(2+NR)	INT(I),I=1,NR	
LDAT(2+2*NR)	NE	Number of energies at which distributions are tabulated
LDAT(3+2*NR)	E(I),I=1,NE	Incident neutron energies
LDAT(3+2*NR+NE)	L(I),I=1,NE	Locations of distributions (relative to JXS(11) or JXS(19))
Data for E(1) (let K=3+2*NR+2*NE):		
LDAT(K)	INTT′	Interpolation scheme for subsequent data INTT=1 histogram distribution INTT=2 linear-linear distribution
LDAT(K+1)	NP	Number of points in the distribution
LDAT(K+2)	EOUT(I),I=1,NP	Outgoing energy grid
LDAT(K+2+NP)	PDF(I),I=1,NP	Probability density function
LDAT(K+2+2*NP)	CDF(I),I=1,NP	Cumulative density function
LDAT(K+2+3*NP)	R(I),I=1,NP	Precompound fraction r
LDAT(K+2+4*NP)	A(I),I=1,NP	Angular distribution slope value a
Data for E(2):		
⋮	⋮	⋮

If the value of LDAT(K) is INTT′>10, then

INTT′=10 ∗ ND + INTT

where INTT is the interpolation scheme and the first ND values of NP describe discrete photon lines. The remaining NP–ND values describe a continuous distribution. In this way the distribution may be discrete, continuous, or a discrete distribution superimposed upon a continuous background.

The angular distributions for neutrons are then sampled from

$$p(\mu, E_{in}, E_{out}) = \frac{1}{2}\frac{A}{\sinh(A)}\left[\cosh(A\mu) + R\sinh(A\mu)\right]$$

as described in the MCNPX theory manual (not yet released).

I. LAW$_i$=61 Like LAW 44 but tabular angular distribution instead of Kalbach-87

Location	Parameter	Description
LDAT(1)	NR	Number of interpolation regions
LDAT(2)	NBT(I),I=1,NR	ENDF interpolation parameters. If NR=0, NBT and INT are omitted and linear-linear interpolation is used.
LDAT(2+NR)	INT(I),I=1,NR	
LDAT(2+2*NR)	NE	Number of energies at which distributions are tabulated
LDAT(3+2*NR)	E(I),I=1,NE	Incident neutron energies
LDAT(3+2*NR+NE)	L(I),I=1,NE	Locations of distributions (relative to JXS(11) or JXS(19))
Data for E(1) (let K=3+2*NR+2*NE):		
LDAT(K)	INTT′	Interpolation scheme for subsequent data INTT=1 histogram distribution INTT=2 linear-linear distribution
LDAT(K+1)	NP	Number of points in the distribution
LDAT(K+2)	EOUT(I),I=1,NP	Outgoing energy grid
LDAT(K+2+NP)	PDF(I),I=1,NP	Probability density function
LDAT(K+2+2*NP)	CDF(I),I=1,NP	Cumulative density function
LDAT(K+2+3*NP)	LC(I),I=1,NP	Location of tables* associated with energies E(I)
	If LC(I) is positive, it points to a tabular angular distribution. If LC(I)=0=isotropic and no further information is needed. 32 equiprobable bin distribution is not allowed.	
*The J^{th} array for a tabular angular distribution has the form:		
JXS(11) or JXS(19)+|LC(J)|−1 is now defined to be:		
LDAT(L+1)	JJ	Interpolation flag: 0=histogram 1=lin-lin
LDAT(L+2)	NP	Number of points in the distribution
LDAT(L+3)	CSOUT(I),I=1,NP	Cosine scattering angular grid
LDAT(L+3+NP)	PDF(I),I=1,NP	Probability density function
LDAT(L+3+2*NP)	CDF(I),I=1,NP	Cumulative density function
Data for E(2):		
⋮	⋮	⋮

If the value of LDAT(K) is INTT′>10, then INTT′=10 ∗ ND + INTT.

m. LAW$_i$=66 N-body phase space distribution (From ENDF File 6 Law 6)

Location	Parameter	Description
LDAT(1)	NPSX	Number of bodies in the phase space
LDAT(2)	A_p	Total mass ratio for the NPSX particles

$$E_{out} = T(\xi) * E_i^{\max}$$

where

$$E_i^{\max} = \frac{A_p - 1}{A_p}\left(\frac{A}{A+1}E_{in} + Q\right)$$

and $T(\xi)$ is sampled from

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

where the sampling scheme is from R28 of LA-9721-MS and is described in the MCNPX theory manual, which is not yet released.

n. LAW$_i$=67 Laboratory Angle-Energy Law (From ENDF File 6 Law 7)

Location	Parameter	Description
LDAT(1)	NR	Number of interpolation regions
LDAT(2)	NBT(I),I=1,NR	ENDF interpolation parameters. If NR=0,
LDAT(2+NR)	INT(I),I=1,NR	NBT and INT are omitted and linear-linear interpolation is used.
LDAT(2+2*NR)	NE	Number of energies at which distributions are tabulated
LDAT(3+2*NR)	E(I),I=1,NE	Incident neutron energies
LDAT(3+2*NR+NE)	L(I),I=1,NE	Locations of distributions (relative to JXS(11) or JXS(19))
Data for E(1) (let K=3+2*NR+2*NE):		
LDAT(K)	INTMU	Interpolation scheme for secondary cosines INTMU=1 histogram distribution INTMU=2 linear-linear distribution
LDAT(K+1)	NMU	Number of secondary cosines
LDAT(K+2)	XMU(I),I=1,NMU	Secondary cosines
LDAT(K+2+NMU)	LMU(I),I=1,NMU)	Location of data for each secondary cosine (relative to JXS(11) or JXS(19))

Location	Parameter	Description
Data for XMU(1) (let J=K+2+2*NMU):		
LDAT(J)	INTEP	Interpolation parameter between secondary energies (INTEP=1 is histogram, INTEP=2 is linear-linear)
LDAT(J+1)	NPEP	Number of secondary energies
LDAT(J+2)	EP(I),I=1,NPEP	Secondary energy grid
LDAT(J+2+NPEP)	PDF(I),I=1,NPEP	Probability density function
LDAT(J+2+2*NPEP)	CDF(I),I=1,NPEP	Cumulative density function
Data for XMU(2) . . .		
Data for XMU(NMU) . . .		
Data for E(2) . . .		
Data for E(NE) . . .		

o. Energy-Dependent Neutron Yields

There are additional numbers to be found for neutrons in the DLW array. For those reactions with entries in the TYR block that are greater than 100 in absolute value, there must be neutron yields Y(E) provided as a function of neutron energy. The neutron yields are handled similar to the average number of neutrons per fission $\bar{\nu}(E)$ that is given for the fission reactions. These yields are a part of the coupled energy-angle distributions given in File 6 of ENDF-6 data.

Location in XSS

JED + |TY$_i$| − 100 Neutron yield data for reaction MT$_i$

where JED=JXS(11)=DLW
i≤number of reactions with negative angular distributions locators

The i^{th} array has the form

Location in XSS	Parameter	Description
KY	NR	Number of interpolation regions
KY+1	NBT(I),I=1,NR	ENDF interpolation parameters. If NR=0
KY+1+NR	INT(I),I=1,NR	NBT and INT are omitted and linear-linear interpolation is used.
KY+1+2*NR	NE	Number of energies
KY+2+2*NR	E(I),I=1,NE	Tabular energy points
KY+2+2*NR+NE	Y(I),I=1,NE	Corresponding Y(E) values
where KY=JED+|TY*i*|-101		

Table F-15. GPD Block

Location in XSS	Parameter	Description
JXS(12)	σ_γ(I),I=1,NXS(3)	Total photon production cross section
JXS(12)+NXS(3)	EG(1,K),K=1,20	20 equally likely outgoing photon energies for incident neutron energy E<EN(2)
JXS(12)+NXS(3)+20	EG(2,K),K=1,20	20 equiprobable outgoing photon energies for incident neutron energy EN(2)≤ E<EN(3)
. . .	. . .	. . .
JXS(12)+NXS(3)+580	EG(30,K),K=1,20	20 equiprobable outgoing photon energies for incident neutron energy E≥EN(30)

Notes: (1) The discrete incident neutron energy array in MeV is EN(J),J=1,30: 1.39E-10, 1.52E-7, 4.14E−7, 1.13E−6, 3.06E−6, 8.32E−6, 2.26E−5, 6.14E−5, 1.67E−4, 4.54E−4, 1.235E−3, 3.35E−3, 9.23E−3, 2.48E−2, 6.76E−2, .184, .303, .500, .823, 1.353, 1.738, 2.232, 2.865, 3.68, 6.07, 7.79, 10., 12., 13.5, 15.

(2) The equiprobable photon energy matrix is used only for those older tables that do not provide expanded photon production data, and no currently supported libraries use this data.

Table F-16. SIGP Block

Location in XSS	Description
JXS(15)+LOCA1−1	Cross-section array* for reaction MT_1
JXS(15)+LOCA2−1	Cross-section array* for reaction MT_2
. . .	. . .
JXS(15)+$LOCA_{NXS(6)}$−1	Cross-section array* for reaction $MT_{NXS(6)}$

*The i^{th} array has three possible forms, depending on the first word in the array:

(a) If MFTYPE=12 (Yield Data taken from ENDF File 12) or
If MFTYPE=16 (Yield Data taken from ENDF File 6)

Location in XSS	Parameter	Description
JXS(15)+LOCA$_i$–1	MFTYPE	12 or 16
JXS(15)+LOCA$_i$	MTMULT	Neutron MT whose cross section should multiply the yield
JXS(15)+LOCA$_i$+1	NR	Number of interpolation regions
JXS(15)+LOCA$_i$+2	NBT(I),I=1,NR	ENDF interpolation parameters. If NR=0, NBT and INT are omitted and
JXS(15)+LOCA$_i$+2+NR	INT(I),I=1,NR	linear-linear interpolation is used.
JXS(15)+LOCA$_i$+2+2*NR	NE	Number of energies at which the yield is tabulated
JXS(15)+LOCA$_i$+3+2*NR	E(I),I=1,NE	Energies
JXS(15)+LOCA$_i$+3 +2*NR+NE	Y(I),I=1,NE	Yields

$$\sigma_{\gamma,i} = Y(E) * \sigma_{MTMULT}(E)$$

(b) If MFTYPE=13 (Cross-Section Data from ENDF File 13)

Location in XSS	Parameter	Description
JXS(15)+LOCA$_i$–1	MFTYPE	13
JXS(15)+LOCA$_i$	IE	Energy grid index
JXS(15)+LOCA$_i$+1	NE	Number of consecutive entries
JXS(15)+LOCA$_i$+2	$\sigma_{\gamma,i}$[E(K)], K=IE,IE+NE–1	Cross sections for reaction MT$_i$

Note: The values of LOCA$_i$ are given in the LSIGP Block. The energy grid E(K) is given in the ESZ Block. The MT$_i$s are defined in the MTRP Block.

Table F-17. LANDP Block

Location in XSS	Parameter	Description
JXS(16)	LOCB$_1$=1	Loc. of angular dist. data for reaction MT$_1$
JXS(16)+1	LOCB$_2$	Loc. of angular dist. data for reaction MT$_2$
. . .	. . .	. . .
JXS(16)+NXS(6)–1	LOCB$_{NXS(6)}$	Loc. of angular dist. data for reaction MT$_{NXS(6)}$

Note: All locator (LOCB$_i$) are relative to JXS(17). If LOCB$_i$=0, there are no angular distribution data give for this reaction and isotropic scattering is assumed in the LAB system. MT$_i$s are defined in the MTRP Block.

Table F-18. ANDP Block

Location in XSS	Description
JXS(17)+LOCB$_1$−1	Angular distribution array* for reaction MT$_1$
JXS(17)+LOCB$_2$−1	Angular distribution array* for reaction MT$_2$
JXS(17)+LOCB$_{NXS(6)}$−1	Angular distribution array* for reaction MT$_{NXS(6)}$

Note: The values of LOCB$_i$ are given in the LANDP Block. If LOCB$_i$=0, then no angular distribution array is given and scattering is isotropic in the LAB system. The MTs are given in the MTRP Block.

*The i^{th} array has the form:

Location in XSS	Parameter	Description
JXS(17)+LOCB$_i$−1	NE	Number of energies at which angular distributions are tabulated.
JXS(17)+LOCB$_i$	E(J),J=1,NE	Energy grid
JXS(17)+LOCB$_i$+NE	LC(J),J=1,NE	Location of tables associated with energies E(J)
JXS(17)+LC(1)−1	P(1,K),K=1,33	32 equiprobable cosine bins for scattering at energy E(1)
JXS(17)+LC(2)−1	P(2,K),K=1,33	32 equiprobable cosine bins for scattering at energy E(2)
. . .	. . .	. . .
JXS(17)+LC(NE)−1	P(NE,K),K=1,33	32 equiprobable cosine bins for scattering at energy E(NE)

Note: All values of LC(J) are relative to JXS(17). If LC(J)=0, no table is given for energy E(J) and scattering is isotopic in the LAB system.

Table F-19. YP Block

Location in XSS	Parameter	Description
JXS(20)	NYP	Number of neutron MTs to follow
JXS(20)+1	MTY(I),I=1,NYP	Neutron MTs

Note: The MTY array contains all neutron MTs that are required as photon-production yield multipliers (See **Error! Reference source not found.**). MCNPX needs this information when expunging data.

Table F-20. FIS Block

Location in XSS	Parameter	Description
JXS(21)	IE	Energy grid index
JXS(21)+1	NE	Number of consecutive entries
JXS(21)+2	σ_f[E(K)],K=IE,IE+NE−1	Total fission cross sections

Note: The FIS Block generally is not provided on individual data tables because the total fission cross section is a redundant quantity [that is, $\sigma_{f,tot}(E) = \sigma_{n,f}(E) + \sigma_{n,n'f}(E) + \sigma_{n,2nf}(E) + \sigma_{n,3nf}(E)$]. MCNPX forms the FIS Block if conditions warrant (for example, for KCODE calculations, coupled neutron/ photon calculations, etc.). The energy grid E(K) is given in the ESZ Block.

Table F-21. UNR Block

Location in XSS	Parameter	Description
JXS(23)	N	Number of incident energies where there is a probability table
JXS(23)+1	M	Length of table; i.e., number of probabilities, typically 20
JXS(23)+2	INT	Interpolation parameter between tables =2 lin-lin; =5 log-log
JXS(23)+3	ILF	Inelastic competition flag (see below)
JXS(23)+4	IOA	Other absorption flag (see below)
JXS(23)+5	IFF	Factors flag (see below)
JXS(23)+6	E(I),I=1,N	Incident energies
JXS(23)+6+N	P(I,J,K)	Probability tables (see below)

Note: ILF is the inelastic competition flag. If this flag is less than zero, the inelastic cross section is zero within the entire unresolved energy range. If this flag is more than zero, then its value is a special MT number whose tabulation is the sum of the inelastic levels. An exception to this scheme is typically made when there is only one inelastic level within the unresolved energy range, because the flag can then just be set to its MT number and the special tabulation is not needed. The flag can also be set to zero, which means that the sum of the contribution of the inelastic reactions will be made using a balance relationship involving the smooth cross sections.

IOA is the other absorption flag for determining the contribution of "other absorptions" (no neutron out or destruction reactions). If this flag is less than zero, the "other absorption" cross section is zero within the entire unresolved energy range. If this flag is more than zero, then its value is a special MT number whose tabulation is the sum of the "other absorption" reactions. An exception to this scheme is typically made when there is only one "other absorption" reaction within the unresolved energy range, because the flag can then just be set to its MT number and the special tabulation is not needed. The flag can also be set to zero, which means that the sum of the contribution of the "other absorption" reactions will be made using a balance relationship involving the smooth cross sections. IFF is the factors flag. If this flag is zero, then the tabulations in the probability tables are cross sections. If the flag is one, the tabulations in the probability tables are factors that must be multiplied by the corresponding "smooth" cross sections to obtain the actual cross sections. P(I,J,K), where I=1,N, J=1,6 , and K=1,M, are the tables at N incident energies for M cumulative probabilities. For each of these probabilities the J values are the following:

J	Description
1	cumulative probability
2	total cross section or total factor
3	elastic cross section or elastic factor
4	fission cross section or fission factor
5	(n,γ cross section or (n,γ) factor
6	neutron heating number or heating factor

The ordering of the probability-table entries is as follows:

M cumulative probabilities for energy I=1 (K=1 through K=M)

M total cross sections (or factors) for energy I=1 (K=1 through K=M)

...

M cumulative probabilities for energy I=2 (K=1 through K=M)

...

M neutron heating numbers (or factors) for energy I=N (K=1 through K=M)

Notes: The cumulative probabilities are monotonically increasing from an implied lower value of zero to the upper value of P(I,1,K=M)=1.0. The total cross section, P(I,2,J), is not used in MCNPX; the total is recalculated from sampled partials to avoid round-off error. The (n,γ) cross section is radiative capture only; it is not the usual MCNPX "capture" cross section, which is really absorption or destruction with other no-neutron-out reactions.

F.5 DATA BLOCKS FOR DOSIMETRY TABLES

Dosimetry tables (NTY=3) provide cross sections that are useful as response functions with the FM feature in MCNPX. They can never be used for actual neutron transport. Therefore, there is a more limited set of information available on dosimetry tables than on neutron transport tables (NTY=1 or 2). Only three blocks of data exist on dosimetry tables. A description of the three blocks follow, with the table numbers in which their formats are detailed.

1. MTR Block—contains a list of the MT numbers for all reactions provided on the table. The MTR Block always exists on dosimetry tables. The format of the block is identical to that of the MTR Block previously described for neutron transport tables. See Table F-6.
2. LSIG Block—contains a list of cross-section locators for all reactions provided on the table. The LSIG Block always exists on dosimetry tables. The format of the block is identical to that of the LSIG Block previously described for neutron transport tables. See Table F-9.
3. SIGD Block—contains (energy, cross-section) pairs for all reactions provided on the table. The SIGD Block always exists on dosimetry tables. See Table F-22.

Table F-22. SIGD Block

Location in XSS	Description
JXS(7)+LOCA$_1$-1	Cross-section array* for reaction MT$_1$
JXS(7)+LOCA$_2$-1	Cross-section array* for reaction MT$_2$
. . .	. . .
JXS(7)+LOCA$_{NXS(4)}$-1	Cross-section array* for reaction MT$_{NXS(4)}$

*The i^{th} array is of the form:

Location in XSS	Parameter	Description
JXS(7)+LOCA$_i$-1	NR	Number of interpolation regions
JXS(7)+LOCA$_i$	NBT(I),I=1,NR	ENDF interpolation parameters. If NR=0, NBT and INT are omitted and linear-linear interpolation is assumed.
JXS(7)+LOCA$_i$+NR	INT(I),I=1,NR	
JXS(7)+LOCA$_i$+2*NR	NE	Number of (energy,cross-section) pairs
JXS(7)+LOCA$_i$+1+2*NR	E(I),I=1,NE	Energies
JXS(7)+LOCA$_i$+1+2*NR+NE	σ(I),I=1,NE	Cross sections

Note: The locators (LOCA$_i$) are provided in the LSIG Block. The MT$_i$s are given in the MTR Block.

F.6 DATA BLOCKS FOR THERMAL $S(\alpha,\beta)$ TABLES

Data from thermal $S(\alpha,\beta)$ tables (NTY=4) provide a complete representation of thermal neutron scattering by molecules and crystalline solids. Cross sections for elastic and inelastic scattering are found on the tables (typically for neutron energies below 4 eV). A coupled energy/angle representation is used to describe the spectra of inelastically scattered neutrons. Angular distributions for elastic scattering are also provided.

Four unique blocks of data are associated with $S(\alpha,\beta)$ tables. Each of the four data blocks is described briefly. Also provided are the table numbers in which their formats are detailed.

1. ITIE Block—contains the energy-dependent inelastic scattering cross sections. The ITIE Block always exists. See Table F-23.
2. ITCE Block—contains the energy-dependent elastic scattering cross sections. The ITCE Block exists if JXS(4)≠0. See Table F-24.
3. ITXE Block—contains coupled energy/angle distributions for inelastic scattering. The ITXE Block always exists. See Table F-25.

4. ITCA Block—contains angular distributions for elastic scattering. The ITCA Block exists if JXS(4)≠0 and NXS(6)≠−1. See Table F-26.

Table F-23. ITIE Block

Location in XSS	Parameter	Description
JXS(1)	NE_{in}	Number of inelastic energies
JXS(1)+1	$E_{in}(I),I=1,NE_{in}$	Energies
JXS(1)+1+NE_{in}	$\sigma_{in}(I),I=1,NE_{in}$	Inelastic cross sections

Note: JXS(2)=JXS(1)+1+NE_{in}. Linear-linear interpolation is assumed between adjacent energies.

Table F-24. ITCE Block

Location in XSS	Parameter	Description
JXS(4)	NE_{el}	Number of elastic energies
JXS(4)+1	$E_{el}(I),I=1,NE_{el}$	Energies
JXS(4)+1+NE_{el}	$P(I),I=1,NE_{el}$	(See Below)
If NXS(5)≠4: $\sigma_{el}(I)=P(I)$, with linear-linear interpolation between points If NXS(5)=4: $\sigma_{el}(E)=P(I)/E$, for $E_{el}(I)<E\leq E_{el}(I+1)$		

Note: JXS(5)=JXS(3)+1+NE_{el}

Table F-25. ITXE Block

For NXS(2)=3 (equally likely cosines; currently the only scattering mode allowed for inelastic angular distributions)		
Location in XSS	**Parameter**	**Description**
JXS(3)	$E_1^{OUT}\left[E_{in}(1)\right]$	First of NXS(4) equally likely outgoing energies for inelastic scattering at $E_{in}(1)$
JXS(3)+1	$\mu_I(1\rightarrow 1)$, I=1,NXS(3)+1	Equally likely discrete cosines for scattering from $E_{in}(1)$ to $E_1^{OUT}\left[E_{in}(1)\right]$
JXS(3)+2+NXS(3)	$E_2^{OUT}\left[E_{in}(1)\right]$	Second of NXS(4) equally likely outgoing energies for inelastic scattering at $E_{in}(1)$
JXS(3)+3+NXS(3)	$\mu_I(1\rightarrow 2)$, I=1,NXS(3)+1	Equally likely discrete cosines for scattering from $E_{in}(1)$ to $E_2^{OUT}\left[E_{in}(1)\right]$
. . .	. . .	. . .
JXS(3)+(NXS(4)−1)*(NXS(3)+2)	$E_{NXS(4)}^{OUT}\left[E_{in}(1)\right]$	Last of NXS(4) equally likely outgoing energies for inelastic scattering at $E_{in}(1)$

For NXS(2)=3 (equally likely cosines; currently the only scattering mode allowed for inelastic angular distributions)		
Location in XSS	**Parameter**	**Description**
JXS(3)+(NXS(4)−1)*(NXS(3)+2)+1	$\mu_I\left(1 \rightarrow \mathrm{NXS(4)}\right)$, I=1,NXS(3)+1	Equally likely discrete cosines for scattering from $E_{in}(1)$ to $E^{OUT}_{\mathrm{NXS(4)}}\left[E_{in}(1)\right]$
. . .	. . .	. . .
(Repeat for all remaining values of E_{in})		.
. . .	. . .	. . .

Note: Incident inelastic energy grid $E_{in}(I)$ is given in ITIE Block. Linear-linear interpolation is assumed between adjacent values of E_{in}.

Table F-26. ITCA Block

Location in XSS	Parameter	Description
JXS(6)	$\mu_I\left[E_{el}(1)\right]$, I=1,NXS(6)+1	Equally likely discrete cosines for elastic scattering at $E_{el}(1)$
JXS(6)+NXS(6)+1	$\mu_I\left[E_{el}(2)\right]$, I=1,NXS(6)+1	Equally likely discrete cosines for elastic scattering at $E_{el}(2)$
. . .	. . .	. . .
JXS(6)+(NE$_{el}$−1)*(NXS(6)+1)	$\mu_I\left[E_{el}(\mathrm{NE}_{el})\right]$, I=1,NXS(6)+1	Equally likely discrete cosines for elastic scattering at $E_{el}(NE_{el})$

Note: Incident elastic energy grid $E_{el}(I)$ and number of energies NE_{el} are given in ITCE Block. Linear-linear interpolation is assumed between adjacent values of E_{el}.

F.7 DATA BLOCKS FOR PHOTON TRANSPORT TABLES

Only five data blocks are found on photon transport tables (NTY=5). Information contained on the blocks includes the following: cross sections for coherent and incoherent scattering, pair production, and the photoelectric effect; scattering functions and form factors that modify the differential Klein-Nishina and Thomson cross sections; energy deposition data; and fluorescence data. The five data blocks follow, with brief descriptions and table numbers where detailed formats may be found.

1. ESZG Block—contains the coherent, incoherent, photoelectric, and pair-production cross sections, all tabulated on a common energy grid. The ESZG Block always exists. See Table F-27.

2. JINC Block—contains the incoherent scattering functions that are used to modify the differential Klein-Nishina cross section. The JINC Block always exists. See Table F-28.
3. JCOH Block—contains the coherent form factors that are used to modify the differential Thomson cross section. The JCOH Block always exists. See Table F-29.
4. JFLO Block—contains fluorescence data. The JFLO Block exists if NXS(4)≠0. See Table F-30.
5. LHNM Block—contains average heating numbers. The LHNM Block always exists. See Table F-31.

Table F-27. ESZG Block

Location in XSS	Parameter	Description
JXS(1)	ln[E(l),l=1,NXS(3)]	Logarithms of energies
JXS(1)+NXS(3)	ln[σ_{IN}(l),l=1,NXS(3)]	Logarithms of incoherent cross sections
JXS(1)+2*NXS(3)	ln[σ_{CO}(l),l=1,NXS(3)]	Logarithms of coherent cross sections
JXS(1)+3*NXS(3)	ln[σ_{PE}(l),l=1,NXS(3)]	Logarithms of photoelectric cross sections
JXS(1)+4*NXS(3)	ln[σ_{PP}(l),l=1,NXS(3)]	Logarithms of pair production cross sections

Note: Linear-linear interpolation is performed on the logarithms as stored, resulting in effective log-log interpolation for the cross sections. If a cross section is zero, a value of 0.0 is stored on the data table.

Table F-28. JINC Block

Location in XSS	Parameter	Description
JXS(2)	FF_{INC}(l),l=1,21	Incoherent scattering functions

Note: The scattering functions for all elements are tabulated on a fixed set of v(l), where v is the momentum of the recoil electron (in inverse angstroms). The grid is: v(l),l=1,21 / 0. , .005 , .01 , .05 , .1 , .15 , .2 , .3 , .4 , .5 , .6 , .7 , .8 , .9 , 1. , 1.5 , 2. , 3. , 4. , 5. , 8. /
Linear-linear interpolation is assumed between adjacent v(l).
The constants v(l) are stored in the VIC array in common block RBLDAT.

Table F-29. JCOH Block

Location in XSS	Parameter	Description
JXS(3)	$FFINT_{COH}(I),I=1,55$	Integrated coherent form factors
JXS(3)+55	$FF_{COH}(I),I=1,55$	Coherent form factors

Note: The form factors for all elements are tabulated on a fixed set of v(I), where v is the momentum transfer of the recoil electron (in inverse angstroms). The grid is: v(I),I=1,55 / 0., .01, .02, .03, .04, .05, .06, .08, .10, .12, .15, .18, .20, .25, .30, .35, .40, .45, .50, .55, .60, .70, .80, .90, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0 /
The integrated form factors are tabulated on a fixed set of $v(I)^2$, where the v(I) are those defined above. See LA-5157-MS for a description of the integrated form factors and the sampling technique used in MCNPX. The constants v(I) are stored in the VCO array. The constants $v(I)^2$ are stored in the WCO array. Both arrays are in common block RBLDAT.

Table F-30. JFLO Block

Location in XSS	Parameter	Description
JXS(4)	e(1),...,e(NXS(4))	(See Below)
JXS(4)+NXS(4)	Φ(1),...,Φ(NXS(4))	(See Below)
JXS(4)+2*NXS(4)	Y(1),...,Y(NXS(4))	(See Below)
JXS(4)+3*NXS(4)	F(1),...,F(NXS(4))	(See Below)
. . .	. . .	. . .

A complete description of the parameters given in this block can be found in LA-5240-MS. Briefly:
- e(I) are the edge energies
- Φ(I) are relative probabilities of ejection from various shells
- Y(I) are yields and
- F(I) are fluorescent energies.

Table F-31. LHNM Block

Location in XSS	Parameter	Description
JXS(5)	$H_{ave}(I),I=1,NXS(3)$	Average heating numbers

Note: Log-log interpolation is performed between adjacent heating numbers. The units of H_{ave} are MeV per collision. Heating numbers are tabulated on the energy grid given in the ESZG Block.

F.8 FORMAT FOR MULTIGROUP TRANSPORT TABLES

Table F-32. NXS Array

Parameter		Description
NXS(1)	LDB	Length of second block of data
NXS(2)	ZA	1000*Z+A for neutrons, 1000*Z for photons
NXS(3)	NLEG	Number of angular distribution variables
NXS(4)	NEDIT	Number of edit reactions
NXS(5)	NGRP	Number of groups
NXS(6)	NUS	Number of upscatter groups
NXS(7)	NDS	Number of downscatter groups
NXS(8)	NSEC	Number of secondary particles
NXS(9)	ISANG	Angular distribution type ISANG=0 for equiprobable cosines bins ISANG=1 for discrete cosines
NXS(10)	NNUBAR	Number of nubars given
NXS(11)	IBFP	Boltzmann-Fokker-Planck indicator IBFP=0 for Boltzmann only IBFP=1 for Boltzmann-Fokker-Planck IBFP=2 for Fokker-Planck only
NXS(12)	IPT	Identifier for incident particle IPT=1 for neutrons IPT=2 for photons IPT=0 for other particles (temporary)
NXS(13)–NXS(16) are presently unused		
All data in the NXS Array is appropriate for the incident particle only.		

Table F-33. JXS Array

Parameter		Description
JXS(1)	LERG	Location of incident particle group structure=1
JXS(2)	LTOT	Location of total cross sections
JXS(3)	LFISS	Location of fission cross sections
JXS(4)	LNU	Location of nubar data
JXS(5)	LCHI	Location of fission chi data
JXS(6)	LABS	Location of absorption cross sections
JXS(7)	LSTOP	Location of stopping powers
JXS(8)	LMOM	Location of momentum transfers

Parameter		Description
JXS(9)	LMTED	Location of edit reaction numbers
JXS(10)	LXSED	Location of edit cross sections
JXS(11)	LIPT	Location of secondary particle types
JXS(12)	LERG2L	Location of secondary group structure locators
JXS(13)	LPOL	Location of P0 locators
JXS(14)	LSANG2	Location of secondary angular distribution types
JXS(15)	LNLEG2	Location of number of angular distribution variables for secondaries
JXS(16)	LXPNL	Location of XP_N locators
JXS(17)	LPNL	Location of P_N locators
JXS(18)	LSIGMA	Location of SIGMA Block locators
JXS(19)	LSIGSC	Location of cumulative P0 scattering cross sections
JXS(20)	LSIGSCS	Location of cumulative P0 scattering cross sections to secondary particle

Note: JXS(18)–JXS(20) are calculated and used internally in MCNPX. These parameters have a value of 0 on the cross-section file. JXS(21)–JXS(32) are presently unused.

Table F-34. ERG Block

Location	Parameter	Description
JXS(1)	ECENT(1)	Center energy of Group 1
. . .	. . .	. . .
JXS(1)+NXS(5)–1	ECENT(NXS(5))	Center energy of Group NXS(5)
JXS(1)+NXS(5)	EWID(1)	Width of Group 1
. . .	. . .	. . .
JXS(1)+2*NXS(5)–1	EWID(NXS(5))	Width of Group NXS(5)
JXS(1)+2*NXS(5)	GMASS(1)	Mass of Group-1 particle
. . .	. . .	. . .
JXS(1)+3*NXS(5)–1	GMASS(NXS(5))	Mass of Group-NXS(5) particle

Notes: Group masses are given only if NXS(12)=0. All entries are in MeV. Group energies are descending, unless NXS(12)=0, in which case there may be discontinuities.

Length: 2*NXS(5) if NXS(12)≠0;3*NXS(5) if NXS(12)=0

Exists: Always

Table F-35. TOT Block

Location	Parameter	Description
JXS(2)	SIGTOT(1)	Total cross section in Group 1
. . .	. . .	. . .
JXS(2)+NXS(5)−1	SIGTOT(NXS(5))	Total cross section in Group NXS(5)

Note: Length: NXS(5)
Exists: If JXS(2)≠0

Table F-36. FISS Block

Location	Parameter	Description
JXS(3)	SIGFIS(1)	Fission cross section in Group 1
. . .	. . .	. . .
JXS(3)+NXS(5)−1	SIGFIS(NXS(5))	Fission cross section in Group NXS(5)

Note: Length: NXS(5)
Exists: If JXS(3)≠0

Table F-37. NU Block

Location	Parameter	Description
JXS(4)	NUBAR(1)	See below
. . .	. . .	. . .
JXS(4)+NXS(10)*NXS(5)−1	NUBAR(NXS(10),NXS(5))	See below

Note: If NXS(10)=1, then one set of nubars is given (NUBAR(1)→NUBAR(NXS(5))). The nubars may be either prompt or total.

If NXS(10)=2, then both prompt and total nubars are given. In this case, NUBAR(1)→NUBAR(NXS(5)) are prompt nubars and NUBAR(NXS(5)+1)→NUBAR(2,NXS(5)) are total nubars.

Length: NXS(5)*NXS(10)

Exists: If JXS(3)≠0

Table F-38. CHI Block

Location	Parameter	Description
JXS(5)	FISFR(1)	Group 1 fission fraction
⋮	⋮	⋮
JXS(5)+NXS(5)−1	FISFR(NXS(5))	Group NXS(5) fission fraction

Note The fission fractions are normalized so that their sum is 1.0.
Length: NXS(5)
Exists: If JXS(3)≠0

Table F-39. ABS Block

Location	Parameter	Description
JXS(6)	SIGABS(1)	Absorption cross section in Group 1
⋮	⋮	⋮
JXS(6)+NXS(5)−1	SIGABS(NXS(5))	Absorption cross section in Group NXS(5)

Note: Length: NXS(5)
Exists: If JXS(6)≠0

Table F-40. STOP Block

Location	Parameter	Description
JXS(7)	SPOW(1)	Stopping power in Group 1
⋮	⋮	⋮
JXS(7)+NXS(5)−1	SPOW(NXS(5))	Stopping power in Group NXS(5)

Note: Length: NXS(5)
Exists: If JXS(7)≠0

Table F-41. MOM Block

Location	Parameter	Description
JXS(8)	MOMTR(1)	Momentum transfer in Group 1
⋮	⋮	⋮
JXS(8)+NXS(5)−1	MOMTR(NXS(5))	Momentum transfer in Group NXS(5)

Note: Length: NXS(5)
Exists: If JXS(8)≠0

Table F-42. MTED Block

Location	Parameter	Description
JXS(9)	MT(1)	Identifier for edit reaction 1
⋮	⋮	⋮
JXS(9)+NXS(4)−1	MT(NXS(4))	Identifier for edit reaction NXS(4)

Note: Length: NXS(4)
Exists: If JXS(4)≠0

Table F-43. XSED Block

Location	Parameter	Description
JXS(10)	XS(1,1)	Edit cross section for reaction 1, Group 1
⋮	⋮	⋮
JXS(10)+NXS(5)−1	XS(1,NXS(5))	Edit cross section for reaction 1, Group NXS(5)
⋮	⋮	⋮
JXS(10)+(NXS(4)−1)*(NXS(5))	XS(NXS(4),1)	Edit cross section for reaction NXS(4), Group 1
⋮	⋮	⋮
JXS(10)+NXS(4)*NXS(5)−1	XS(NXS(4), NXS(5))	Edit cross section for reaction NXS(4), Group NXS(5)

Note: Length: NXS(4)*NXS(5)
Exists: If JXS(4)≠0

Table F-44. IPT Block

Location	Parameter	Description
JXS(11)	IPT(1)	Identifier for secondary particle 1
⋮	⋮	⋮
JXS(11)+NXS(8)−1	IPT(NXS(8))	Identifier for secondary particle NXS(8)

Note: Present values of IPT are: IPT=1 for neutrons, IPT=2 for photons
Length: NXS(8)
Exists: If JXS(8)≠0

Table F-45. ERG2L Block

Location	Parameter	Description
JXS(12)	LERG2(1)	Location of ERG2 Block* for secondary particle 1
. . .	. . .	. . .
JXS(12)+NXS(8)−1	LERG2(NXS(8))	Location of ERG2 Block* for secondary particle NXS(8)

Note: Length: NXS(8)
Exists: If JXS(8)≠0

*The ERG2 Block for secondary particle *i* is of the form:

Location	Parameter	Description
LERG2(*i*)	NERG(*i*)	Number of energy groups for secondary particle *i*
LERG2(*i*)+1	ECENT2(1)	Center energy of Group 1 for secondary particle *i*
. . .	. . .	. . .
LERG2(*i*)+NERG(*i*)	ECENT2(NERG(*i*))	Center energy of Group NERG(*i*) for secondary particle i
LERG2(*i*)+NERG(*i*)+1	EWID2(1)	Width of Group 1 for secondary particle *i*
. . .	. . .	. . .
LERG2(*i*)+2*NERG(*i*)	EWID2(NERG(*i*))	Width of Group NERG(*i*) for secondary particle *i*

Note: Values of LERG2(*i*) are from ERG2L Block. Group energies are descending.
Length: 2*NERG(*i*)+1
Exists: If NXS(8)≠0, then ERG2 Block is repeated NXS(8) times.

Table F-46. POL Block

Location	Parameter	Description
JXS(13)	LPO(1)	Location of P0 Block* for incident particle
. . .	. . .	. . .
JXS(13)+NXS(8)	.LPO(NXS(8)+1)	Location of P0 Block* for secondary particle NXS(8)

Note: Length: NXS(8)+1
Exists: If JXS(13)≠0

*The PO Block for particle *i* is of the form:

Location	Parameter	Description
LPO(*i*)	SIG(1→1)	P0 cross section for scattering from incident particle Group 1 to exiting particle Group 1
. . .	. . .	. . .
LPO(*i*+L−1)	SIG(NXS(5)→K)	P0 cross section for scattering from incident particle group NXS(5) to exiting particle Group K

Note: See Table F-54 for a complete description of the ordering and length of the P0 block.
Exists: If JXS(13)≠0, then the P0 Block is repeated NXS(8)+1 times.

Table F-47. SANG2 Block

Location	Parameter	Description
JXS(14)	ISANG2(1)	Angular distribution type for secondary particle 1
. . .	. . .	. . .
JXS(14)+NXS(8)−1	ISANG2(NXS(8))	Angular distribution type for secondary particle NXS(8)

Note: ISANG2(*i*)=0 for equiprobable cosine bins; ISANG2(*i*)=1 for discrete cosines.
Length: NXS(8)
Exists: If JXS(8)≠0.

Table F-48. NLEG2 Block

Location	Parameter	Description
JXS(15)	NLEG2(1)	Number of angular distribution variables for secondary particle 1
. . .	. . .	. . .
JXS(15)+NXS(8)−1	NLEG2(NXS(8))	Number of angular distribution variables for secondary particle NXS(8)

Note: Length: NXS(8)
Exists: If JXS(8)≠0.

Table F-49. XPNL Block

Location	Parameter	Description
JXS(16)	LXPN(1)	Location of XPN Block* for incident particle
. . .	. . .	. . .
JXS(16)+NXS(8)	LXPN(NXS(8)+1)	Location of XPN Block* for secondary particle NXS(8)

Note: If LXPN(*i*)=0, then all possible scattering is isotropic and no XPN block exists.
Length: NXS(8)+1
Exists: If JXS(13)≠0.

*The XPN Block for particle *i* is of the form:

Location	Parameter	Description
LXPN(*i*)	LPND(1→1)	Location of PND Block† for scattering from incident particle Group 1 to exiting particle Group 1
. . .	. . .	. . .
LXPN(*i*+L−1)	LPND(NXS(5)→K)	Location of PND Block† for scattering from incident particle Group NXS(5) to exiting particle Group K

† Note: See Table F-50 for a description of the PND Block
Note: See Table F-54 for a complete description of the ordering and length of the XPN Block. Also see the notes to the PN Block in for more complete description of the meanings of the LPND parameters.
Exists: If JXS(13)≠0, then the XPN Block is repeated NXS(8)+1 times.

Table F-50. PNL Block

Location	Parameter	Description
JXS(17)	LPN(1)	Location of PN Block* for incident particle
. . .	. . .	. . .
JXS(17)+NXS(8)	LPN(NXS(8)+1)	Location of PN Block* for secondary particle NXS(8)

Note: If LPN(i)=0, then all possible scattering is isotropic and no PN Block exists.
Length: NXS(8)+1
Exists: If JXS(13)≠0.

*The PN Block for particle *i* is of the form:

Location	Parameter	Description
LPN(*i*)+LPND(1→1)−1	PND(1→1,I) I=1,NLEG(*i*)	Angular distribution data for scattering from incident particle Group 1 to exiting particle Group 1
. . .	. . .	. . .
LPN(*i*)+LPND(NXS(5)→K)−1	PND(NXS(5)→K,I), I=1, NLEG(*i*)	Angular distribution data for scattering from incident particle Group NXS(5) to exiting particle Group K

Note: Values of LPND are from the XPN Block (see Table F-49). Values of LPN(*i*) are from the PNL Block. If LPND>0, then data exists in the PN Block as described above. If LPND=0, scattering is isotropic in the laboratory system and no data exist in the PN Block. If LPND=−1, then scattering is impossible for the combination of incident and exiting groups; again no data exist in the PN Block. The appropriate value of NLEG is found in Table F-32 or Table F-48. The value of ISANG (from Table F-32 or Table F-47) determines what data are found in the PND array. If ISANG=0, then PND contains NLEG cosines, which are boundaries of NLEG-1 equiprobable cosine bins. If ISANG=1, then PND contains (NLEG1)/2 cumulative probabilities followed by (NLEG+1)/2 discrete cosines. The cumulative probability corresponding to the final discrete cosine is defined to be 1.0.

Exists: If JXS(13)≠0, then the PN Block is repeated NXS(8)+1 times.

Table F-51. SIGMA Block*

Location	Parameter	Description
JXS(18)	$SCAT_{gg}(1)$	Location of the within-group scattering cross section for group 1 within the P0 Block
. . .	. . .	. . .
JXS(18)+NXS(5)−1	$SCAT_{gg}(NXS(5))$	Location of the within-group scattering cross section for group NXS(5) in the P0 Block

* Note: The SIGMA, SIGSC, and SIGSCS Blocks are calculated and used internally within MCNPX and do not actually appear on the cross-section file.

Table F-52. SIGSC Block*

Location	Parameter	Description
JXS(19)	SIGSC(1)	Total P0 scattering cross section for group 1 excluding scattering to secondary particle
. . .	. . .	. . .
JXS(19)+NXS(5)−1	SIGSC(NXS(5))	Total P0 scattering cross section for group NXS(5) excluding scattering to secondary particle

* Note: The SIGMA, SIGSC, and SIGSCS Blocks are calculated and used internally within MCNPX and do not actually appear on the cross-section file.

Table F-53. SIGSCS Block*

Location	Parameter	Description
JXS(20)	SIGSCS(1)	Total P0 scattering cross section to a secondary particle for group 1
. . .	. . .	. . .
JXS(20)+NXS(5)-1	SIGSCS(NXS(5))	Total P0 scattering cross section to a secondary particle for group NXS(5)

* Note: The SIGMA, SIGSC, and SIGSCS Blocks are calculated and used internally within MCNPX and do not actually appear on the cross-section file.

Table F-54. Additional Information for P0 and XPN Blocks

1. Ordering

Entries in these blocks always start with data for scattering from the highest energy group of the incident particle to the highest energy group of the exiting particle. The last entry is always data for scattering from the lowest energy group of the exiting particle. The remaining entries are ordered according to the following prescription:

X(1→J), J=I1(1), I2(1),
X(2→J), J=I1(2), I2(2),
.
.
.
X(NXS(5)→J), J=I1(NXS(5)), I2(NXS(5)).

If the incident and exiting particles are the same:

I1(K)=MAX(1,K-NXS(6)),
I2(K)=MIN(NXS(5),K+NXS(7)).

If the incident and exiting particles are different:

I1(K)=1,
I2(K)=NERG(*i*) for the appropriate secondary particle from Table F-45.

2. Length

If the incident and exiting particles are the same:

$$L = NXS(5) * (1 + NXS(7) + NXS(6)) - \frac{\left(NXS(7) * \left(NXS(7)+1\right)\right) + \left(NXS(6) * \left(NXS(6)+1\right)\right)}{2}$$

If the incident and exiting particles are different:

L=NXS(5)*NERG(*i*), where NERG(*i*) is for the appropriate secondary particle from Table F-45.

F.9 CONVERTING CROSS-SECTION FILES WITH MAKXS

The auxiliary code MAKXS can be used to convert cross-section libraries from one format to another and to construct custom-designed cross-section libraries.

MCNPX can read cross-section data from two types of files. Type-1 files are formatted and have sequential access. Type-2 files are unformatted and have direct access. The cross-section files distributed by RSICC are all Type-1 files because Type-1 files are portable. But reading large formatted files is slow and formatted files are more bulky than unformatted files. The portable auxiliary program MAKXS has been provided for translating big, slow, portable, Type-1 files into compact, fast, unportable (but still in compliance with FORTRAN 77, 90, and 95), Type-2 files. You can also use MAKXS to delete cross-section tables that you do not need and to reorganize the cross-section tables into custom-designed cross-section libraries.

MAKXS must be preprocessed and compiled in a manner similar to that described for MCNPX. The PATCH file consists only of the same *DEFINE directive used for MCNPX.

The input files to MAKXS are one or more existing cross-section libraries, a directory file that describes the input cross-section libraries, and a file called SPECS that tells MAKXS what it is supposed to do. The output files are one or more new cross-section libraries, a new directory file that describes the new cross-section libraries, and a file called TPRINT that contains any error messages generated during the run. The input and output cross-section libraries can be any combination of Type-1 and Type-2 files. The various types of cross-section libraries and the form and contents of the cross-section directory file are described in detail earlier in this appendix. The directory file XSDIR in the MCNPX code package contains complete descriptions of all of the cross-section files in that package. You might print XSDIR and keep the listing as a reference that will tell you what cross-section tables you actually have on hand. The sample SPECS file in the MCNPX code package is provided not only as an example of the correct form for a SPECS file but also as one that will be immediately useful to many users. With SPECS and MAKXS you can create a complete set of Type-2 files from the Type-1 files in the MCNPX code package.

The SPECS file is a formatted sequential file with records not exceeding 80 characters in length. The data items in each record may start in any column and are delimited by blanks. The contents of the file are given in Table F--55.

Table F--55

Record	Contents		
1	name of old dir file	name of new dir file	
2	name of old xs lib*	name of new xs lib	Type Recl* Epr*
3	access route* entered into new directory file (or blank line)		
4 +	nuclide list, if old xs lib is absent		
Blank record			

Where * = optional
Recl = record length; default is 4096, 2048, or 512, depending on system
Epr = entries per record; default is 512

Records 2 through 4+ can be repeated any number of times with data for additional new cross-section libraries. The SPECS file ends with a blank record. If "name of old cross-section library" exists on record 2, all nuclides from that library will be converted.

Table F-56

Record	Contents				
1	xsdir1	xsdir2			
2	el1	el2	2	4096	512
3	home/scratch/el2				
4	rmccsab2 2				
5	datalib/rmccsab2				
6	7015.55c				
7	1001.50c				
8	blank record				

In Table F-56, the SPECS file starts with Type-1 directory XSDIR1, electron library EL1, and neutron libraries RMCCSA1 and RMCCS1. All nuclides on the electron data file EL1 are to be converted to a Type-2 file called EL2. For electron files only, all data is double precision, so for 512 entries per record (Epr) the record length (Recl) will be 4096 on both Cray and UNIX systems. Records 4–7 tell MAKXS to search all libraries listed in XSDIR1 until it finds nuclides 7015.55c and 1001.50c (which happen to be on RMCCSA1 and RMCCS1, respectively) and construct a new Type-2 library RMCCSAB2 consisting only of these nuclides. The entries per record (Epr) and record length (Recl) will be defaulted. The new directory file XSDIR2 will tell MCNPX to look for the electron cross sections in `/home/scratch/el2` and for the neutron cross sections in `/datalib/rmccsab2`.

If the Type of the new cross-section file is specified to be 1 in record 2, only the name of the new cross-section file and the 1 for the Type are read in that record. If the Type in record 2 is 2, the record length and the number of entries per record can be specified in case the defaults in MAKXS are wrong for your system. If the record length is in words, it must be set equal to the number of entries per record (Recl=Epr). If the record length is in bytes, Recl=4Epr for CHEAP systems with 32-bit numeric storage units (except for electrons) and Recl=8Epr for electron data and systems with 64-bit numeric storage units. The best value to use for the number of entries per record depends on the characteristics of the secondary storage, usually disks, on your computer system. If the number of entries is too large, there will be a lot of wasted space in the file because of the partial record at the end of each cross-section table. If the number of entries is too small, reading may be slow because of the large number of accesses. For many systems the default value, Epr=512, is a good value. If you intend to use the SPECS file from the MCNPX code package, be sure that the values of the record length and number of entries per record are suitable for your system. The default is Epr=512 and Recl=4096, 2048 or 512 depending upon the kind of system as determined in the `*DEFINE` command when MAKXS is preprocessed by PRPR.

The access route on record 3 of the SPECS file is a concatenation of a datapath with the library name and becomes the fourth entry for each nuclide in the library in the XSDIR file.

It is not necessary to generate all the cross-section files that you will ever need in one MAKXS run. You can combine and edit directory files at any time with a text editor or with another MAKXS run. The only requirement is that you must give MCNPX a directory file that points to all the cross-section tables that are needed by the current problem. If you plan to run a long series of MCNPX problems that all use the same small set of cross-section tables, it might be convenient to generate with MAKXS a small special-purpose cross-section file and directory file just for your project.

There is another good use for MAKXS that has nothing to do with cross-section tables, which is to use it as a test code to see whether your computer system fully supports FORTRAN 90. You might compile MAKXS and convert the Type-1 cross-section files to Type-2 before tackling MCNPX. The small size of MAKXS makes it more convenient than MCNPX for this testing purpose.

APPENDIX G CROSS-SECTION LIBRARIES

This appendix is divided into ten sections, including the references. Section G.1 lists some of the more frequently used ENDF/B reaction types that can be used with the FM input card. Table G-1 in Section G.2 lists the currently available $S(\alpha,\beta)$ data available for use with the MT card. Section G.3 provides a brief description of the available continuous-energy and discrete neutron data libraries. Table G-2 in Section G.3 is a list of the continuous-energy and discrete neutron data libraries maintained by X-Division. Section G.4 describes the multigroup data library MGXSNP (Table G-3), Section G.5 the photoatomic data (Table G-4); Section G.6 the photonuclear data (Table G-5); and Section G.7 the dosimetry data libraries (Table G-6). These MCNP data libraries are distributed by the Radiation Safety Information Computational Center (RSICC).

Additional libraries available to MCNPX users include two electron data libraries, EL and EL03 (Section G.8), and the proton data library, LA150H (Section G.9).

G.1 ENDF/B REACTION TYPES

The following partial list includes some of the more useful reactions for use with the FM input card and with the cross-section plotter. The complete ENDF/B list can be found in the ENDF/B manual [MCL95]. The MT column lists the ENDF/B reaction number. The FM column lists special MCNPX reaction numbers that can be used with the FM card and cross-section plotter.

The nomenclature between MCNPX and ENDF/B is inconsistent in that MCNPX often refers to the number of the reaction type as R whereas ENDF/B uses MT, but they are the same. The problem arises because MCNPX has an MT input card used for the $S(\alpha,\beta)$ thermal treatment. However, the nomenclature between Monte Carlo transport and deterministic transport techniques can be radically different. The reference [FRA96c] provides more information.

Generally only a subset of reactions are available for a particular nuclide. Some reaction data are eliminated by MCNPX in cross-section processing if they are not required by the problem. Examples are photon production in a MODE N problem, or certain reaction cross sections not requested on an FM card. FM numbers should be used when available, rather than MT numbers. If an MT number is requested, the equivalent FM number will be displayed on the legend of cross-section plots.

APPENDIX G

Neutron Continuous-Energy and Discrete Reactions:

MT	FM	Microscopic Cross-Section Description
1	-1	Total (see note 1 following)
2	-3	Elastic (see note 1 following)
16		(*n*,2*n*)
17		(*n*,3*n*)
18		Total fission (*n*,*fx*) if and only if MT=18 is used to specify fission in the original evaluation.
	-6	Total fission cross section. (equal to MT=18 if MT=18 exists; otherwise equal to the sum of MTs 19, 20, 21, and 38.)
19		(*n*,*f*)
20		(*n*,*n'f*)
21		(*n*,2*nf*)
22		(*n*,*n'*α)
28		(*n*,*n'p*)
32		(*n*,*n'd*)
33		(*n*,*n't*)
38		(*n*,3*nf*)
51		(*n*,*n'*) to 1st excited state
52		(*n*,*n'*) to 2nd excited state
. . .		. . .
90		(*n*,*n'*) to 40th excited state
91		(*n*,*n'*) to continuum
101	–2	Absorption: sum of MT=102–117 (neutron disappearance; does not include fission)
102		(*n*,γ)
103		(*n*,*p*)
104		(*n*,*d*)
105		(*n*,*t*)
106		(*n*,^{3}He)
107		(*n*,α)

In addition, the following special reactions are available for many nuclides:

MT	FM	Microscopic Cross-Section Description
202	–5	Total photon production
203		Total proton production (see note 2 following)
204		Total deuterium production (see note 2 following)
205		Total tritium production (see note 2 following)
206		Total ^{3}He production (see note 2 following)
207		Total alpha production (see note 2 following)
301	–4	Average heating numbers (MeV/collision)
	–7	Nubar (prompt or total)
	–8	Fission Q (in `print table 98`, but not plots)

$S(\alpha,\beta)$:

MT	FM	Microscopic Cross-Section Description
1		Total cross section
2		Elastic scattering cross section
4		Inelastic scattering cross section

Neutron and Photon Multigroup:

MT	FM	Microscopic Cross-Section Description
1	–1	Total cross section
18	–2	Fission cross section
	–3	Nubar data
	–4	Fission chi data
101	–5	Absorption cross section
	–6	Stopping powers
	–7	Momentum transfers
n		Edit reaction *n*
202		Photon production
301		Heating number
318		Fission Q
401		Heating number times total cross section

APPENDIX G

Photoatomic Data:

MT	FM	Microscopic Cross-Section Description
501	−5	Total
504	−1	Incoherent (Compton + Form Factor)
502	−2	Coherent (Thomson + Form Factor)
522	−3	Photoelectric with fluorescence
516	−4	Pair production
301	−6	Heating number

Photonuclear Data:

MT	FM	Microscopic Cross-Section Description
	1	Total
	2	Non-elastic
	3	Elastic
	4	Heating
	5	Other
	1005	Neutron production from reaction 5
	2005	Photon production from reaction 5
	9005	Proton production from reaction 5

Electrons (see note 3 following):

MT	FM	Microscopic Cross-Section Description
	1	de/dx electron collision stopping power
	2	de/dx electron radiative stopping power
	3	de/dx total electron stopping power
	4	electron range
	5	electron radiation yield
	6	relativistic β^2
	7	stopping power density correction
	8	ratio of rad/col stopping powers
	9	drange
	10	dyield
	11	rng array values
	12	qav array values
	13	ear array values

Notes:

1. At the time they are loaded, the total and elastic cross sections from the data library are thermally adjusted by MCNPX to the temperature of the problem, if that temperature is different from the temperature at which the cross-section set was processed. If different cells have different temperatures, the cross sections first are adjusted to zero degrees and adjusted again to the appropriate cell temperatures during transport. The cross-section plot will *never* display the *transport* adjustment. Therefore, for plotting, reactions 1 and −1 are equivalent and reactions 2 and −3 are equivalent. But for the FM card, reactions −1 and −3 will use the zero-degree data and reactions 1 and 2 will use the transport-adjusted data. For example, if a library evaluated at 300° is used in a problem with cells at 400° and 500°, the cross-section plotter and MT=−1 and MT=−3 options on the FM card will use 0° data. The MT=1 and MT=2 options on the FM card will use 400° and 500° data.
2. The user looking for total production of p, d, t, ^{3}He, and ^{4}He should be warned that in some evaluations, such processes are represented using reactions with MT (or R) numbers other than the standard ones given in the above list. This is of particular importance with the so-called "pseudolevel" representation of certain reactions which take place in light isotopes. For example, the ENDF/B-V evaluation of carbon includes cross sections for the (n,n'3α) reaction in MT=52 to 58. The user interested in particle production from light isotopes should check for the existence of pseudolevels and thus possible deviations from the above standard reaction list.
3. LANL maintains two electron-transport libraries, EL and EL03. The electron transport algorithms and data in MCNPX were adapted from the ITS code [HAL92]. The EL library was developed and released in 1990 in conjunction with the addition of electron transport into MCNPX4; the electron-transport algorithms and data correspond (roughly) to that found in ITS version 1. The EL03 library [ADA00] was developed and released in 2000 in conjunction with upgrades to the electron physics package; these upgrades correspond (roughly) to that of ITS version 3.The MT numbers for use in plotting the cross-section values for these tables should be taken from `print table 85` column headings and are not from ENDF.

G.2 S(α,β) DATA FOR USE WITH THE MT CARD

Table G-1 lists all the *S*(α,β) data libraries that are maintained. The number(s) in parentheses following the description in words ([Beryllium Metal (4009)] specify the nuclides for which the *S*(α,β) data are valid. For example, lwtr.01t provides scattering

data only for ^{1}H; ^{16}O would still be represented by the default free-gas treatment. The entries in each of the columns of Table G-1 are described as follows:

ZAID → The table identification number to be specified on the MT cards. The portion of the ZAID before the decimal point provides a shorthand alphanumeric description of the material. The two digits after the decimal point differentiate among different tables for the same material. The final character in the ZAID is a "t," which indicates a thermal $S(\alpha,\beta)$ table.

Source → There are currently three evaluated sources of MCNPX $S(\alpha,\beta)$ tables:

(1) ENDF5—Indicates that the data were processed from evaluations distributed by the National Nuclear Data Center at Brookhaven National Laboratory as part of ENDF/B-V. Note that these evaluations were carried over from ENDF/B-III [KOP78].

(2) LANL89—Initial work on cold moderator scattering data performed at Los Alamos National Laboratory [MAC88, MAC91].

(3) ENDF6.3—Indicates that the data were processed from evaluations distributed by the National Nuclear Data Center at Brookhaven National Laboratory as part of ENDF/B-VI, Release 3 [MAC94b].

Library → Name of the library that contains the data file for that ZAID.

Date Processed → Date that the data table was processed by the NJOY code.

Temperature → The temperature of the data is Kelvin.

Number of Angles → The number of equally likely discrete secondary cosines provided at each combination of incident and secondary energy for inelastic scattering and for each incident energy for incoherent elastic scattering.

Number of Energies → The number of secondary energies provided for each incident energy for inelastic scattering.

Elastic Scattering Data → There are three options:

(1) none—no elastic scattering data for this material

(2) coh—coherent elastic scattering data provided for this material (Bragg scattering)

(3) inco—incoherent elastic scattering data provided for this material

Table G-1. Thermal $S(\alpha,\beta)$ Cross-Section Libraries

ZAID	Source	Library Name	Date of Processing	Temp (K)	Num of Angles	Num of Energies	Elastic Data

ZAID	Source	Library Name	Date of Processing	Temp (K)	Num of Angles	Num of Energies	Elastic Data
Beryllium Metal (4009)							
be.01t	endf5	tmccs	10/24/85	300	8	20	coh
be.04t	endf5	tmccs	10/24/85	600	8	20	coh
be.05t	endf5	tmccs	10/24/85	800	8	20	coh
be.06t	endf5	tmccs	10/24/85	1200	8	20	coh
be.60t	endf6.3	sab2002	09/13/99	294	16	64	coh
be.61t	endf6.3	sab2002	09/13/99	400	16	64	coh
be.62t	endf6.3	sab2002	09/13/99	600	16	64	coh
be.63t	endf6.3	sab2002	09/14/99	800	16	64	coh
be.64t	endf6.3	sab2002	09/14/99	1000	16	64	coh
be.65t	endf6.3	sab2002	09/14/99	1200	16	64	coh
be.69t	endf6.3	sab2002	09/17/99	77	16	64	coh
Benzene (1001, 6000, 6012)							
benz.01t	endf5	tmccs	09/08/86	300	8	32	none
benz.02t	endf5	tmccs	09/08/86	400	8	32	none
benz.03t	endf5	tmccs	09/08/86	500	8	32	none
benz.04t	endf5	tmccs	09/08/86	600	8	32	none
benz.05t	endf5	tmccs	09/08/86	800	8	32	none
benz.60t	endf6.3	sab2002	09/14/99	294	16	64	none
benz.61t	endf6.3	sab2002	09/14/99	400	16	64	none
benz.62t	endf6.3	sab2002	09/14/99	600	16	64	none
benz.63t	endf6.3	sab2002	09/14/99	800	16	64	none
Beryllium Oxide (4009, 8016)							
beo.01t	endf5	tmccs	09/08/86	300	8	32	coh
beo.04t	endf5	tmccs	09/08/86	600	8	32	coh
beo.05t	endf5	tmccs	09/08/86	800	8	32	coh
beo.06t	endf5	tmccs	09/08/86	1200	8	32	coh
beo.60t	endf6.3	sab2002	09/14/99	294	16	64	coh
beo.61t	endf6.3	sab2002	09/14/99	400	16	64	coh
beo.62t	endf6.3	sab2002	09/14/99	600	16	64	coh
beo.63t	endf6.3	sab2002	09/14/99	800	16	64	coh
beo.64t	endf6.3	sab2002	09/14/99	1000	16	64	coh
beo.65t	endf6.3	sab2002	09/14/99	1200	16	64	coh
Ortho Deuterium (1002)							
dortho.01t	lanl89	therxs	05/30/89	20	8	8	none
dortho.60t	endf6.3	sab2002	09/16/99	19	16	64	none
Para Deuterium (1002)							
dpara.01t	lanl89	therxs	05/30/89	20	8	8	none
dpara.60t	endf6.3	sab2002	09/16/99	19	16	64	none
Graphite (6000,6012)							
grph.01t	endf5	tmccs	09/08/86	300	8	32	coh
grph.04t	endf5	tmccs	09/08/86	600	8	32	coh
grph.05t	endf5	tmccs	09/08/86	800	8	32	coh
grph.06t	endf5	tmccs	09/08/86	1200	8	32	coh
grph.07t	endf5	tmccs	09/08/86	1600	8	32	coh
grph.08t	endf5	tmccs	09/08/86	2000	8	32	coh

ZAID	Source	Library Name	Date of Processing	Temp (K)	Num of Angles	Num of Energies	Elastic Data
grph.60t	endf6.3	sab2002	09/14/99	294	16	64	coh
grph.61t	endf6.3	sab2002	09/14/99	400	16	64	coh
grph.62t	endf6.3	sab2002	09/14/99	600	16	64	coh
grph.63t	endf6.3	sab2002	09/14/99	800	16	64	coh
grph.64t	endf6.3	sab2002	09/14/99	1000	16	64	coh
grph.65t	endf6.3	sab2002	09/14/99	1200	16	64	coh
Hydrogen in Zirconium Hydride (1001)							
h/zr.01t	endf5	tmccs	10/22/85	300	8	20	inco
h/zr.02t	endf5	tmccs	10/22/85	400	8	20	inco
h/zr.04t	endf5	tmccs	10/22/85	600	8	20	inco
h/zr.05t	endf5	tmccs	10/22/85	800	8	20	inco
h/zr.06t	endf5	tmccs	10/22/85	1200	8	20	inco
h/zr.60t	endf6.3	sab2002	09/14/99	294	16	64	inco
h/zr.61t	endf6.3	sab2002	09/14/99	400	16	64	inco
h/zr.62t	endf6.3	sab2002	09/14/99	600	16	64	inco
h/zr.63t	endf6.3	sab2002	09/14/99	800	16	64	inco
h/zr.64t	endf6.3	sab2002	09/14/99	1000	16	64	inco
h/zr.65t	endf6.3	sab2002	09/14/99	1200	16	64	inco
Ortho Hydrogen (1001)							
hortho.01t	lanl89	therxs	03/03/89	20	8	8	none
hortho.60t	endf6.3	sab2002	01/21/03	19	16	64	none
hortho.61t	endf6.3	sab2002	06/14/00	20	16	64	none
hortho.62t	endf6.3	sab2002	06/14/00	21	16	64	none
hortho.63t	endf6.3	sab2002	06/14/00	22	16	64	none
hortho.64t	endf6.3	sab2002	06/14/00	23	16	64	none
hortho.65t	endf6.3	sab2002	06/14/00	24	16	64	none
hortho.66t	endf6.3	sab2002	06/14/00	25	16	64	none
Para Hydrogen (1001)							
hpara.01t	lanl89	therxs	03/03/89	20	8	8	none
hpara.60t	endf6.3	sab2002	06/14/00	19	16	64	none
hpara.61t	endf6.3	sab2002	06/13/00	20	16	64	none
hpara.62t	endf6.3	sab2002	06/14/00	21	16	64	none
hpara.63t	endf6.3	sab2002	06/14/00	22	16	64	none
hpara.64t	endf6.3	sab2002	06/14/00	23	16	64	none
hpara.65t	endf6.3	sab2002	06/14/00	24	16	64	none
hpara.66t	endf6.3	sab2002	06/14/00	25	16	64	none
Deuterium in Heavy Water (1002)							
hwtr.01t	endf5	tmccs	10/22/85	300	8	20	none
hwtr.02t	endf5	tmccs	10/22/85	400	8	20	none
hwtr.03t	endf5	tmccs	10/22/85	500	8	20	none
hwtr.04t	endf5	tmccs	10/22/85	600	8	20	none
hwtr.05t	endf5	tmccs	10/22/85	800	8	20	none
hwtr.60t	endf6.3	sab2002	09/14/99	294	16	64	none
hwtr.61t	endf6.3	sab2002	01/20/03	400	16	64	none
hwtr.62t	endf6.3	sab2002	09/14/99	600	16	64	none
hwtr.63t	endf6.3	sab2002	09/14/99	800	16	64	none
hwtr.64t	endf6.3	sab2002	01/20/03	1000	16	64	none

ZAID	Source	Library Name	Date of Processing	Temp (K)	Num of Angles	Num of Energies	Elastic Data
Hydrogen in Liquid Methane (1001)							
lmeth.01t	lanl89	therxs	04/10/88	100	8	8	none
lmeth.60t	endf6.3	sab2002	09/17/99	100	16	64	none
Hydrogen in Light Water (1001)							
lwtr.01t	endf5	tmccs	10/22/85	300	8	20	none
lwtr.02t	endf5	tmccs	10/22/85	400	8	20	none
lwtr.03t	endf5	tmccs	10/22/85	500	8	20	none
lwtr.04t	endf5	tmccs	10/22/85	600	8	20	none
lwtr.05t	endf5	tmccs	10/22/85	800	8	20	none
lwtr.60t	endf6.3	sab2002	09/13/99	294	16	64	none
lwtr.61t	endf6.3	sab2002	09/13/99	400	16	64	none
lwtr.62t	endf6.3	sab2002	09/13/99	500	16	64	none
lwtr.63t	endf6.3	sab2002	09/13/99	800	16	64	none
lwtr.64t	endf6.3	sab2002	01/21/03	1000	16	64	none
Hydrogen in Polyethylene (1001)							
poly.01t	endf5	tmccs	10/22/85	300	8	20	inco
poly.60t	endf6.3	sab2002	09/14/99	294	16	64	inco
Hydrogen in Solid Methane (1001)							
smeth.01t	lanl89	therxs	04/10/88	22	8	8	inco
smeth.60t	endf6.3	sab2002	09/17/99	22	16	64	inco
Zirconium in Zirconium Hydride (40000, 40090, 40091, 40092, 40094, 40096)							
zr/h.01t	endf5	tmccs	09/08/86	300	8	32	inco
zr/h.02t	endf5	tmccs	09/08/86	400	8	32	inco
zr/h.04t	endf5	tmccs	09/08/86	600	8	32	inco
zr/h.05t	endf5	tmccs	09/08/86	800	8	32	inco
zr/h.06t	endf5	tmccs	09/08/86	1200	8	32	inco
zr/h.60t	endf6.3	sab2002	09/14/99	294	16	64	inco
zr/h.61t	endf6.3	sab2002	09/14/99	400	16	64	inco
zr/h.62t	endf6.3	sab2002	09/14/99	600	16	64	inco
zr/h.63t	endf6.3	sab2002	09/14/99	800	16	64	inco
zr/h.64t	endf6.3	sab2002	09/14/99	1000	16	64	inco
zr/h.65t	endf6.3	sab2002	09/14/99	1200	16	64	inco

G.3 MCNPX NEUTRON CROSS-SECTION LIBRARIES

Table G-2 lists all the continuous-energy and discrete neutron data libraries maintained by LANL's X-Division. *Not all libraries are publicly available.* The entries in each of the columns of Table G-2 are described as follows:

ZAID → The nuclide identification number with the form `ZZZAAA.abX` where
`ZZZ` is the atomic number,
`AAA` is the mass number (`000` for naturally occurring elements),

`ab` is the unique alphanumeric table identifier
`X=C` for continuous-energy neutron tables
`X=D` for discrete-reaction tables

Atomic Weight Ratio → The atomic weight ratio (AWR) is the ratio of the atomic mass of the nuclide to a neutron. This is the AWR that is contained in the original evaluation and that was used in the NJOY processing of the evaluation.

Library → Name of the library that contains the data file for that ZAID. The number in brackets following a filename refers to one of the special notes at the end of Table G-2.

Source → Indicates the originating evaluation for that data file.

ENDF/B-V.# or ENDF/B-VI.# (such as B-V.0 and B-VI.1) are the Evaluated Nuclear Data Files, a US effort coordinated by the National Nuclear Data Center at Brookhaven National Laboratory. The evaluations are updated periodically by evaluators from all over the country, and the release number of the evaluation is given. This is not necessarily the same as the ENDF revision number for that evaluation. For example, Pu-242 is noted as ENDF/B-VI.2 as it is from release 2 of ENDF/B-VI, but it is revision 1 of that evaluation.

LLNL—evaluated nuclear data libraries compiled by the Nuclear Data Group at Lawrence Livermore National Laboratory. The number in the library name indicates the year the library was produced or received.

LANL—evaluations from the Nuclear Physics Group T-16 at Los Alamos National Laboratory.

:T or :X—the original evaluation has been modified by the Los Alamos National Laboratory groups T-16 or X-Division.

Evaluation Date → Denotes the year that the evaluation was completed or accepted. In cases where this information is not known, the date that the data library was produced is given. It is rare that a completely new evaluation is produced. Most often, only a section of an existing evaluation is updated, but a new evaluation date is assigned. This can be misleading for the users, and we encourage you to read the File 1 information for data tables important to your application to understand the history of a specific evaluation. This information is available form the Data Team's web site. The notation "<1985" means "before" 1985.

Temperature → Indicates the temperature (K) at which the data were processed. The temperature enters into the processing of the evaluation of a data file only through the Doppler broadening of cross sections. The user must be aware that without the proper use of the `TMP` card, MCNPX will attempt to correct the data libraries to the default 300K by modifying the elastic and total cross sections *only*.

Doppler broadening refers to a change in cross section resulting from thermal motion (translation, rotation and vibration) of nuclei in a target material. Doppler broadening is done on all cross sections for incident neutrons (nonrelativistic energies) on a target at some temperature (TEMP) in which the free-atom approximation is valid. In general an increase in the temperature of the material containing neutron-absorbing nuclei in a homogeneous system results in Doppler broadening of resonances and an increase in resonance absorption. Furthermore, a constant cross section at zero K goes to 1/*v* behavior as the temperature increases. You should not only use the best evaluations but also use evaluations that are at temperatures approximating the temperatures in your application.

Length → The total length of a particular cross-section file in words. It is understood that the actual storage requirement in an MCNPX problem will often be less because certain data that are not needed for a problem may be expunged.

Number of Energies → The number of energy points (NE) on the grid used for the neutron cross section for that data file. In general, a finer energy grid (or greater number of points) indicates a more accurate representation of the cross sections, particularly through the resonance region.

E_{max} → The maximum incident neutron energy for that data file. For all incident neutron energies greater than E_{max}, MCNPX assumes the last cross-section value given.

GPD → "yes" means that photon-production data are included;
"no" means that such data are not included.

$\overline{\nu}$ → for fissionable material, $\overline{\nu}$ indicates the type of fission nu data available.
"pr" means that only prompt nu data are given;
"tot" means that only total nu data are given;
"both" means that prompt and total nu are given.

CP → "yes" means that secondary charged-particles data are present;
"no" means that such data are not present.

DN → "yes" means that delayed neutron data are present;
"no" means that such data are not present.

UR → "yes" means that unresolved resonance data are present;
"no" means that such data are not present.

Table G-2 contains no indication of a "recommended" library for each isotope. Because of the wide variety of applications MCNPX is used to simulate, no one set is "best." The default cross-section set for each isotope is determined by the XSDIR file being used.

Finally, you can introduce a cross-section library of your own by using the XS input card.

Table G-2. Continuous-Energy and Discrete Neutron Data Libraries Maintained by X-Division

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
Z = 1 ********** Hydrogen **********													
** H-1 **													
1001.24c	0.9991	la150n	B-VI.6	1998	293.6	10106	686	150.0	yes	no	yes	no	no
1001.42c	0.9992	endl92	LLNL	<1992	300.0	1968	121	30.0	yes	no	no	no	no
1001.50c	0.9992	rmccs	B-V.0	1977	293.6	2766	244	20.0	yes	no	no	no	no
1001.50d	0.9992	drmccs	B-V.0	1977	293.6	3175	263	20.0	yes	no	no	no	no
1001.53c	0.9992	endf5mt[1]	B-V.0	1977	587.2	4001	394	20.0	yes	no	no	no	no
1001.60c	0.9992	endf60	B-VI.1	1989	293.6	3484	357	100.0	yes	no	no	no	no
1001.62c	0.9992	actia	B-VI.8	1998	293.6	10128	688	150.0	yes	no	yes	no	no
1001.66c	0.9992	endf66a	B-VI.6:X	1998	293.6	10128	688	150.0	yes	no	yes	no	no
** H-2 **													
1002.24c	1.9968	la150n	B-VI.6	1997	293.6	10270	538	150.0	yes	no	yes	no	no
1002.50c	1.9968	endf5p	B-V.0	1967	293.6	3987	214	20.0	yes	no	no	no	no
1002.50d	1.9968	dre5	B-V.0	1967	293.6	4686	263	20.0	yes	no	no	no	no
1002.55c	1.9968	rmccs	LANL/T	1982	293.6	5981	285	20.0	yes	no	no	no	no
1002.55d	1.9968	drmccs	LANL/T	1982	293.6	5343	263	20.0	yes	no	no	no	no
1002.60c	1.9968	endf60	B-VI.0	1967[2]	293.6	2704	178	20.0	yes	no	no	no	no
1002.66c	1.9968	endf66a.	B-VI.6	1997	293.6	10270	538	150.0	yes	no	yes	no	no
** H-3 **													
1003.42c	2.9901	endl92	LLNL	<1992	300.0	2308	52	30.0	no	no	no	no	no
1003.50c	2.9901	rmccs	B-V.0	1965	293.6	2428	184	20.0	no	no	no	no	no
1003.50d	2.9901	drmccs	B-V.0	1965	293.6	2807	263	20.0	no	no	no	no	no
1003.60c	2.9901	endf60	B-VI.0	1965	293.6	3338	180	20.0	no	no	no	no	no
1003.66c	2.9901	endf66a	B-VI.0	1965	293.6	5782	389	20.0	no	no	no	no	no
Z = 2 ********** Helium **********													
** He-3 **													
2003.42c	2.9901	endl92	LLNL	<1992	300.0	1477	151	30.0	yes	no	no	no	no
2003.50c	2.9901	rmccs	B-V.0	1971	293.6	2320	229	20.0	no	no	no	no	no
2003.50d	2.9901	drmccs	B-V.0	1971	293.6	2612	263	20.0	no	no	no	no	no
2003.60c	2.9890	endf60	B-VI.1	1990	293.6	2834	342	20.0	no	no	no	no	no
2003.66c	2.9890	endf66a	B-VI.1	1990	293.6	9679	668	20.0	no	no	yes	no	no
** He-4 **													
2004.42c	3.9682	endl92	LLNL	<1992	300.0	1332	49	30.0	no	no	no	no	no
2004.50c	4.0015	rmccs	B-V.0	1973	293.6	3061	345	20.0	no	no	no	no	no
2004.50d	4.0015	drmccs	B-V.0	1973	293.6	2651	263	20.0	no	no	no	no	no
2004.60c	4.0015	endf60	B-VI.0	1973	293.6	2971	327	20.0	no	no	no	no	no
2004.62c	3.9682	actia	B-VI.0	1973	293.6	5524	588	20.0	no	no	no	no	no
2004.66c	3.9682	endf66a	B-VI.0:X	1973	293.6	5524	588	20.0	no	no	no	no	no
Z = 3 ********** Lithium **********													
** Li-6 **													
3006.42c	5.9635	endl92	LLNL	<1992	300.0	7805	294	30.0	yes	no	no	no	no

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
3006.50c	5.9634	rmccs	B-V.0	1977	293.6	9932	373	20.0	yes	no	no	no	no
3006.50d	5.9634	drmccs	B-V.0	1977	293.6	8716	263	20.0	yes	no	no	no	no
3006.60c	5.9634	endf60	B-VI.1	1989	293.6	12385	498	20.0	yes	no	no	no	no
3006.66c	5.9634	endf66a	B-VI.1	1989	293.6	28012	870	20.0	yes	no	no	no	no
** Li-7 **													
3007.42c	6.9557	endl92	LLNL	<1992	300.0	5834	141	30.0	yes	no	no	no	no
3007.50c	6.9557	endf5p	B-V.0	1972	293.6	4864	343	20.0	yes	no	no	no	no
3007.50d	6.9557	dre5	B-V.0	1972	293.6	4935	263	20.0	yes	no	no	no	no
3007.55c	6.9557	rmccs	B-V.2	1979	293.6	13171	328	20.0	yes	no	no	no	no
3007.55d	6.9557	drmccs	B-V.2	1979	293.6	12647	263	20.0	yes	no	no	no	no
3007.60c	6.9557	endf60	B-VI.0	1988	293.6	14567	387	20.0	yes	no	no	no	no
3007.66c	6.9557	endf66a	B-VI.0	1988	293.6	19559	677	20.0	yes	no	no	no	no
Z = 4 ********** Beryllium **********													
** Be-7 **													
4007.42c	6.9567	endl92	LLNL	<1992	300.0	1544	127	30.0	yes	no	no	no	no
** Be-9 **													
4009.21c	8.9348	100xs[3]	LANL/T:X	1989	300.0	28964	316	100.0	yes	no	no	no	no
4009.24c	8.9347	la150n	LANL	1989	293.6	68468	619	100.0	yes	no	yes	no	no
4009.50c	8.9348	rmccs	B-V.0	1976	293.6	8886	329	20.0	yes	no	no	no	no
4009.50d	8.9348	drmccs	B-V.0	1976	293.6	8756	263	20.0	yes	no	no	no	no
4009.60c	8.9348	endf60	B-VI.0	1986	293.6	64410	276	20.0	yes	no	no	no	no
4009.62c	8.9348	actia	B-VI.8	2000	293.6	115407	514	20.0	yes	no	yes	no	no
4009.66c	8.9348	endf66a	B-VI.0	1986	293.6	113907	538	20.0	yes	no	yes	no	no
Z = 5 ********** Boron **********													
** B-10 **													
5010.42c	9.9269	endl92	LLNL	<1992	300.0	4733	175	30.0	yes	no	no	no	no
5010.50c	9.9269	rmccs	B-V.0	1977	293.6	20200	514	20.0	yes	no	no	no	no
5010.50d	9.9269	drmccs	B-V.0	1977	293.6	12322	263	20.0	yes	no	no	no	no
5010.53c	9.9269	endf5mt[1]	B-V.0	1977	587.2	23676	700	20.0	yes	no	no	no	no
5010.60c	9.9269	endf60	B-VI.1	1989	293.6	27957	673	20.0	yes	no	no	no	no
5010.66c	9.9269	endf66a	B-VI.1	1989	293.6	51569	1035	20.0	yes	no	no	no	no
** B-11 **													
5011.42c	10.9147	endl92	LLNL	<1992	300.0	4285	244	30.0	yes	no	no	no	no
5011.50c	10.9150	endf5p	B-V.0	1974	293.6	4344	487	20.0	no	no	no	no	no
5011.50d	10.9150	dre5	B-V.0	1974	293.6	2812	263	20.0	no	no	no	no	no
5011.55c	10.9150	rmccsa	B-V.0:T	1971[4]	293.6	12254	860	20.0	yes	no	no	no	no
5011.55d	10.9150	drmccs	B-V.0:T	1971[4]	293.6	7106	263	20.0	yes	no	no	no	no
5011.56c	10.9147	newxs	LANL/T	1986	293.6	56929	1762	20.0	yes	no	no	no	no
5011.56d	10.9147	newxsd	LANL/T	1986	293.6	17348	263	20.0	yes	no	no	no	no
5011.60c	10.9147	endf60	B-VI.0	1989	293.6	108351	2969	20.0	yes	no	no	no	no
5011.66c	10.9147	endf66a	B-VI.0:X	1989	293.6	149785	3442	20.0	yes	no	no	no	no
Z = 6 ********** Carbon **********													
** C-nat **													
6000.24c	11.8980	la150n	B-VI.6	1996	293.6	79070	1267	150.0	yes	no	yes	no	no

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ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
6000.50c	11.8969	rmccs	B-V.0	1977	293.6	23326	875	20.0	yes	no	no	no	no
6000.50d	11.8969	drmccs	B-V.0	1977	293.6	16844	263	20.0	yes	no	no	no	no
6000.60c	11.8980	endf60	B-VI.1	1989	293.6	22422	978	32.0	yes	no	no	no	no
6000.66c	11.8980	endf66a	B-VI.6	1989	293.6	79070	1267	150.0	yes	no	yes	no	no
** C-12 **													
6012.21c	11.8969	100xs[3]	LANL/T:X	1989	300.0	28809	919	100.0	yes	no	no	no	no
6012.42c	11.8969	endl92	LLNL	<1992	300.0	6229	191	30.0	yes	no	no	no	no
6012.50c	11.8969	rmccs[5]	B-V.0	1977	293.6	23326	875	20.0	yes	no	no	no	no
6012.50d	11.8969	drmccs[5]	B-V.0	1977	293.6	16844	263	20.0	yes	no	no	no	no
** C-13 **													
6013.42c	12.8916	endl92	LLNL	<1992	300.0	5993	429	30.0	yes	no	no	no	no
Z = 7 ********** Nitrogen **********													
** N-14 **													
7014.24c	13.8827	la150n	B-VI.6	1997	293.6	144740	1824	150.0	yes	no	yes	no	no
7014.42c	13.8828	endl92	LLNL	<1992	300.0	20528	770	30.0	yes	no	no	no	no
7014.50c	13.8830	rmccs	B-V.0	1973	293.6	45457	1196	20.0	yes	no	no	no	no
7014.50d	13.8830	drmccs	B-V.0	1973	293.6	26793	263	20.0	yes	no	no	no	no
7014.60c	13.8828	endf60	LANL/T	1992	293.6	60397	1379	20.0	yes	no	no	no	no
7014.62c	13.8828	actia	B-VI.8	2000	293.6	145340	1824	150.0	yes	no	yes	no	no
7014.66c	13.8828	endf66a	B-VI.6	1997	293.6	144740	1824	150.0	yes	no	yes	no	no
** N-15 **													
7015.42c	14.8713	endl92	LLNL	<1992	300.0	22590	352	30.0	yes	no	no	no	no
7015.55c	14.8710	rmccsa	LANL/T	1983	293.6	20920	744	20.0	yes	no	no	no	no
7015.55d	14.8710	drmccs	LANL/T	1983	293.6	15273	263	20.0	yes	no	no	no	no
7015.60c	14.8710	endf60	B-VI.0	1993	293.6	24410	653	20.0	yes	no	no	no	no
7015.66c	14.8710	endf66a	B-VI.0	1993	293.6	31755	880	20.0	yes	no	no	no	no
Z = 8 ********** Oxygen **********													
** O-16 **													
8016.21c	15.8575	100xs[3]	LANL/T:X	1989	300.0	45016	1427	100.0	yes	no	no	no	no
8016.24c	15.8831	la150n	B-VI.6	1996	293.6	164461	1935	150.0	yes	no	yes	no	no
8016.42c	15.8575	endl92	LLNL	<1992	300.0	9551	337	30.0	yes	no	no	no	no
8016.50c	15.8580	rmccs	B-V.0	1972	293.6	37942	1391	20.0	yes	no	no	no	no
8016.50d	15.8580	drmccs	B-V.0	1972	293.6	20455	263	20.0	yes	no	no	no	no
8016.53c	15.8580	endf5mt[1]	B-V.0	1972	587.2	37989	1398	20.0	yes	no	no	no	no
8016.54c	15.8580	endf5mt[1]	B-V.0	1972	880.8	38017	1402	20.0	yes	no	no	no	no
8016.60c	15.8532	endf60	B-VI.0	1990	293.6	58253	1609	20.0	yes	no	no	no	no
8016.62c	15.8575	actia	B-VI.8	2000	293.6	407432	2759	150.0	yes	no	yes	no	no
8016.66c	15.8532	endf66a	B-VI.6	1996	293.6	164461	1935	150.0	yes	no	yes	no	no
** O-17 **													
8017.60c	16.8531	endf60	B-VI.0	1978	293.6	4200	335	20.0	no	no	no	no	no
8017.66c	16.8531	endf66a	B-VI.0	1978	293.6	8097	612	20.0	no	no	no	no	no
Z = 9 ********** Fluorine **********													
** F-19 **													
9019.42c	18.8352	endl92	LLNL	<1992	300.0	37814	1118	30.0	yes	no	no	no	no

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
9019.50c	18.8350	endf5p	B-V.0	1976	293.6	44130	1569	20.0	yes	no	no	no	no
9019.50d	18.8350	dre5	B-V.0	1976	293.6	23156	263	20.0	yes	no	no	no	no
9019.51c	18.8350	rmccs	B-V.0	1976	293.6	41442	1541	20.0	yes	no	no	no	no
9019.51d	18.8350	drmccs	B-V.0	1976	293.6	23156	263	20.0	yes	no	no	no	no
9019.60c	18.8350	endf60	B-VI.0	1990	300.0	93826	1433	20.0	yes	no	no	no	no
9019.62c	18.8350	actia	B-VI.8	2000	293.6	127005	1888	20.0	yes	no	yes	no	no
9019.66c	18.8350	endf66a	B-VI.0:X	1990	293.6	122324	1870	20.0	yes	no	yes	no	no
Z = 10 ********** Neon **********													
** Ne-20 **													
10020.42c	19.8207	endl92	LLNL	<1992	300.0	14286	1011	30.0	yes	no	no	no	no
Z = 11 ********** Sodium **********													
** Na-23 **													
11023.42c	22.7923	endl92	LLNL	<1992	300.0	19309	1163	30.0	yes	no	no	no	no
11023.50c	22.7920	endf5p	B-V.0	1977	293.6	52252	2703	20.0	yes	no	no	no	no
11023.50d	22.7920	dre5	B-V.0	1977	293.6	41665	263	20.0	yes	no	no	no	no
11023.51c	22.7920	rmccs	B-V.0	1977	293.6	48863	2228	20.0	yes	no	no	no	no
11023.51d	22.7920	drmccs	B-V.0	1977	293.6	41665	263	20.0	yes	no	no	no	no
11023.60c	22.7920	endf60	B-VI.1	1977	293.6	50294	2543	20.0	yes	no	no	no	no
11023.62c	22.7920	actia	B-VI.8	2000	293.6	69562	3239	20.0	yes	no	no	no	no
11023.66c	22.7920	endf66a	B-VI.1	1977	293.6	64249	3239	20.0	yes	no	no	no	no
Z = 12 ********** Magnesium **********													
** Mg-nat **													
12000.42c	24.0962	endl92	LLNL	<1992	300.0	9288	468	30.0	yes	no	no	no	no
12000.50c	24.0963	endf5u	B-V.0	1978	293.6	56334	2430	20.0	yes	no	no	no	no
12000.50d	24.0963	dre5	B-V.0	1978	293.6	14070	263	20.0	yes	no	no	no	no
12000.51c	24.0963	rmccs	B-V.0	1978	293.6	48917	1928	20.0	yes	no	no	no	no
12000.51d	24.0963	drmccs	B-V.0	1978	293.6	14070	263	20.0	yes	no	no	no	no
12000.60c	24.0963	endf60	B-VI.0	1978	293.6	55776	2525	20.0	yes	no	no	no	no
12000.61c	24.0963	actib	B-VI.8	2000	77.0	69108	3213	20.0	yes	no	no	no	no
12000.62c	24.0963	actia	B-VI.8	2000	293.6	68746	3172	20.0	yes	no	no	no	no
12000.64c	24.0963	endf66d	B-VI.0	1978	77.0	67880	3213	20.0	yes	no	no	no	no
12000.66c	24.0963	endf66a	B-VI.0	1978	293.6	67511	3172	20.0	yes	no	no	no	no
Z = 13 ********** Aluminum **********													
** Al-27 **													
13027.21c	26.7498	100xs[3]	LANL/T:X	1989	300.0	35022	1473	100.0	yes	no	no	no	no
13027.24c	26.7497	la150n	B-VI.6	1997	293.6	214549	3148	150.0	yes	no	yes	no	no
13027.42c	26.7498	endl92	LLNL	<1992	300.0	32388	1645	30.0	yes	no	no	no	no
13027.50c	26.7500	rmccs	B-V.0	1973	293.6	54162	2028	20.0	yes	no	no	no	no
13027.50d	26.7500	drmccs	B-V.0	1973	293.6	41947	263	20.0	yes	no	no	no	no
13027.60c	26.7500	endf60	B-VI.0	1973	293.6	55427	2241	20.0	yes	no	no	no	no
13027.61c	26.7497	actib	B-VI.8	2000	77.0	220073	3038	150.0	yes	no	yes	no	no
13027.62c	26.7497	actia	B-VI.8	2000	293.6	220418	3081	150.0	yes	no	yes	no	no
13027.64c	26.7497	endf66d	B-VI.6	1997	77.0	213659	3037	150.0	yes	no	yes	no	no

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13027.66c	26.7497	endf66a	B-VI.6	1997	293.6	214004	3036	150.0	yes	no	yes	no	no
13027.91c	26.7497	actib[6]	B-VI.8	2000	77.0	220104	3038	150.0	yes	no	yes	no	no
13027.92c	26.7497	actia[6]	B-VI.8	2000	293.6	220449	3081	150.0	yes	no	yes	no	no
Z = 14 ********** Silicon **********													
** Si-nat **													
14000.21c	27.8440	100xs[3]	LANL/T:X	1989	300.0	76399	2883	100.0	yes	no	no	no	no
14000.42c	27.8442	endl92	LLNL	<1992	300.0	16696	855	30.0	yes	no	no	no	no
14000.50c	27.8440	endf5p	B-V.0	1976	293.6	98609	2440	20.0	yes	no	no	no	no
14000.50d	27.8440	dre5	B-V.0	1976	293.6	69498	263	20.0	yes	no	no	no	no
14000.51c	27.8440	rmccs	B-V.0	1976	293.6	88129	1887	20.0	yes	no	no	no	no
14000.51d	27.8440	drmccs	B-V.0	1976	293.6	69498	263	20.0	yes	no	no	no	no
14000.60c	27.8440	endf60	B-VI.0	1976	293.6	104198	2824	20.0	yes	no	no	no	no
** Si-28 **													
14028.24c	27.7370	la150n	LANL	1997	293.6	264892	7417	150.0	yes	no	yes	no	no
14028.61c	27.7370	actib	B-VI.6	1997	77.0	264592	7472	150.0	yes	no	yes	no	no
14028.62c	27.7370	actia	B-VI.6	1997	293.6	263728	7364	150.0	yes	no	yes	no	no
14028.64c	27.7370	endf66d	B-VI.6	1997	77.0	264592	7472	150.0	yes	no	yes	no	no
14028.66c	27.7370	endf66a	B-VI.6	1997	293.6	263728	7364	150.0	yes	no	yes	no	no
** Si-29 **													
14029.24c	28.7280	la150n	LANL	1997	293.6	252663	4878	150.0	yes	no	yes	no	no
14029.61c	28.7280	actib	B-VI.8	1999	77.0	252671	4879	150.0	yes	no	yes	no	no
14029.62c	28.7280	actia	B-VI.8	1999	293.6	252591	4869	150.0	yes	no	yes	no	no
14029.64c	28.7280	endf66d	B-VI.6	1997	77.0	252791	4894	150.0	yes	no	yes	no	no
14029.66c	28.7280	endf66a	B-VI.6	1997	293.6	252615	4872	150.0	yes	no	yes	no	no
** Si-30 **													
14030.24c	29.7160	la150n	LANL	1997	293.6	195933	5791	150.0	yes	no	yes	no	no
14030.61c	29.7160	actib	B-VI.6	1997	77.0	196525	5831	150.0	yes	no	yes	no	no
14030.62c	29.7160	actia	B-VI.6	1997	293.6	195852	5781	150.0	yes	no	yes	no	no
14030.64c	29.7160	endf66d	B-VI.6	1997	77.0	196252	5831	150.0	yes	no	yes	no	no
14030.66c	29.7160	endf66a	B-VI.6	1997	293.6	195852	5781	150.0	yes	no	yes	no	no
Z = 15 ********** Phosphorus **********													
** P-31 **													
15031.24c	30.7080	la150n	B-VI.6	1997	293.6	71942	990	150.0	yes	no	yes	no	no
15031.42c	30.7077	endl92	LLNL	<1992	300.0	6805	224	30.0	yes	no	no	no	no
15031.50c	30.7080	endf5u	B-V.0	1977	293.6	5733	326	20.0	yes	no	no	no	no
15031.50d	30.7080	dre5	B-V.0	1977	293.6	5761	263	20.0	yes	no	no	no	no
15031.51c	30.7080	rmccs	B-V.0	1977	293.6	5732	326	20.0	yes	no	no	no	no
15031.51d	30.7080	drmccs	B-V.0	1977	293.6	5761	263	20.0	yes	no	no	no	no
15031.60c	30.7080	endf60	B-VI.0	1977	293.6	6715	297	20.0	yes	no	no	no	no
15031.66c	30.7080	endf66a	B-VI.6	1997	293.6	71942	990	150.0	yes	no	yes	no	no
Z = 16 ********** Sulfur **********													
** S-nat **													
16000.60c	31.7882	endf60	B-VI.0	1979	293.6	108683	8382	20.0	yes	no	no	no	no
16000.61c	31.7888	actib	B-VI.8	2000	77.0	162749	10459	20.0	yes	no	no	no	no

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16000.62c	31.7888	actia	B-VI.8	2000	293.6	160505	10272	20.0	yes	no	no	no	no
16000.64c	31.7882	endf66d	B-VI.0	1979	77.0	162138	10460	20.0	yes	no	no	no	no
16000.66c	31.7882	endf66a	B-VI.0	1979	293.6	159894	10273	20.0	yes	no	no	no	no
** S-32 **													
16032.42c	31.6974	endl92	LLNL	<1992	300.0	6623	307	30.0	yes	no	no	no	no
16032.50c	31.6970	endf5u	B-V.0	1977	293.6	6789	363	20.0	yes	no	no	no	no
16032.50d	31.6970	dre5	B-V.0	1977	293.6	6302	263	20.0	yes	no	no	no	no
16032.51c	31.6970	rmccs	B-V.0	1977	293.6	6780	362	20.0	yes	no	no	no	no
16032.51d	31.6970	drmccs	B-V.0	1977	293.6	6302	263	20.0	yes	no	no	no	no
16032.60c	31.6970	endf60	B-VI.0	1977	293.6	7025	377	20.0	yes	no	no	no	no
16032.61c	31.6970	actib	B-VI.8	2000	77.0	14930	885	20.0	yes	no	no	no	no
16032.62c	31.6970	actia	B-VI.8	2000	293.6	16050	993	20.0	yes	no	no	no	no
16032.64c	31.6970	endf66d	B-VI.0	1977	77.0	12714	885	20.0	yes	no	no	no	no
16032.66c	31.6970	endf66a	B-VI.0	1977	293.6	13834	993	20.0	yes	no	no	no	no
Z = 17 ********** Chlorine **********													
** Cl-nat **													
17000.42c	35.1484	endl92	LLNL	<1992	300.0	12012	807	30.0	yes	no	no	no	no
17000.50c	35.1480	endf5p	B-V.0	1967	293.6	23313	1499	20.0	yes	no	no	no	no
17000.50d	35.1480	dre5	B-V.0	1967	293.6	18209	263	20.0	yes	no	no	no	no
17000.51c	35.1480	rmccs	B-V.0	1967	293.6	21084	1375	20.0	yes	no	no	no	no
17000.51d	35.1480	drmccs	B-V.0	1967	293.6	18209	263	20.0	yes	no	no	no	no
17000.60c	35.1480	endf60	B-VI.0	1967	293.6	24090	1816	20.0	yes	no	no	no	no
17000.64c	35.1480	endf66d	B-VI.0	1967	77.0	44517	2799	20.0	yes	no	no	no	no
17000.66c	35.1480	endf66a	B-VI.0	1967	293.6	45407	2888	20.0	yes	no	no	no	no
** Cl-35 **													
17035.61c	34.6684	actib	B-VI.8	2000	77.0	316441	7217	20.0	yes	no	yes	no	no
17035.62c	34.6684	actia	B-VI.8	2000	293.6	311841	6987	20.0	yes	no	yes	no	no
** Cl-37 **													
17037.61c	36.6483	actib	B-VI.8	2000	77.0	137963	3495	20.0	yes	no	yes	no	no
17037.62c	36.6483	actia	B-VI.8	2000	293.6	137404	3425	20.0	yes	no	yes	no	no
Z = 18 ********** Argon **********													
** Ar-nat **													
18000.35c	39.6048	rmccsa	LLNL	<1985	0.0	5585	259	20.0	yes	no	no	no	no
18000.35d	39.6048	drmccs	LLNL	<1985	0.0	14703	263	20.0	yes	no	no	no	no
18000.42c	39.6048	endl92	LLNL	<1992	300.0	5580	152	30.0	yes	no	no	no	no
18000.59c	39.6048	misc5xs[7,8]	LANL/T	1982	293.6	3473	252	20.0	yes	no	no	no	no
Z = 19 ********** Potassium **********													
** K-nat **													
19000.42c	38.7624	endl92	LLNL	<1992	300.0	11060	544	30.0	yes	no	no	no	no
19000.50c	38.7660	endf5u	B-V.0	1974	293.6	22051	1243	20.0	yes	no	no	no	no
19000.50d	38.7660	dre5	B-V.0	1974	293.6	23137	263	20.0	yes	no	no	no	no
19000.51c	38.7660	rmccs	B-V.0	1974	293.6	18798	1046	20.0	yes	no	no	no	no
19000.51d	38.7660	drmccs	B-V.0	1974	293.6	23137	263	20.0	yes	no	no	no	no
19000.60c	38.7660	endf60	B-VI.0	1974	293.6	24482	1767	20.0	yes	no	no	no	no

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19000.62c	38.7660	actia	B-VI.8	2000	293.6	52304	2734	20.0	yes	no	no	no	no
19000.66c	38.7660	endf66a	B-VI.0	1974	293.6	51384	2734	20.0	yes	no	no	no	no
Z = 20 ********** Calcium **********													
** Ca-nat **													
20000.24c	39.7360	la150n	B-VI.6	1997	293.6	187818	4470	150.0	yes	no	yes	no	no
20000.42c	39.7357	endl92	LLNL	<1992	300.0	13946	1002	30.0	yes	no	no	no	no
20000.50c	39.7360	endf5u	B-V.0	1976	293.6	62624	2394	20.0	yes	no	no	no	no
20000.50d	39.7360	dre5	B-V.0	1976	293.6	29033	263	20.0	yes	no	no	no	no
20000.51c	39.7360	rmccs	B-V.0	1976	293.6	53372	1796	20.0	yes	no	no	no	no
20000.51d	39.7360	drmccs	B-V.0	1976	293.6	29033	263	20.0	yes	no	no	no	no
20000.60c	39.7360	endf60	B-VI.0	1980	293.6	76468	2704	20.0	yes	no	no	no	no
20000.61c	39.7360	actib	B-VI.8	2000	77.0	185636	4178	150.0	yes	no	yes	no	no
20000.62c	39.7360	actia	B-VI.8	2000	293.6	187296	4344	150.0	yes	no	yes	no	no
20000.64c	39.7360	endf66d	B-VI.6	1997	77.0	184909	4179	150.0	yes	no	yes	no	no
20000.66c	39.7360	endf66a	B-VI.6	1997	293.6	186569	4345	150.0	yes	no	yes	no	no
** Ca-40 **													
20040.21c	39.6193	100xs[3]	LANL/T:X	1989	300.0	53013	2718	100.0	yes	no	no	no	no
Z = 21 ********** Scandium **********													
** Sc-45 **													
21045.60c	44.5679	endf60	B-VI.2	1992	293.6	105627	10639	20.0	yes	no	no	no	no
21045.62c	44.5679	actia	B-VI.8:X	2000	293.6	267570	22382	20.0	yes	no	no	no	no
21045.66c	44.5679	endf66a	B-VI.2:X	1992	293.6	256816	22383	20.0	yes	no	no	no	no
Z = 22 ********** Titanium **********													
** Ti-nat **													
22000.42c	47.4885	endl92	LLNL	<1992	300.0	8979	608	30.0	yes	no	no	no	no
22000.50c	47.4676	endf5u	B-V.0	1977	293.6	54801	4434	20.0	yes	no	no	no	no
22000.50d	47.4676	dre5	B-V.0	1977	293.6	10453	263	20.0	yes	no	no	no	no
22000.51c	47.4676	rmccs	B-V.0	1977	293.6	31832	1934	20.0	yes	no	no	no	no
22000.51d	47.4676	drmccs	B-V.0	1977	293.6	10453	263	20.0	yes	no	no	no	no
22000.60c	47.4676	endf60	B-VI.0	1977	293.6	76454	7761	20.0	yes	no	no	no	no
22000.61c	47.4676	actib	B-VI.8	2000	77.0	131345	11427	20.0	yes	no	no	no	no
22000.62c	47.4676	actia	B-VI.8	2000	293.6	125641	10859	20.0	yes	no	no	no	no
22000.64c	47.4676	endf66d	B-VI.0	1977	77.0	131040	11428	20.0	yes	no	no	no	no
22000.66c	47.4676	endf66a	B-VI.0	1977	293.6	125336	10860	20.0	yes	no	no	no	no
Z = 23 ********** Vanadium **********													
** V-nat **													
23000.50c	50.5040	endf5u	B-V.0	1977	293.6	38312	2265	20.0	yes	no	no	no	no
23000.50d	50.5040	dre5	B-V.0	1977	293.6	8868	263	20.0	yes	no	no	no	no
23000.51c	50.5040	rmccs	B-V.0	1977	293.6	34110	1899	20.0	yes	no	no	no	no
23000.51d	50.5040	drmccs	B-V.0	1977	293.6	8868	263	20.0	yes	no	no	no	no
23000.60c	50.5040	endf60	B-VI.0	1988	293.6	167334	8957	20.0	yes	no	no	no	no
23000.62c	50.5040	actia	B-VI.8	2000	293.6	198692	10393	20.0	yes	no	no	no	no
23000.66c	50.5040	endf66a	B-VI.0	1988	293.6	192051	10393	20.0	yes	no	no	no	no

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** V-51 **													
23051.42c	50.5063	endl92	LLNL	<1992	300.0	94082	5988	30.0	yes	no	no	no	no
Z = 24 ********** Chromium **********													
** Cr-nat **													
24000.42c	51.5493	endl92	LLNL	<1992	300.0	12573	377	30.0	yes	no	no	no	no
24000.50c	51.5490	rmccs	B-V.0	1977	293.6	134454	11050	20.0	yes	no	no	no	no
24000.50d	51.5490	drmccs	B-V.0	1977	293.6	30714	263	20.0	yes	no	no	no	no
** Cr-50 **													
24050.24c	49.5170	la150n	B-VI.6	1997	293.6	391112	28453	150.0	yes	no	yes	no	no
24050.60c	49.5170	endf60	B-VI.1	1989	293.6	119178	11918	20.0	yes	no	no	no	no
24050.61c	49.5170	actib	B-VI.8	2000	77.0	405367	29959	150.0	yes	no	yes	no	no
24050.62c	49.5170	actia	B-VI.8	2000	293.6	390799	28138	150.0	yes	no	yes	no	no
24050.64c	49.5170	endf66d	B-VI.6	1997	77.0	403210	29954	150.0	yes	no	yes	no	no
24050.66c	49.5170	endf66a	B-VI.6	1997	293.6	388600	28139	150.0	yes	no	yes	no	no
** Cr-52 **													
24052.24c	51.4940	la150n	B-VI.6	1997	293.6	346350	21232	150.0	yes	no	yes	no	no
24052.60c	51.4940	endf60	B-VI.1	1989	293.6	117680	10679	20.0	yes	no	no	no	no
24052.61c	51.4940	actib	B-VI.8	2000	77.0	344811	21143	150.0	yes	no	yes	no	no
24052.62c	51.4940	actia	B-VI.8	2000	293.6	342461	20849	150.0	yes	no	yes	no	no
24052.64c	51.4940	endf66d	B-VI.6	1997	77.0	344376	21132	150.0	yes	no	yes	no	no
24052.66c	51.4940	endf66a	B-VI.6	1997	293.6	342098	20847	150.0	yes	no	yes	no	no
** Cr-53 **													
24053.24c	52.4860	la150n	B-VI.6	1997	293.6	286602	13873	150.0	yes	no	yes	no	no
24053.60c	52.4860	endf60	B-VI.1	1989	293.6	114982	10073	20.0	yes	no	no	no	no
24053.61c	52.4860	actib	B-VI.8	2000	77.0	292322	14242	150.0	yes	no	yes	no	no
24053.62c	52.4860	actia	B-VI.8	2000	293.6	287642	13657	150.0	yes	no	yes	no	no
24053.64c	52.4860	endf66d	B-VI.6	1997	77.0	289469	14231	150.0	yes	no	yes	no	no
24053.66c	52.4860	endf66a	B-VI.6	1997	293.6	284837	13652	150.0	yes	no	yes	no	no
** Cr-54 **													
24054.24c	53.4760	la150n	B-VI.6	1997	293.6	259040	13750	150.0	yes	no	yes	no	no
24054.60c	53.4760	endf60	B-VI.1	1989	293.6	98510	9699	20.0	yes	no	no	no	no
24054.61c	53.4760	actib	B-VI.8	2000	77.0	262192	13814	150.0	yes	no	yes	no	no
24054.62c	53.4760	actia	B-VI.8	2000	293.6	260423	13593	150.0	yes	no	yes	no	no
24054.64c	53.4760	endf66d	B-VI.6	1997	77.0	259591	13819	150.0	yes	no	yes	no	no
24054.66c	53.4760	endf66a	B-VI.6	1997	293.6	257750	13589	150.0	yes	no	yes	no	no
Z = 25 ********** Manganese **********													
** Mn-55 **													
25055.42c	54.4661	endl92	LLNL	<1992	300.0	10262	460	30.0	yes	no	no	no	no
25055.50c	54.4661	endf5u	B-V.0	1977	293.6	105093	12525	20.0	yes	no	no	no	no
25055.50d	54.4661	dre5	B-V.0	1977	293.6	9681	263	20.0	yes	no	no	no	no
25055.51c	54.4661	rmccs	B-V.0	1977	293.6	25727	1578	20.0	yes	no	no	no	no
25055.51d	54.4661	drmccs	B-V.0	1977	293.6	9681	263	20.0	yes	no	no	no	no
25055.60c	54.4661	endf60	B-VI.0	1988	293.6	184269	8207	20.0	yes	no	no	no	no
25055.61c	54.4661	actib	B-VI.8	2000	77.0	279378	11967	20.0	yes	no	yes	no	no

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25055.62c	54.4661	actia	B-VI.8	2000	293.6	272554	11114	20.0	yes	no	yes	no	no
25055.64c	54.4661	endf66d	B-VI.5	1988	77.0	270711	11967	20.0	yes	no	yes	no	no
25055.66c	54.4661	endf66a	B-VI.5	1988	293.6	263887	11114	20.0	yes	no	yes	no	no
Z = 26 ********** Iron **********													
** Fe-nat **													
26000.21c	55.3650	100xs[3]	LANL/T:X	1989	300.0	149855	15598	100.0	yes	no	no	no	no
26000.42c	55.3672	endl92	LLNL	<1992	300.0	38653	3385	30.0	yes	no	no	no	no
26000.50c	55.3650	endf5p	B-V.0	1978	293.6	115447	10957	20.0	yes	no	no	no	no
26000.50d	55.3650	dre5	B-V.0	1978	293.6	33896	263	20.0	yes	no	no	no	no
26000.55c	55.3650	rmccs	LANL/T	1986	293.6	178392	6899	20.0	yes	no	no	no	no
26000.55d	55.3650	drmccs	LANL/T	1986	293.6	72632	263	20.0	yes	no	no	no	no
** Fe-54 **													
26054.24c	53.4760	la150n	B-VI.6	1996	293.6	311741	19323	150.0	yes	no	yes	no	no
26054.60c	53.4760	endf60	B-VI.1	1989	293.6	121631	10701	20.0	yes	no	no	no	no
26054.61c	53.4760	actib	B-VI.8	2000	77.0	318575	20129	150.0	yes	no	yes	no	no
26054.62c	53.4760	actia	B-VI.8	2000	293.6	311639	19262	150.0	yes	no	yes	no	no
26054.64c	53.4760	endf66d	B-VI.6	1996	77.0	317271	20129	150.0	yes	no	yes	no	no
26054.66c	53.4760	endf66a	B-VI.6	1996	293.6	310335	19262	150.0	yes	no	yes	no	no
** Fe-56 **													
26056.24c	55.4540	la150n	B-VI.6	1996	293.6	461888	25792	150.0	yes	no	yes	no	no
26056.60c	55.4540	endf60	B-VI.1	1989	293.6	174517	11618	20.0	yes	no	no	no	no
26056.61c	55.4540	actib	B-VI.8	2000	77.0	475976	26821	150.0	yes	no	yes	no	no
26056.62c	55.4540	actia	B-VI.8	2000	293.6	466257	25606	150.0	yes	no	yes	no	no
26056.64c	55.4540	endf66d	B-VI.6	1996	77.0	468162	26821	150.0	yes	no	yes	no	no
26056.66c	55.4540	endf66a	B-VI.6	1996	293.6	458443	25606	150.0	yes	no	yes	no	no
** Fe-57 **													
26057.24c	56.4460	la150n	B-VI.6	1996	293.6	315349	14285	150.0	yes	no	yes	no	no
26057.60c	56.4460	endf60	B-VI.1	1989	293.6	133995	7606	20.0	yes	no	no	no	no
26057.61c	56.4460	actib	B-VI.8	2000	77.0	319262	14390	150.0	yes	no	yes	no	no
26057.62c	56.4460	actia	B-VI.8	2000	293.6	318268	14266	150.0	yes	no	yes	no	no
26057.64c	56.4460	endf66d	B-VI.6	1996	77.0	316191	14390	150.0	yes	no	yes	no	no
26057.66c	56.4460	endf66a	B-VI.6	1996	293.6	315197	14266	150.0	yes	no	yes	no	no
** Fe-58 **													
26058.60c	57.4360	endf60	B-VI.1	1989	293.6	93450	6788	20.0	yes	no	no	no	no
26058.61c	57.4360	actib	B-VI.8	2000	77.0	169389	11556	20.0	yes	no	yes	no	no
26058.62c	57.4360	actia	B-VI.8	2000	293.6	165829	11111	20.0	yes	no	yes	no	no
26058.64c	57.4360	endf66d	B-VI.5	1989	77.0	165636	11556	20.0	yes	no	yes	no	no
26058.66c	57.4360	endf66a	B-VI.5	1989	293.6	162076	11111	20.0	yes	no	yes	no	no
Z = 27 ********** Cobalt **********													
** Co-59 **													
27059.42c	58.4269	endl92	LLNL	<1992	300.0	119231	13098	30.0	yes	no	no	no	no
27059.50c	58.4269	endf5u	B-V.0	1977	293.6	117075	14502	20.0	yes	no	no	no	no
27059.50d	58.4269	dre5	B-V.0	1977	293.6	11769	263	20.0	yes	no	no	no	no
27059.51c	58.4269	rmccs	B-V.0	1977	293.6	28355	1928	20.0	yes	no	no	no	no
27059.51d	58.4269	drmccs	B-V.0	1977	293.6	11769	263	20.0	yes	no	no	no	no

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27059.60c	58.4269	endf60	B-VI.2	1992	293.6	186618	11838	20.0	yes	no	no	no	no
27059.66c	58.4269	endf66a	B-VI.2	1992	293.6	266952	19759	20.0	yes	no	no	no	no
Z = 28 ********** Nickel **********													
** Ni-nat **													
28000.42c	58.1957	endl92	LLNL	<1992	300.0	44833	3116	30.0	yes	no	no	no	no
28000.50c	58.1826	rmccs	B-V.0	1977	293.6	139913	8927	20.0	yes	no	no	no	no
28000.50d	58.1826	drmccs	B-V.0	1977	293.6	21998	263	20.0	yes	no	no	no	no
** Ni-58 **													
28058.24c	57.4380	la 150n	B-VI.6	1997	293.6	613673	39258	150.0	yes	no	yes	no	no
28058.42c	57.4376	endl92	LLNL	<1992	300.0	38930	4914	30.0	yes	no	no	no	no
28058.60c	57.4380	endf60	B-VI.1	1989	293.6	172069	16445	20.0	yes	no	no	no	no
28058.61c	57.4380	actib	B-VI.8	2000	77.0	630981	40646	150.0	yes	no	yes	no	no
28058.62c	57.4380	actia	B-VI.8	2000	293.6	617974	39020	150.0	yes	no	yes	no	no
28058.64c	57.4380	endf66d	B-VI.6	1997	77.0	623330	40632	150.0	yes	no	yes	no	no
28058.66c	57.4380	endf66a	B-VI.6	1997	293.6	610483	39026	150.0	yes	no	yes	no	no
** Ni-60 **													
28060.24c	59.4160	la 150n	B-VI.6	1997	293.6	408148	21448	150.0	yes	no	yes	no	no
28060.60c	59.4160	endf60	B-VI.1	1991	293.6	110885	10055	20.0	yes	no	no	no	no
28060.61c	59.4160	actib	B-VI.8	2000	77.0	424742	22574	150.0	yes	no	yes	no	no
28060.62c	59.4160	actia	B-VI.8	2000	293.6	407398	21131	150.0	yes	no	yes	no	no
28060.64c	59.4160	endf66d	B-VI.6	1997	77.0	420274	22569	150.0	yes	no	yes	no	no
28060.66c	59.4160	endf66a	B-VI.6	1997	293.6	403014	21133	150.0	yes	no	yes	no	no
** Ni-61 **													
28061.24c	60.4080	la 150n	B-VI.6	1997	293.6	244768	7384	150.0	yes	no	yes	no	no
28061.60c	60.4080	endf60	B-VI.1	1989	293.6	93801	5882	20.0	yes	no	no	no	no
28061.61c	60.4080	actib	B-VI.8	2000	77.0	247660	7438	150.0	yes	no	yes	no	no
28061.62c	60.4080	actia	B-VI.8	2000	293.6	247188	7379	150.0	yes	no	yes	no	no
28061.64c	60.4080	endf66d	B-VI.6	1997	77.0	245215	7440	150.0	yes	no	yes	no	no
28061.66c	60.4080	endf66a	B-VI.6	1997	293.6	244743	7381	150.0	yes	no	yes	no	no
** Ni-62 **													
28062.24c	61.3960	la 150n	B-VI.6	1997	293.6	232065	9219	150.0	yes	no	yes	no	no
28062.60c	61.3960	endf60	B-VI.1	1989	293.6	82085	7230	20.0	yes	no	no	no	no
28062.61c	61.3960	actib	B-VI.8	2000	77.0	234983	9227	150.0	yes	no	yes	no	no
28062.62c	61.3960	actia	B-VI.8	2000	293.6	234511	9168	150.0	yes	no	yes	no	no
28062.64c	61.3960	endf66d	B-VI.6	1997	77.0	232193	9235	150.0	yes	no	yes	no	no
28062.66c	61.3960	endf66a	B-VI.6	1997	293.6	231705	9174	150.0	yes	no	yes	no	no
** Ni-64 **													
28064.24c	63.3790	la 150n	B-VI.6	1997	293.6	197799	7958	150.0	yes	no	yes	no	no
28064.60c	63.3790	endf60	B-VI.1	1989	293.6	66656	6144	20.0	yes	no	no	no	no
28064.61c	63.3790	actib	B-VI.8	2000	77.0	199097	7992	150.0	yes	no	yes	no	no
28064.62c	63.3790	actia	B-VI.8	2000	293.6	198313	7894	150.0	yes	no	yes	no	no
28064.64c	63.3790	endf66d	B-VI.6	1997	77.0	198112	7997	150.0	yes	no	yes	no	no
28064.66c	63.3790	endf66a	B-VI.6	1997	293.6	197296	7895	150.0	yes	no	yes	no	no

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ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
Z = 29 ********** Copper **********													
** Cu-nat **													
29000.50c	63.5460	rmccs	B-V.0	1978	293.6	51850	3435	20.0	yes	no	no	no	no
29000.50d	63.5460	drmccs	B-V.0	1978	293.6	12777	263	20.0	yes	no	no	no	no
** Cu-63 **													
29063.24c	62.3890	la 150n	B-VI.6	1998	293.6	329768	23123	150.0	yes	no	yes	no	no
29063.60c	62.3890	endf60	B-VI.2	1989	293.6	119097	11309	20.0	yes	no	no	no	no
29063.61c	62.3890	actib	B-VI.8	2000	77.0	348384	24556	150.0	yes	no	yes	no	no
29063.62c	62.3890	actia	B-VI.8	2000	293.6	335072	22892	150.0	yes	no	yes	no	no
29063.64c	62.3890	endf66d	B-VI.6	1997	77.0	339601	24549	150.0	yes	no	yes	no	no
29063.66c	62.3890	endf66a	B-VI.6	1997	293.6	326281	22884	150.0	yes	no	yes	no	no
** Cu-65 **													
29065.24c	64.3700	la 150n	B-VI.6	1998	293.6	285628	17640	150.0	yes	no	yes	no	no
29065.60c	64.3700	endf60	B-VI.2	1989	293.6	118385	11801	20.0	yes	no	no	no	no
29065.61c	64.3700	actib	B-VI.8	2000	77.0	304772	18575	150.0	yes	no	yes	no	no
29065.62c	64.3700	actia	B-VI.8	2000	293.6	296916	17593	150.0	yes	no	yes	no	no
29065.64c	64.3700	endf66d	B-VI.6	1997	77.0	291518	18562	150.0	yes	no	yes	no	no
29065.66c	64.3700	endf66a	B-VI.6	1997	293.6	283630	17576	150.0	yes	no	yes	no	no
Z = 30 ********** Zinc **********													
** Zn-nat **													
30000.40c	64.8183	endl92	LLNL	<1992	300.0	271897	33027	30.0	yes	no	no	no	no
30000.42c	64.8183	endl92	LLNL:X	<1992	300.0	271897	33027	30.0	yes	no	no	no	no
Z = 31 ********** Gallium **********													
** Ga-nat **													
31000.42c	69.1211	endl92	LLNL	<1992	300.0	6311	219	30.0	yes	no	no	no	no
31000.50c	69.1211	rmccs	B-V.0	1980	293.6	7928	511	20.0	yes	no	no	no	no
31000.50d	69.1211	drmccs	B-V.0	1980	293.6	6211	263	20.0	yes	no	no	no	no
31000.60c	69.1211	endf60	B-VI.0	1980	293.6	9228	566	20.0	yes	no	no	no	no
31000.66c	69.1211	endf66a	B-VI.0	1980	293.6	14640	1130	20.0	yes	no	no	no	no
Z = 33 ********** Arsenic **********													
** As-74 **													
33074.42c	73.2889	endl92	LLNL	<1992	300.0	55752	6851	30.0	yes	no	no	no	no
** As-75 **													
33075.35c	74.2780	rmccsa	B-V.0	1974	0.0	50931	6421	20.0	yes	no	no	no	no
33075.35d	74.2780	drmccs	B-V.0	1974	0.0	8480	263	20.0	yes	no	no	no	no
33075.42c	74.2780	endl92	LLNL	<1992	300.0	56915	6840	30.0	yes	no	no	no	no
Z = 35 ********** Bromine **********													
** Br-79 **													
35079.55c	78.2404	misc5xs[7,9]	LANL/T	1982	293.6	10431	1589	20.0	no	no	no	no	no
** Br-81 **													
35081.55c	80.2212	misc5xs[7,9]	LANL/T	1982	293.6	5342	831	20.0	no	no	no	no	no

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Z = 36 ********** Krypton **********													
** Kr-78 **													
36078.50c	77.2510	rmccsa	B-V.0	1978	293.6	9057	939	20.0	no	no	no	no	no
36078.50d	77.2510	drmccs	B-V.0	1978	293.6	4358	263	20.0	no	no	no	no	no
36078.66c	77.2510	endf66a	B-VI.0	1978	293.6	27045	2221	20.0	no	no	no	no	no
** Kr-80 **													
36080.50c	79.2298	rmccsa	B-V.0	1978	293.6	10165	1108	20.0	no	no	no	no	no
36080.50d	79.2298	drmccs	B-V.0	1978	293.6	4276	263	20.0	no	no	no	no	no
36080.66d	79.2298	endf66a	B-VI.0	1978	293.6	26039	2361	20.0	no	no	no	no	no
** Kr-82 **													
36082.50c	81.2098	rmccsa	B-V.0	1978	293.6	7220	586	20.0	no	no	no	no	no
36082.50d	81.2098	drmccs	B-V.0	1978	293.6	4266	263	20.0	no	no	no	no	no
36082.59c	81.2098	misc5xs[7,8]	LANL/T	1982	293.6	7010	499	20.0	yes	no	no	no	no
36082.66c	81.2098	endf66a	B-VI.0	1978	293.6	19674	1296	20.0	no	no	no	no	no
** Kr-83 **													
36083.50c	82.2018	rmccsa	B-V.0	1978	293.6	8078	811	20.0	no	no	no	no	no
36083.50d	82.2018	drmccs	B-V.0	1978	293.6	4359	263	20.0	no	no	no	no	no
36083.59c	82.2018	misc5xs[7,8]	LANL/T	1982	293.6	8069	704	20.0	yes	no	no	no	no
36083.66c	82.2018	endf66a	B-VI.0	1978	293.6	21271	1760	20.0	no	no	no	no	no
** Kr-84 **													
36084.50c	83.1906	rmccsa	B-V.0	1978	293.6	9364	944	20.0	no	no	no	no	no
36084.50d	83.1906	drmccs	B-V.0	1978	293.6	4463	263	20.0	no	no	no	no	no
36084.59c	83.1906	misc5xs[7,8]	LANL/T	1982	293.6	10370	954	20.0	yes	no	no	no	no
36084.66c	83.1906	endf66a	B-VI.0	1978	293.6	24427	2098	20.0	no	no	no	no	no
** Kr-86 **													
36086.50c	85.1726	rmccsa	B-V.0	1975	293.6	10416	741	20.0	no	no	no	no	no
36086.50d	85.1726	drmccs	B-V.0	1975	293.6	4301	263	20.0	no	no	no	no	no
36086.59c	85.1726	misc5xs[7,8]	LANL/T	1982	293.6	8740	551	20.0	yes	no	no	no	no
36086.66c	85.1726	endf66a	B-VI.0	1978	293.6	22203	1425	20.0	no	no	no	no	no
Z = 37 ********** Rubidium **********													
** Rb-85 **													
37085.55c	84.1824	misc5xs[7,9]	LANL/T	1982	293.6	27304	4507	20.0	no	no	no	no	no
37085.66c	84.1824	endf66a	B-VI.0	1979	293.6	179843	15316	20.0	no	no	no	no	no
** Rb-87 **													
37087.55c	86.1626	misc5xs[7.9]	LANL/T	1982	293.6	8409	1373	20.0	no	no	no	no	no
37087.66c	86.1624	endf66a	B-VI.0	1979	293.6	42718	3637	20.0	no	no	no	no	no
Z = 39 ********** Yttrium **********													
** Y-88 **													
39088.42c	87.1543	endl92	LLNL	<1992	300.0	11682	181	30.0	yes	no	no	no	no
** Y-89 **													
39089.35c	88.1421	misc5xs[7]	LLNL	<1985	0.0	49885	6154	20.0	yes	no	no	no	no
39089.42c	88.1421	endl92	LLNL	<1992	300.0	69315	8771	30.0	yes	no	no	no	no
39089.50c	88.1421	endf5u	B-V.0[10]	1985	293.6	18631	3029	20.0	no	no	no	no	no
39089.50d	88.1421	dre5	B-V.0[10]	1985	293.6	2311	263	20.0	no	no	no	no	no

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39089.60c	88.1420	endf60	B-VI.0	1986	293.6	86556	9567	20.0	yes	no	no	no	no
39089.66c	88.1420	endf66c	B-VI.4	1986	293.6	144304	13207	20.0	yes	no	no	no	no
Z = 40 ********** Zirconium **********													
** Zr-nat **													
40000.42c	90.4364	endl92	LLNL	<1992	300.0	131855	17909	30.0	yes	no	no	no	no
40000.56c	90.4360	misc5xs[7,11]	B-V:X-5	1976	300.0	52064	7944	20.0	no	no	no	no	no
40000.56d	90.4360	misc5xs[7,11]	B-V:X-5	1976	300.0	5400	263	20.0	no	no	no	no	no
40000.57c	90.4360	misc5xs[7,11]	B-V:X-5	1976	300.0	16816	2116	20.0	no	no	no	no	no
40000.57d	90.4360	misc5xs[7,11]	B-V:X-5	1976	300.0	5400	263	20.0	no	no	no	no	no
40000.58c	90.4360	misc5xs[7,11]	B-V:X-5	1976	587.2	57528	8777	20.0	no	no	no	no	no
40000.60c	90.4360	endf60	B-VI.1	1976[11]	293.6	66035	10298	20.0	no	no	no	no	no
40000.66c	90.4360	endf66b	B-VI.1	1976	293.6	165542	22226	20.0	no	no	no	no	no
** Zr-90 **													
40090.66c	89.1320	endf66b	B-VI.0:X	1976	293.6	51841	6243	20.0	no	no	no	no	no
** Zr-91 **													
40091.65c	90.1220	endf66e	B-VI.0:X	1976	3000.1	86834	10971	20.0	no	no	no	no	no
40091.66c	90.1220	endf66b	B-VI.0:X	1976	293.6	106833	13828	20.0	no	no	no	no	yes
** Zr-92 **													
40092.66c	91.1120	endf66b	B-VI.0:X	1976	293.6	82986	10664	20.0	no	no	no	no	no
** Zr-93 **													
40093.50c	92.1083	kidman	B-V.0	1974	293.6	2579	236	20.0	no	no	no	no	no
** Zr-4 **													
40094.66c	93.0960	endf66b	B-VI.0:X	1976	293.6	86543	11144	20.0	no	no	no	no	no
** Zr-96 **													
40096.66c	95.0810	endf66b	B-VI.0:X	1976	293.6	47405	5652	20.0	no	no	no	no	no
Z = 41 ********** Niobium **********													
** Nb-93 **													
41093.24c	92.1051	la150n	LANL	1997	293.6	375888	23213	150.0	yes	no	yes	no	no
41093.42c	92.1083	endl92	LLNL	<1992	300.0	73324	9277	30.0	yes	no	no	no	no
41093.50c	92.1051	endf5p	B-V.0	1974	293.6	128960	17279	20.0	yes	no	no	no	no
41093.50d	92.1051	dre5	B-V.0	1974	293.6	10332	263	20.0	yes	no	no	no	no
41093.51c	92.1051	rmccs	B-V.0	1974	293.6	14675	963	20.0	yes	no	no	no	no
41093.51d	92.1051	drmccs	B-V.0	1974	293.6	10332	263	20.0	yes	no	no	no	no
41093.60c	92.1051	endf60	B-VI.1	1990	293.6	110269	10678	20.0	yes	no	no	no	no
41063.66c	92.1051	endf66b	B-VI.6	1997	293.6	367638	23063	150.0	yes	no	yes	no	no
Z = 42 ********** Molybdenum **********													
** Mo-nat **													
42000.42c	95.1158	endl92	LLNL	<1992	300.0	9293	442	30.0	yes	no	no	no	no
42000.50c	95.1160	endf5u	B-V.0	1979	293.6	35634	4260	20.0	yes	no	no	no	no
42000.50d	95.1160	dre5	B-V.0	1979	293.6	7754	263	20.0	yes	no	no	no	no
42000.51c	95.1160	rmccs	B-V.0	1979	293.6	10139	618	20.0	yes	no	no	no	no
42000.51d	95.1160	drmccs	B-V.0	1979	293.6	7754	263	20.0	yes	no	no	no	no
42000.60c	95.1160	endf60	B-VI.0	1979	293.6	45573	5466	20.0	yes	no	no	no	no
42000.66c	95.1160	endf66b	B-VI.0	1979	293.6	68710	7680	20.0	yes	no	no	no	no

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
** Mo-95 **													
42095.50c	94.0906	kidman	B-V.0	1980	293.6	15411	2256	20.0	no	no	no	no	no
Z = 43 ********** Technetium **********													
** Tc-99 **													
43099.50c	98.1500	kidman	B-V.0	1978	293.6	12152	1640	20.0	no	no	no	no	no
43099.60c	98.1500	endf60	B-VI.0	1978	293.6	54262	8565	20.0	no	no	no	no	no
43099.65c	98.1500	endf66e	B-VI.0	1978	3000.1	67583	8545	20.0	no	no	no	no	yes
43099.66c	98.1500	endf66b	B-VI.0	1978	293.6	90039	11853	20.0	no	no	no	no	yes
Z = 44 ********** Ruthenium **********													
** Ru-101 **													
44101.50c	100.0390	kidman	B-V.0	1980	293.6	5299	543	20.0	no	no	no	no	no
** Ru-103 **													
44103.50c	102.0220	kidman	B-V.0	1974	293.6	3052	235	20.0	no	no	no	no	no
Z = 45 ********** Rhodium **********													
** Rh-103 **													
45103.50c	102.0210	rmccsa	B-V.0	1978	293.6	18870	2608	20.0	no	no	no	no	no
45103.50d	102.0210	drmccs	B-V.0	1974	293.6	4663	263	20.0	no	no	no	no	no
45103.65c	102.0210	endf66e	B-VI.0	1978	3000.1	83883	10715	20.0	no	no	no	no	yes
45103.66c	102.0210	endf66b	B-VI.0	1978	293.6	116685	15401	20.0	no	no	no	no	yes
** Rh-105 **													
45105.50c	104.0050	kidman	B-V.0	1974	293.6	1591	213	20.0	no	no	no	no	no
** Rh-117 **													
45117.90d	115.5446	drmccs	LANL/T	1982	293.6	9507	263	20.0	yes	no	no	no	no
45117.90c	115.5446	rmccs	LANL/T	1982	293.6	10314	399	20.0	yes	no	no	no	no
Z = 46 ********** Palladium **********													
** Pd-102 **													
46102.66c	101.0302	endf66b	B-VI.5	1996	293.6	148683	659	30.0	yes	no	yes	no	no
** Pd-104 **													
46104.66c	103.0114	endf66b	B-VI.5	1996	293.6	155873	1197	30.0	yes	no	yes	no	no
** Pd-105 **													
46105.50c	104.0040	kidman	B-V.0	1980	293.6	4647	505	20.0	no	no	no	no	no
46105.66c	104.0039	endf66b	B-VI.5	1996	293.6	634077	13480	30.0	yes	no	yes	no	no
** Pd-106 **													
46106.66c	104.9937	endf66b	B-VI.5	1996	293.6	150930	1154	30.0	yes	no	yes	no	no
** Pd-108 **													
46108.50c	106.9770	kidman	B-V.0	1980	293.6	4549	555	20.0	no	no	no	no	no
46108.66c	106.9769	endf66b	B-VI.5	1996	293.6	168900	1981	30.0	yes	no	yes	no	no
** Pd-110 **													
46110.66c	108.9610	endf66b	B-VI.5	1996	293.6	127359	862	30.0	yes	no	yes	no	no
** Pd-119 **													
46119.90d	117.5255	drmccs	LANL/T	1982	293.6	9542	263	20.0	yes	no	no	no	no
46119.90c	117.5255	rmccs	LANL/T	1982	293.6	10444	407	20.0	yes	no	no	no	no

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Z = 47 ********** Silver **********													
** Ag-nat **													
47000.55c	106.9420	rmccsa	LANL/T	1984	293.6	29092	2350	20.0	yes	no	no	no	no
47000.55d	106.9420	drmccs	LANL/T	1984	293.6	12409	263	20.0	yes	no	no	no	no
** Ag-107 **													
47107.42c	105.9867	endl92	LLNL	<1992	300.0	27108	2885	30.0	yes	no	no	no	no
47107.50c	105.9870	rmccsa	B-V.0	1978	293.6	12111	1669	20.0	no	no	no	no	no
47107.50d	105.9870	drmccs	B-V.0	1978	293.6	4083	263	20.0	no	no	no	no	no
47107.60c	105.9870	endf60	B-VI.0	1983	293.6	64008	10101	20.0	no	no	no	no	no
47107.66c	105.9870	endf66b	B-VI.0	1983	293.6	104321	13835	20.0	no	no	no	no	no
** Ag-109 **													
47109.42c	107.9692	endl92	LLNL	<1992	300.0	33603	3796	30.0	yes	no	no	no	no
47109.50c	107.9690	rmccsa	B-V.0	1978	293.6	14585	2120	20.0	no	no	no	no	no
47109.50d	107.9690	drmccs	B-V.0	1978	293.6	3823	263	20.0	no	no	no	no	no
47109.60c	107.9690	endf60	B-VI.0	1983	293.6	76181	11903	20.0	no	no	no	no	no
47109.66c	107.9690	endf66b	B-VI.0	1983	293.6	121474	16086	20.0	no	no	no	no	no
Z = 48 ********** Cadmium **********													
** Cd-nat **													
48000.42c	111.4443	endl92	LLNL	<1992	300.0	211537	29369	30.0	yes	no	no	no	no
48000.50c	111.4600	endf5u	B-V.0	1974	293.6	19714	2981	20.0	no	no	no	no	no
48000.50d	111.4600	dre5	B-V.0	1974	293.6	3026	263	20.0	no	no	no	no	no
48000.51c	111.4600	rmccs	B-V.0	1974	293.6	6734	818	20.0	no	no	no	no	no
48000.51d	111.4600	drmccs	B-V.0	1974	293.6	3026	263	20.0	no	no	no	no	no
** Cd-106 **													
48106.65c	105.0000	endf66e	B-VI.4	1996	3000.1	121059	10194	20.0	no	no	no	no	yes
48106.66c	105.0000	endf66b	B-VI.4	1996	293.6	151365	12949	20.0	no	no	no	no	yes
** Cd-108 **													
48108.65c	106.9770	endf66e	B-VI.4	1996	3000.1	112404	11496	20.0	no	no	no	no	yes
48108.66c	106.9770	endf66b	B-VI.4	1996	293.6	141658	14744	20.0	no	no	no	no	yes
** Cd-110 **													
48110.65c	108.9590	endf66e	B-VI.4:X	1996	3000.1	105350	10737	20.0	no	no	no	no	yes
48110.66c	108.9590	endf66b	B-VI.4:X	1996	293.6	133785	13902	20.0	no	no	no	no	yes
** Cd-111 **													
48111.66c	109.9520	endf66b	B-VI.3	1995	293.6	153808	16016	20.0	no	no	no	no	no
** Cd-112 **													
48112.65c	110.9420	endf66e	B-VI.4	1996	3000.1	101915	11153	20.0	no	no	no	no	yes
48112.66c	110.9420	endf66b	B-VI.4	1996	293.6	130334	14515	20.0	no	no	no	no	yes
** Cd-113 **													
48113.66c	111.9300	endf66b	B-VI.3	1995	293.6	97047	9799	20.0	no	no	no	no	no
** Cd-114 **													
48114.65c	112.9250	endf66e	B-VI.4	1996	3000.1	83882	10534	20.0	no	no	no	no	yes
48114.66c	112.9250	endf66b	B-VI.4	1996	293.6	102222	13154	20.0	no	no	no	no	yes
** Cd-116 **													
48116.65c	114.9090	endf66e	B-VI.4	1996	3000.1	55903	6607	20.0	no	no	no	no	yes
48116.66c	114.9090	endf66b	B-VI.4	1996	293.6	66642	8141	20.0	no	no	no	no	yes

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Z = 49 ********** Indium **********													
** In-nat **													
49000.42c	113.8336	endl92	LLNL	<1992	300.0	65498	7870	30.0	yes	no	no	no	no
49000.60c	113.8340	endf60	B-VI.0	1990	293.6	93662	10116	20.0	yes	no	no	no	no
49000.66c	113.8340	endf66b	B-VI.0	1990	293.6	169821	30337	20.0	yes	no	no	no	no
** In-120 **													
49120.42c	116.4906	endl92fp[12]	LLNL	<1992	300.0	12755	164	30.0	yes	no	no	no	no
** In-125 **													
49125.42c	116.4906	endl92fp[12]	LLNL	<1992	300.0	9142	119	30.0	yes	no	no	no	no
Z = 50 ********** Tin **********													
** Sn-nat **													
50000.40c	117.6704	endl92	LLNL	<1992	300.0	248212	34612	30.0	yes	no	no	no	no
50000.42c	117.6704	endl92	LLNL:X	<1992	300.0	248212	34612	30.0	yes	no	no	no	no
** Sn-120 **													
50120.35c	116.4906	rmccs	LLNL	<1985	0.0	8366	232	20.0	yes	no	no	no	no
50120.35d	116.4906	drmccs	LLNL	<1985	0.0	8963	263	20.0	yes	no	no	no	no
Z = 51 ********** Antimony **********													
** Sb-nat **													
51000.42c	120.7041	endl92	LLNL	<1992	300.0	95953	10721	30.0	yes	no	no	no	no
Z = 53 ********** Iodine **********													
** I-127 **													
53127.42c	125.8143	endl92	LLNL	<1992	300.0	76321	10	30.0	yes	no	no	no	no
53127.55c	125.8140	misc5xs[7,9]	LANL/T	1982	293.6	59725	9423	20.0	no	no	no	no	no
53127.60c	125.8143	endf60[13]	LANL/T	1991	293.6	399760	7888	30.0	yes	no	no	no	no
53127.66c	125.8143	endf66b	B-VI.2	1991	293.6	373991	11519	30.0	yes	no	yes	no	no
** I-129 **													
53129.60c	127.7980	endf60	B-VI.0	1980	293.6	8792	1237	20.0	no	no	no	no	no
** I-135 **													
53135.50c	133.7510	kidman	B-V.0	1974	293.6	1232	194	20.0	no	no	no	no	no
Z = 54 ********** Xenon **********													
** Xe-nat **													
54000.42c	130.1721	endl92	LLNL	<1992	300.0	43411	5173	30.0	yes	no	no	no	no
** Xe-124 **													
54124.66c	122.8420	endf66b	B-VI.0	1978	293.6	221034	1979	20.0	no	no	no	no	no
** Xe-126 **													
54126.66	124.8230	endf66b	B-VI.0	1978	293.6	21388	2133	20.0	no	no	no	no	no
** Xe-128 **													
54128.66c	126.8050	endf66b	B-VI.0	1978	293.6	32739	3817	20.0	no	no	no	no	no
** Xe-129 **													
54129.66c	127.7970	endf66b	B-VI.0	1978	293.6	118721	15971	20.0	no	no	no	no	no
** Xe-130 **													
54130.66c	128.7880	endf66b	B-VI.0	1978	293.6	34346	3984	20.0	no	no	no	no	no

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** Xe-131 **													
54131.50c	129.7810	kidman	B-V.0	1978	293.6	22572	3376	20.0	no	no	no	no	no
54131.66c	129.7810	endf66b	B-VI.0	1978	293.6	79510	10434	20.0	no	no	no	no	no
** Xe-132 **													
54132.66c	130.7710	endf66b	B-VI.0	1978	293.6	17947	1709	20.0	no	no	no	no	no
** Xe-134 **													
54134.42c	132.7551	endl92	LLNL	<1992	300.0	8033	192	30.0	yes	no	no	no	no
54134.66c	132.7550	endf66b	B-VI.0	1978	293.6	15028	1349	20.0	no	no	no	no	no
** Xe-135 **													
54135.50c	133.7480	endf5mt[1]	B-V	1975	293.6	5529	704	20.0	no	no	no	no	no
54135.53c	133.7480	endf5mt[1]	B-V	1975	587.2	5541	706	20.0	no	no	no	no	no
54135.54c	133.7480	endf5mt[1]	B-V	1975	880.8	5577	712	20.0	no	no	no	no	no
** Xe-136 **													
54136.66c	134.7400	endf66b	B-VI.0	1978	293.6	10700	764	20.0	no	no	no	no	no
Z = 55 ********** Cesium **********													
** Cs-133 **													
55133.50c	131.7640	kidman	B-V.0	1978	293.6	26713	4142	20.0	no	no	no	no	no
55133.55c	131.7640	misc5xs[7,9]	LANL/T	1982	293.6	67893	11025	20.0	no	no	no	no	no
55133.60c	131.7640	endf60	B-VI.0	1978	293.6	54723	8788	20.0	no	no	no	no	no
55133.66c	131.7640	endf66b	B-VI.0	1978	293.6	141927	19648	20.0	no	no	no	no	no
** Cs-134 **													
55134.60c	132.7570	endf60	B-VI.0	1988	293.6	10227	1602	20.0	no	no	no	no	no
** Cs-135 **													
55135.50c	133.7470	kidman	B-V.0	1974	293.6	1903	199	20.0	no	no	no	no	no
55135.60c	133.7470	endf60	B-VI.0	1974	293.6	3120	388	20.0	no	no	no	no	no
** Cs-136 **													
55136.60c	134.7400	endf60	B-VI.0	1974	293.6	10574	1748	20.0	no	no	no	no	no
** Cs-137 **													
55137.60c	135.7310	endf60	B-VI.0	1974	293.6	2925	369	20.0	no	no	no	no	no
Z = 56 ********** Barium **********													
** Ba-138 **													
56138.50c	136.7150	rmccs	B-V.0	1978	293.6	6018	292	20.0	yes	no	no	no	no
56138.50d	136.7150	drmccs	B-V.0	1978	293.6	6320	263	20.0	yes	no	no	no	no
56138.60c	136.7150	endf60	B-VI.0	1978	293.6	7347	267	20.0	yes	no	no	no	no
56138.66c	136.7150	endf66b	B-VI.3	1994	293.6	79268	8920	20.0	yes	no	no	no	no
Z = 59 ********** Praseodymium **********													
** Pr-141 **													
59141.50c	139.6970	kidman	B-V.0	1980	293.6	15620	1354	20.0	no	no	no	no	no
Z = 60 ********** Neodymium **********													
** Nd-143 **													
60143.50c	141.6820	kidman	B-V.0	1980	293.6	17216	1701	20.0	no	no	no	no	no
** Nd-145 **													
60145.50c	143.6680	kidman	B-V.0	1980	293.6	38473	3985	20.0	no	no	no	no	no

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** Nd-147 **													
60147.50c	145.6540	kidman	B-V.0	1979	293.6	1816	251	20.0	no	no	no	no	no
** Nd-148 **													
60148.50c	146.6460	kidman	B-V.0	1980	293.6	10867	1054	20.0	no	no	no	no	no
Z = 61 ********** Promethium **********													
** Pm-147 **													
61147.50c	145.6530	kidman	B-V.0	1980	293.6	9152	825	20.0	no	no	no	no	no
** Pm-148 **													
61148.50c	146.6470	kidman	B-V.0	1979	293.6	1643	257	20.0	no	no	no	no	no
** Pm-149 **													
61149.50c	147.6390	kidman	B-V.0	1979	293.6	2069	238	20.0	no	no	no	no	no
Z = 62 ********** Samarium **********													
** Sm-147 **													
62147.50c	145.6530	kidman	B-V.0	1980	293.6	33773	2885	20.0	no	no	no	no	no
621147.65c	145.6530	endf66e	B-VI.0	1980	3000.1	186194	15025	20.0	no	no	no	no	yes
62147.66c	145.6530	endf66b	B-VI.0	1980	293.6	315674	25815	20.0	no	no	no	no	yes
** Sm-149 **													
62149.49c	147.6380	uresa	B-VI.0	1978	300.0	57787	7392	20.0	no	no	no	no	yes
62149.50c	147.6380	endf5u	B-V.0	1978	293.6	15662	2008	20.0	no	no	no	no	no
62149.50d	147.6380	dre5	B-V.0	1978	293.6	4429	263	20.0	no	no	no	no	no
62149.65c	147.6380	endf66e	B-VI.0	1978	3000.1	47902	5399	20.0	no	no	no	no	yes
62149.66c	147.6380	endf66b	B-VI.0	1978	293.6	64240	7733	20.0	no	no	no	no	yes
** Sm-150 **													
62150.49c	148.6290	uresa	B-VI.2	1992	300.0	60992	8183	20.0	no	no	no	no	yes
62150.50c	148.6290	kidman	B-V.0	1974	293.6	9345	1329	20.0	no	no	no	no	no
** Sm-151 **													
62151.50c	149.6230	kidman	B-V.0	1980	293.6	7303	605	20.0	no	no	no	no	no
** Sm-152 **													
62152.49c	150.6150	uresa	B-VI.2	1992	300.0	203407	19737	20.0	no	no	no	no	yes
62152.50c	150.6150	kidman	B-V.0	1980	293.6	41252	4298	20.0	no	no	no	no	no
Z = 63 ********** Europium **********													
** Eu-nat **													
63000.35c	150.6546	rmccsa	LLNL	<1985	0.0	6926	364	20.0	yes	no	no	no	no
63000.35d	150.6546	drmccs	LLNL	<1985	0.0	6654	263	20.0	yes	no	no	no	no
63000.42c	150.6546	endl92	LLNL	<1992	300.0	37421	4498	30.0	yes	no	no	no	no
** Eu-151 **													
63151.49c	149.6230	uresa	B-VI.0	1986	300.0	147572	10471	20.0	yes	no	no	no	yes
63151.50c	149.6230	rmccs	B-V.0	1977	293.6	68057	5465	20.0	yes	no	no	no	no
63151.50d	149.6230	drmccs	B-V.0	1977	293.6	10013	263	20.0	yes	no	no	no	no
63151.55c	149.6230	newxs	LANL/T	1986	293.6	86575	4749	20.0	yes	no	no	no	no
63151.55d	149.6230	newxsd	LANL/T	1986	293.6	35199	263	20.0	yes	no	no	no	no
63151.60c	149.6230	endf60	B-VI.0	1986	293.6	96099	7394	20.0	yes	no	no	no	no
63151.65c	149.6230	endf66e	B-VI.0	1986	3000.1	98867	5220	20.0	yes	no	no	no	yes

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63151.66c	149.6230	endf66b	B-VI.0	1986	293.6	155078	10841	20.0	yes	no	no	no	yes
** Eu-152 **													
63152.49c	150.6200	uresa	B-VI.0	1975	300.0	81509	6540	20.0	no	no	no	no	yes
63152.50c	150.6200	endf5u	B-V.0	1975	293.6	49313	4553	20.0	no	no	no	no	no
63152.50d	150.6200	dre5	B-V.0	1975	293.6	5655	263	20.0	no	no	no	no	no
63152.65c	150.6200	endf66e	B-VI.0	1988	3000.1	53516	3563	20.0	no	no	no	no	yes
63152.66c	150.6200	endf66b	B-VI.0	1988	293.6	89485	6833	20.0	no	no	no	no	yes
** Eu-153 **													
63153.49c	151.6080	uresa	B-VI.0	1986	300.0	129446	8784	20.0	yes	no	no	no	yes
63153.50c	151.6070	rmccs	B-V.0	1978	293.6	55231	4636	20.0	yes	no	no	no	no
63153.50d	151.6070	drmccs	B-V.0	1978	293.6	11244	263	20.0	yes	no	no	no	no
63153.55c	151.6080	newxs	LANL/T	1986	293.6	72971	4174	20.0	yes	no	no	no	no
63153.55d	151.6080	newxsd	LANL/T	1986	293.6	36372	263	20.0	yes	no	no	no	no
63153.60c	151.6080	endf60	B-VI.0	1986	293.6	86490	6198	20.0	yes	no	no	no	no
63153.65c	151.6080	endf66e	B-VI.0	1986	3000.1	93021	4791	20.0	yes	no	no	no	yes
63153.66c	151.6080	endf66b	B-VI.0	1986	293.6	135491	9038	20.0	yes	no	no	no	yes
** Eu-154 **													
63154.49c	152.6000	uresa	B-VI.0	1975	300.0	72804	6627	20.0	no	no	no	no	yes
63154.50c	152.6000	endf5u	B-V.0	1975	293.6	37008	4030	20.0	no	no	no	no	no
63154.50d	152.6000	dre5	B-V.0	1975	293.6	5458	263	20.0	no	no	no	no	no
63154.65c	152.6000	endf66e	B-VI.0	1989	3000.1	54676	4078	20.0	no	no	no	no	yes
63154.66c	152.6000	endf66b	B-VI.0	1989	293.6	80218	6916	20.0	no	no	no	no	yes
** Eu-155 **													
63155.50c	153.5920	kidman	B-V.0	1974	293.6	4532	273	20.0	no	no	no	no	no
63155.66c	153.5920	endf66b	B-VI.1	1988	293.6	27638	2440	20.0	no	no	no	no	no
Z = 64 ********** Gadolinium **********													
** Gd-nat **													
64000.35c	155.8991	rmccsa	LLNL	<1985	0.0	7878	454	20.0	yes	no	no	no	no
64000.35d	155.8991	drmccs	LLNL	<1985	0.0	6833	263	20.0	yes	no	no	no	no
** Gd-152 **													
64152.50c	150.6150	endf5u	B-V.0	1977	293.6	26251	3285	20.0	no	no	no	no	no
64152.50d	150.6150	dre5	B-V.0	1977	293.6	5899	263	20.0	no	no	no	no	no
64152.55c	150.6150	misc5xs[7,14]	B-V.0:T	1986	293.6	32590	3285	20.0	yes	no	no	no	no
64152.60c	150.6150	endf60	B-VI.0	1977	293.6	32760	4391	20.0	no	no	no	no	no
64152.65c	150.6150	endf66e	B-VI.4	1994	3000.1	263235	20777	20.0	no	no	no	no	yes
64152.66c	150.6150	endf66b	B-VI.4	1994	293.6	341562	29480	20.0	no	no	no	no	yes
** Gd-154 **													
64154.50c	152.5990	endf5u	B-V.0	1977	293.6	49572	7167	20.0	no	no	no	no	no
64154.50d	152.5990	dre5	B-V.0	1977	293.6	5930	263	20.0	no	no	no	no	no
64154.55c	152.5990	misc5xs[7,14]	B-V.0:T	1986	293.6	59814	7167	20.0	yes	no	no	no	no
64154.60c	152.5990	endf60	B-VI.0	1977	293.6	67662	10189	20.0	no	no	no	no	no
64154.65c	152.5990	endf66e	B-VI.4	1994	3000.1	218806	21530	20.0	no	no	no	no	yes
64154.66c	152.5990	endf66b	B-VI.4	1994	293.6	286357	31180	20.0	no	no	no	no	yes
** Gd-155 **													
64155.50c	153.5920	endf5u	B-V.0	1977	293.6	44965	6314	20.0	no	no	no	no	no
64155.50d	153.5920	dre5	B-V.0	1977	293.6	6528	263	20.0	no	no	no	no	no

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64155.55c	153.5920	misc5xs[7,14]	B-V.0:T	1986	293.6	54346	6314	20.0	yes	no	no	no	no
64155.60c	153.5920	endf60	B-VI.0	1977	293.6	61398	9052	20.0	no	no	no	no	no
64155.65c	153.5920	endf66e	B-VI.0	1977	3000.1	62954	6748	20.0	no	no	no	no	yes
64155.66c	153.5920	endf66b	B-VI.0	1977	293.6	106795	13011	20.0	no	no	no	no	yes
** Gd-156 **													
64156.50c	154.5830	endf5u	B-V.0	1977	293.6	37371	3964	20.0	no	no	no	no	no
64156.50d	154.5830	dre5	B-V.0	1977	293.6	6175	263	20.0	no	no	no	no	no
64156.55c	154.5830	misc5xs[7,14]	B-V.0:T	1986	293.6	44391	3964	20.0	yes	no	no	no	no
64156.60c	154.5830	endf60	B-VI.0	1977	293.6	42885	5281	20.0	no	no	no	no	no
64156.66c	154.5830	endf66b	B-VI.0	1977	293.6	79827	7354	20.0	no	no	no	no	no
** Gd-157 **													
64157.50c	155.5760	endf5u	B-V.0	1977	293.6	38975	5370	20.0	no	no	no	no	no
64157.50d	155.5760	dre5	B-V.0	1977	293.6	6346	263	20.0	no	no	no	no	no
64157.55c	155.5760	misc5xs[7,14]	B-V.0:T	1986	293.6	47271	5370	20.0	yes	no	no	no	no
64157.60c	155.5760	endf60	B-VI.0	1977	293.6	56957	8368	20.0	no	no	no	no	no
64157.65c	155.5760	endf66e	B-VI.0	1977	3000.1	71857	8101	20.0	no	no	no	no	yes
64157.66c	155.5760	endf66b	B-VI.0	1977	293.6	99199	12007	20.0	no	no	no	no	yes
** Gd-158 **													
64158.50c	156.5670	endf5u	B-V.0	1977	293.6	95876	15000	20.0	no	no	no	no	no
64158.50d	156.5670	dre5	B-V.0	1977	293.6	5811	263	20.0	no	no	no	no	no
64158.55c	156.5670	misc5xs[7,14]	B-V.0:T	1986	293.6	113916	15000	20.0	yes	no	no	no	no
64158.60c	156.5670	endf60	B-VI.0	1977	293.6	59210	8909	20.0	no	no	no	no	no
64158.66c	156.5670	endf66b	B-VI.0	1977	293.6	152895	19903	20.0	no	no	no	no	no
** Gd-160 **													
64160.50c	158.5530	endf5u	B-V.0	1977	293.6	53988	8229	20.0	no	no	no	no	no
64160.50d	158.5530	dre5	B-V.0	1977	293.6	5030	263	20.0	no	no	no	no	no
64160.55c	158.5530	misc5xs[7,14]	B-V.0:T	1986	293.6	65261	8229	20.0	yes	no	no	no	no
64160.60c	158.5530	endf60	B-VI.0	1977	293.6	54488	8304	20.0	no	no	no	no	no
64160.66c	158.5530	endf66b	B-VI.0	1977	293.6	90407	11183	20.0	no	no	no	no	no
Z = 67 ********** Holmium **********													
** Ho-165 **													
67165.35c	163.5135	rmccsa	LLNL	<1985	0.0	54279	7075	20.0	yes	no	no	no	no
67165.35d	163.5135	drmccs	LLNL	<1985	0.0	7019	263	20.0	yes	no	no	no	no
67165.42c	163.5135	endl92	LLNL	<1992	300.0	103467	13884	30.0	yes	no	no	no	no
67165.55c	163.5130	newxs	LANL/T	1986	293.6	56605	2426	30.0	yes	no	no	no	no
67165.55d	163.5130	newxsd	LANL/T	1986	293.6	42266	263	20.0	yes	no	no	no	no
67165.60c	163.5130	endf60	B-VI.0	1988	293.6	75307	4688	30.0	yes	no	no	no	no
67165.66c	163.5130	endf66b	B-VI.5	1988	293.6	101124	6648	30.0	yes	no	no	no	no
Z = 69 ********** Thulium **********													
** Tm-169 **													
69169.55c	167.4830	misc5xs[7]	LANL/T	1986	300.0	47941	4738	20.0	no	no	no	no	no
Z = 71 ********** Lutetium **********													
** Lu-175 **													
71175.65c	173.4380	endf66e	B-VI.0	1967	3000.1	34931	3631	20.0	no	no	no	no	yes

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71175.66c	173.4380	endf66b	B-VI.0	1967	293.6	42687	4739	20.0	no	no	no	no	yes
** Lu-176 **													
71176.65c	174.4300	endf66e	B-VI.0	1967	3000.1	37422	3903	20.0	no	no	no	no	yes
71176.66c	174.4300	endf66b	B-VI.0	1967	293.6	48096	5428	20.0	no	no	no	no	yes
Z = 72 ********** Hafnium **********													
** Hf-nat **													
72000.42c	176.9567	endl92	LLNL	<1992	300.0	108989	14113	30.0	yes	no	no	no	no
72000.50c	176.9540	newxs	B-V.0	1976	293.6	52231	8270	20.0	no	no	no	no	no
72000.50d	176.9540	newxsd	B-V.0	1976	293.6	4751	263	20.0	no	no	no	no	no
72000.60c	176.9540	endf60	B-VI.0	1976	293.6	84369	13634	20.0	no	no	no	no	no
** Hf-174 **													
72174.65c	172.4460	endf66e	B-VI.2	1992	3000.1	35072	3834	20.0	no	no	no	no	yes
72174.66c	172.4460	endf66b	B-VI.2	1992	293.6	39545	4473	20.0	no	no	no	no	yes
** Hf-176 **													
72176.65c	174.4300	endf66e	B-VI.2	1992	3000.1	55807	6869	20.0	no	no	no	no	yes
72176.66c	174.4300	endf66b	B-VI.2	1992	293.6	66727	8429	20.0	no	no	no	no	yes
** Hf-177 **													
72177.65c	175.4230	endf66e	B-VI.2	1991	3000.1	115867	15278	20.0	no	no	no	no	yes
72177.66c	175.4230	endf66b	B-VI.2	1991	293.6	219075	30022	20.0	no	no	no	no	yes
** Hf-178 **													
72178.65c	176.4150	endf66e	B-VI.2	1991	3000.1	58452	7291	20.0	no	no	no	no	yes
72178.66c	176.4150	endf66b	B-VI.2	1991	293.6	67580	8595	20.0	no	no	no	no	yes
** Hf-179 **													
72179.65c	177.4090	endf66e	B-VI.2	1992	3000.1	79130	10151	20.0	no	no	no	no	yes
72179.66c	177.4090	endf66b	B-VI.2	1992	293.6	106850	14111	20.0	no	no	no	no	yes
** Hf-180 **													
72180.65c	178.4010	endf66e	B-VI.2	1991	3000.1	112444	15082	20.0	no	no	no	no	yes
72180.66c	178.4010	endf66b	B-VI.2	1991	293.6	145939	19867	20.0	no	no	no	no	yes
Z = 73 ********** Tantalum **********													
** Ta-181 **													
73181.42c	179.3936	endl92	LLNL	<1992	300.0	47852	4927	30.0	yes	no	no	no	no
73181.50c	179.4000	endf5u	B-V.0	1972	293.6	60740	6341	20.0	yes	no	no	no	no
73181.50d	179.4000	dre5	B-V.0	1972	293.6	16361	263	20.0	yes	no	no	no	no
73181.51c	179.4000	rmccs	B-V.0	1972	293.6	21527	753	20.0	yes	no	no	no	no
73181.51d	179.4000	drmccs	B-V.0	1972	293.6	16361	263	20.0	yes	no	no	no	no
73181.60c	179.4000	endf60	B-VI.0	1972	293.6	91374	10352	20.0	yes	no	no	no	no
73181.64c	179.4000	endf66d	B-VI.0	1972	77.0	158545	17152	20.0	yes	no	no	no	no
73181.66c	179.4000	endf66b	B-VI.0	1972	293.6	140345	14877	20.0	yes	no	no	no	no
** Ta-182 **													
73182.49c	180.3870	uresa	B-VI.0	1971	300.0	20850	2463	20.0	no	no	no	no	yes
73182.60c	180.3870	endf60	B-VI.0	1971	293.6	12085	1698	20.0	no	no	no	no	no
73182.64c	180.3870	endf66d	B-VI.0	1971	77.0	29837	3020	20.0	no	no	no	no	yes
73182.65c	180.3870	endf66e	B-VI.0	1971	3000.1	25028	2333	20.0	no	no	no	no	yes
73182.66c	180.3870	endf66b	B-VI.0	1971	293.6	28577	2840	20.0	no	no	no	no	yes

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Z = 74 ********** Tungsten **********													
** W-nat **													
74000.21c	182.2706	100xs[3]	LANL/T:X	1989	300.0	194513	21386	100.0	yes	no	no	no	no
74000.55c	182.2770	rmccs	B-V.2	1982	293.6	50639	1816	20.0	yes	no	no	no	no
74000.55d	182.2770	drmccs	B-V.2	1982	293.6	34272	263	20.0	yes	no	no	no	no
** W-182 **													
74182.24c	180.3900	la150n	B-VI.6	1996	239.6	246875	16896	150.0	yes	no	yes	no	yes
74182.48c	180.3900	uresa[16]	B-VI.0	1980	300.0	150072	16495	20.0	no	no	no	no	yes
74182.50c	180.3900	endf5p	B-V.0	1973	293.6	94367	11128	20.0	yes	no	no	no	no
74182.50d	180.3900	dre5	B-V.0	1973	293.6	17729	263	20.0	yes	no	no	no	no
74182.55c	180.3900	rmccsa	B-V.2	1980	293.6	122290	13865	20.0	yes	no	no	no	no
74182.55d	180.3900	drmccs	B-V.2	1980	293.6	26387	263	20.0	yes	no	no	no	no
74182.60c	180.3900	endf60	B-VI.0	1980	293.6	113177	12283	20.0	yes	no	no	no	no
74182.61c	180.3900	actib	B-VI.8	2000	77.0	269718	18237	150.0	yes	no	yes	no	yes
74182.62c	180.3900	actia	B-VI.8	2000	293.6	258342	16815	150.0	yes	no	yes	no	yes
74182.63c	180.3900	actib	B-VI.8	2000	3000.1	232047	13528	150.0	yes	no	yes	no	yes
74182.64c	180.3900	endf66d	B-VI.6	1996	77.0	257611	18238	150.0	yes	no	yes	no	yes
74182.65c	180.3900	endf66e	B-VI.6	1996	3000.1	219900	13524	150.0	yes	no	yes	no	yes
74182.66c	180.3900	endf66b	B-VI.6	1996	293.6	246251	16818	150.0	yes	no	yes	no	yes
** W-183 **													
74183.24c	181.3800	la150n	B-VI.6	1996	293.6	217095	13034	150.0	yes	no	yes	no	yes
74183.48c	181.3800	uresa[16]	B-VI.0	1980	300.0	119637	12616	20.0	no	no	no	no	yes
74183.50c	181.3800	endf5p	B-V.0	1973	293.6	58799	5843	20.0	yes	no	no	no	no
74183.50d	181.3800	dre5	B-V.0	1973	293.6	19443	263	20.0	yes	no	no	no	no
74183.55c	181.3800	rmccsa	B-V.2	1980	293.6	79534	8083	20.0	yes	no	no	no	no
74183.55d	181.3800	drmccs	B-V.2	1980	293.6	26320	263	20.0	yes	no	no	no	no
74183.60c	181.3800	endf60	B-VI.0	1980	293.6	89350	9131	20.0	yes	no	no	no	no
74183.61c	181.3800	actib	B-VI.8	2000	77.0	235761	14449	150.0	yes	no	yes	no	yes
74183.62c	181.3800	actia	B-VI.8	2000	293.6	224856	13086	150.0	yes	no	yes	no	yes
74183.63c	181.3800	actib	B-VI.8	2000	3000.1	198226	9757	150.0	yes	no	yes	no	yes
74183.64c	181.3800	endf66d	B-VI.6	1996	77.0	228392	14446	150.0	yes	no	yes	no	yes
74183.65c	181.3800	endf66e	B-VI.6	1996	3000.1	190833	9751	150.0	yes	no	yes	no	yes
74183.66c	181.3800	endf66b	B-VI.6	1996	293.6	217447	13078	150.0	yes	no	yes	no	yes
** W-184 **													
74184.24c	182.3700	lal150n	B-VI.6	1996	293.6	192693	10180	150.0	yes	no	yes	no	yes
74184.48c	182.3700	uresa[16]	B-VI.0	1980	300.0	97118	9794	20.0	no	no	no	no	yes
74184.50c	182.3700	endf5p	B-V.0	1973	293.6	58870	6173	20.0	yes	no	no	no	no
74184.50d	182.3700	dre5	B-V.0	1973	293.6	17032	263	20.0	yes	no	no	no	no
74184.55c	182.3700	rmccsa	B-V.2	1980	293.6	80006	7835	20.0	yes	no	no	no	no
74184.55d	182.3700	drmccs	B-V.2	1980	293.6	26110	263	20.0	yes	no	no	no	no
74184.60c	182.3700	endf60	B-VI.0	1980	293.6	78809	7368	20.0	yes	no	no	no	no
74184.61c	182.3700	actib	B-VI.8	2000	77.0	200883	10902	150.0	yes	no	yes	no	yes
74184.62c	182.3700	actia	B-VI.8	2000	293.6	194523	10107	150.0	yes	no	yes	no	yes
74184.63c	182.3700	actib	B-VI.8	2000	3000.1	181213	8443	150.0	yes	no	yes	no	yes
74184.64c	182.3700	endf66d	B-VI.6	1996	77.0	198499	10906	150.0	yes	no	yes	no	yes
74184.65c	182.3700	endf66e	B-VI.6	1996	3000.1	178773	8440	150.0	yes	no	yes	no	yes

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74184.66c	182.3700	endf66b	B-VI.6	1996	293.6	192123	10109	150.0	yes	no	yes	no	yes
** W-186 **													
74186.24c	187.3600	la150n	B-VI.6	1996	293.6	187863	10848	150.0	yes	no	yes	no	yes
74186.48c	184.3600	uresa[16]	B-VI.0	1980	300.0	102199	10485	20.0	no	no	no	no	yes
74186.50c	184.3600	endf5p	B-V.0	1973	293.6	63701	6866	20.0	yes	no	no	no	no
74186.50d	184.3600	dre5	B-V.0	1973	293.6	17018	263	20.0	yes	no	no	no	no
74186.55c	184.3600	rmccsa	B-V.2	1980	293.6	83618	8342	20.0	yes	no	no	no	no
74186.55d	184.3600	drmccs	B-V.2	1980	293.6	26281	263	20.0	yes	no	no	no	no
74186.60c	184.3600	endf60	B-VI.0	1980	293.6	82010	7793	20.0	yes	no	no	no	no
74186.61c	184.3600	actib	B-VI.8	2000	77.0	207824	11635	150.0	yes	no	yes	no	yes
74186.62c	184.3600	actia	B-VI.8	2000	293.6	202211	10833	150.0	yes	no	yes	no	yes
74186.63c	184.3600	actib	B-VI.8	2000	3000.1	190276	9128	150.0	yes	no	yes	no	yes
74186.64c	184.3600	endf66d	B-VI.6	1996	77.0	193372	11635	150.0	yes	no	yes	no	yes
74186.65c	184.3600	endf66e	B-VI.6	1996	3000.1	175817	9127	150.0	yes	no	yes	no	yes
74186.66c	184.3600	endf66b	B-VI.6	1996	293.6	187731	10829	150.0	yes	no	yes	no	yes
Z = 75 ********** Rhenium **********													
** Re-185 **													
75185.32c	183.3612	misc5xs[7]	LLNL	<1985	0.0	13650	1488	20.0	yes	no	no	no	no
75185.42c	183.3641	endl92	LLNL	<1992	300.0	23715	2214	30.0	yes	no	no	no	no
75185.50c	183.3640	rmccsa	B-V.0	1968	293.6	9190	1168	20.0	no	no	no	no	no
75185.50d	183.3640	drmccs	B-V.0	1968	293.6	4252	263	20.0	no	no	no	no	no
75185.60c	183.3640	endf60	B-VI.0	1990	293.6	102775	16719	20.0	no	no	no	no	no
75185.65c	183.3640	endf66e	B-VI.0	1990	3000.1	179325	24470	20.0	no	no	no	no	yes
75185.66c	183.3640	endf66c	B-VI.0	1990	293.6	397396	55623	20.0	no	no	no	no	yes
** Re-187 **													
75187.32c	185.3539	misc5xs[7]	LLNL	<1985	0.0	12318	1296	20.0	yes	no	no	no	no
75187.42c	185.3497	endl92	LLNL	<1992	300.0	20969	1821	30.0	yes	no	no	no	no
75187.50c	185.3500	rmccsa	B-V.0	1968	293.6	8262	959	20.0	no	no	no	no	no
75187.50d	185.3500	drmccs	B-V.0	1968	293.6	4675	263	20.0	no	no	no	no	no
75187.60c	185.3500	endf60	B-VI.0	1990	293.6	96989	15624	20.0	no	no	no	no	no
75187.65c	185.3500	endf66e	B-VI.0	1990	3000.1	180705	24518	20.0	no	no	no	no	yes
75187.66c	185.3500	endf66c	B-VI.0	1990	293.6	358295	49888	20.0	no	no	no	no	yes
Z = 77 ********** Iridium **********													
** Ir-nat **													
77000.55c	190.5630	misc5xs[7]	LANL/T	1986	300.0	43071	3704	20.0	no	no	no	no	no
** Ir-191 **													
77191.49c	189.3200	uresa	B-VI.4	1995	300.0	83955	8976	20.0	yes	no	no	no	yes
77191.65c	189.3200	endf66e	B-VI.4:X	1995	3000.1	64690	6116	20.0	yes	no	no	no	yes
77191.66c	189.3200	endf66c	B-VI.4:X	1995	293.6	90082	9290	20.0	yes	no	no	no	yes
** Ir-193 **													
77193.49c	191.3050	uresa	B-VI.4	1995	300.0	82966	8943	20.0	yes	no	no	no	yes
77193.65c	191.3050	endf66e	B-VI.4:X	1995	3000.1	69056	6751	20.0	yes	no	no	no	yes
77193.66c	191.3050	endf66c	B-VI.4:X	1995	293.6	88688	9205	20.0	yes	no	no	no	yes

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Z = 78 ********** Platinum **********													
** pt-nat **													
78000.35c	193.4141	rmccsa	LLNL	<1985	0.0	15371	1497	20.0	yes	no	no	no	no
78000.35d	193.4141	drmccs	LLNL	<1985	0.0	6933	263	20.0	yes	no	no	no	no
78000.40c	193.4141	endl92	LLNL	<1992	300.0	43559	5400	30.0	yes	no	no	no	no
78000.42c	193.4141	endl92	LLNL:X	<1992	300.0	43559	5400	30.0	yes	no	no	no	no
Z = 79 ********** Gold **********													
** Au-197 **													
79197.50c	195.2740	endf5p	B-V.0	1977	293.6	139425	22632	20.0	no	no	no	no	no
79197.50d	195.2740	dre5	B-V.0	1977	293.6	4882	263	20.0	no	no	no	no	no
79197.55c	195.2740	rmccsa	LANL/T	1983[4]	293.6	134325	17909	20.0	yes	no	no	no	no
79197.55d	195.2740	drmccs	LANL/T	1983[4]	293.6	7883	263	20.0	yes	no	no	no	no
79197.56c	195.2740	newxs	LANL/T	1984	293.6	122482	11823	30.0	yes	no	no	no	no
79197.56d	195.2740	newxsd	LANL/T	1984	293.6	38801	263	20.0	yes	no	no	no	no
79197.60c	195.2740	endf60	B-VI.1	1984	293.6	161039	17724	30.0	yes	no	no	no	no
79197.66c	195.2740	endf66c	B-VI.1	1984	293.6	377905	39417	30.0	yes	no	no	no	no
Z = 80 ********** Mercury **********													
** Hg-nat **													
80000.40c	198.8668	endl92	LLNL	<1992	300.0	29731	2507	30.0	yes	no	no	no	no
80000.42c	198.8668	endl92	LLNL:X	<1992	300.0	29731	2507	30.0	yes	no	no	no	no
** Hg-196 **													
80196.24c	194.2820	la150n	LANL	1998	293.6	153206	1690	150.0	yes	no	yes	no	no
** Hg-198 **													
80198.24c	196.2660	la150n	LANL	1998	293.6	172481	3205	150.0	yes	no	yes	no	no
** Hg-199 **													
80199.24c	197.2590	la150n	LANL	1998	293.6	173336	4126	150.0	yes	no	yes	no	no
** Hg-200 **													
80200.24c	198.2500	la150n	LANL	1998	293.6	192339	2560	150.0	yes	no	yes	no	no
** Hg-201 **													
80201.24c	199.2440	la150n	LANL	1998	293.6	166179	3492	150.0	yes	no	yes	no	no
** Hg-202 **													
80202.24c	200.2360	la150n	LANL	1998	293.6	154736	1887	150.0	yes	no	yes	no	no
** Hg-204 **													
80204.24c	202.2210	la150n	LANL	1998	293.6	140754	832	150.0	yes	no	yes	no	no
Z = 82 ********** Lead **********													
** Pb-nat **													
82000.42c	205.4200	endl92	LLNL	<1992	300.0	270244	18969	30.0	yes	no	no	no	no
82000.50c	205.4300	rmccs	B-V.0	1976	293.6	37633	1346	20.0	yes	no	no	no	no
82000.50d	205.4300	drmccs	B-V.0	1976	293.6	20649	263	20.0	yes	no	no	no	no
** Pb-206 **													
82206.24c	204.2000	la150n	B-VI.6	1996	293.6	424548	30415	150.0	yes	no	yes	no	no
82206.60c	204.2000	endf60	B-VI.0	1989	293.6	148815	12872	20.0	yes	no	no	no	no
82206.66c	204.2000	endf66c	B-VI.6	1997	293.6	420901	30414	150.0	yes	no	yes	no	no

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ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
** Pb-207 **													
82207.24c	205.2000	la150n	B-VI.6	1996	293.6	280309	10689	150.0	yes	no	yes	no	no
82207.60c	205.2000	endf60	B-VI.1	1991	293.6	111750	7524	20.0	yes	no	no	no	no
82207.66c	205.2000	endf66c	B-VI.6	1997	293.6	276136	10689	150.0	yes	no	yes	no	no
** Pb-208 **													
82208.24c	206.1900	la150n	LANL	1996	293.6	344772	6633	150.0	yes	no	yes	no	no
82208.60c	206.1900	endf60	B-VI.0	1989	293.6	70740	5105	20.0	yes	no	no	no	no
82208.66c	206.1900	endf66c	B-VI.6:X	1996	293.6	344865	6634	150.0	yes	no	yes	no	no
Z = 83 ********** Bismuth **********													
** Bi-209 **													
83209.24c	207.1850	la150n	LANL	1999	293.6	249386	11047	150.0	yes	no	yes	no	no
83209.42c	207.1851	endl92	LLNL	<1992	300.0	20921	1200	30.0	yes	no	no	no	no
83209.50c	207.1850	endf5u	B-V.0	1980	293.6	14939	1300	20.0	yes	no	no	no	no
83209.50d	207.1850	dre5	B-V.0	1980	293.6	7516	263	20.0	yes	no	no	no	no
83209.51c	207.1850	rmccs	B-V.0	1980	293.6	13721	1186	20.0	yes	no	no	no	no
83209.51d	207.1850	drmccs	B-V.0	1980	293.6	7516	263	20.0	yes	no	no	no	no
83209.60c	207.1850	endf60	B-VI.0	1989	293.6	100138	8427	20.0	yes	no	no	no	no
83209.66c	207.1850	endf66c	B-VI.3	1989	293.6	161302	10906	20.0	yes	no	no	no	no
Z = 90 ********** Thorium **********													
** Th-230 **													
90230.60c	228.0600	endf60	B-VI.0	1977	293.6	35155	5533	20.0	no	tot	no	no	no
90230.66c	228.0600	endf66c	B-VI.0	1977	293.6	64761	8428	20.0	no	tot	no	no	no
** Th-231 **													
90231.42c	229.0516	endl92	LLNL	<1992	300.0	15712	187	30.0	yes	both	no	no	no
** Th-232 **													
90232.42c	230.0447	endl92	LLNL	<1992	300.0	109829	13719	30.0	yes	both	no	no	no
90232.48c	230.0400	uresa[16]	B-VI.0	1977	300.0	305942	41414	20.0	no	both	no	no	yes
90232.50c	230.0400	endf5u	B-V.0	1977	293.6	152782	17901	20.0	yes	both	no	no	no
90232.50d	230.0400	dre5	B-V.0	1977	293.6	11937	263	20.0	yes	both	no	no	no
90232.51c	230.0400	rmccs	B-V.0	1977	293.6	17925	1062	20.0	yes	both	no	no	no
90232.51d	230.0400	drmccs	B-V.0	1977	293.6	11937	263	20.0	yes	both	no	no	no
90232.60c	230.0400	endf60	B-VI.0	1977	293.6	127606	16381	20.0	yes	both	no	no	no
90232.61c	230.0400	endf6dn	B-VI.0	1977	293.6	132594	16381	20.0	yes	both	no	yes	no
90232.65c	230.0400	endf66e	B-VI.0	1977	3000.1	238295	25915	20.0	yes	both	no	yes	yes
90232.66c	230.0400	endf66c	B-VI.0	1977	293.6	362871	41487	20.0	yes	both	no	yes	yes
** Th-233 **													
90233.42c	231.0396	endl92	LLNL	<1992	300.0	16015	206	30.0	yes	both	no	no	no
Z = 91 ********** Protactinium **********													
** Pa-231 **													
91231.60c	229.0500	endf60	B-VI.0	1977	293.6	19835	2610	20.0	no	both	no	no	no
91231.61c	229.0500	endf6dn	B-VI.0	1977	293.6	24733	2610	20.0	no	both	no	yes	no
91231.65c	229.0500	endf66e	B-VI.0	1977	3000.1	31463	2422	20.0	no	both	no	yes	yes
91231.66c	229.0500	endf66c	B-VI.0	1977	293.6	45111	4128	20.0	no	both	no	yes	yes

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** Pa-233 **													
91233.42c	231.0383	endl92	LLNL	<1992	300.0	27720	1982	30.0	yes	both	no	no	no
91233.50c	231.0380	endf5u	B-V.0	1974	293.6	19519	2915	20.0	no	tot	no	no	no
91233.50d	231.0380	dre5	B-V.0	1974	293.6	3700	263	20.0	no	tot	no	no	no
91233.51c	231.0380	rmccs	B-V.0	1974	293.6	5641	637	20.0	no	tot	no	no	no
91233.51d	231.0380	drmccs	B-V.0	1974	293.6	3700	263	20.0	no	tot	no	no	no
91233.65c	231.0380	endf66e	B-VI.0	1974	3000.1	34848	3993	20.0	no	tot	no	no	yes
91233.66c	231.0380	endf66c	B-VI.0	1974	293.6	50577	6240	20.0	no	tot	no	no	yes
Z = 92 ********** Uranium **********													
** U-232 **													
92232.49c	230.0400	uresa	B-VI.0	1977	300.0	21813	2820	20.0	no	both	no	no	yes
92232.60c	230.0400	endf60	B-VI.0	1977	293.6	13839	1759	20.0	no	both	no	no	no
92232.61c	230.0400	endf6dn	B-VI.0	1977	293.6	18734	1759	20.0	no	both	no	yes	no
92232.65c	230.0400	endf66e	B-VI.0	1977	3000.1	29048	2318	20.0	no	both	no	yes	yes
92232.66c	230.0400	endf66c	B-VI.0	1977	293.6	32792	2786	20.0	no	both	no	yes	yes
** U-233 **													
92233.42c	231.0377	endl92	LLNL	<1992	300.0	29521	2163	30.0	yes	both	no	no	no
92233.49c	231.0430	uresa	B-VI.0	1978	300.0	47100	4601	20.0	yes	both	no	no	yes
92233.50c	231.0430	rmccs	B-V.0	1978	293.6	18815	2293	20.0	no	both	no	no	no
92233.50d	231.0430	drmccs	B-V.0	1978	293.6	4172	263	20.0	no	both	no	no	no
92233.60c	231.0430	endf60[15]	B-VI.0	1978	293.6	32226	3223	20.0	yes	both	no	no	no
92233.61c	231.0430	endf6dn	B-VI.0	1978	293.6	37218	3223	20.0	yes	both	no	yes	no
92233.65c	231.0430	endf66e	B-VI.0	1978	3000.1	49260	3354	20.0	no	both	no	yes	yes
92233.66c	231.0430	endf66c	B-VI.0	1978	293.6	62463	4821	20.0	no	both	no	yes	yes
** U-234 **													
92234.42c	232.0304	endl92	LLNL	<1992	300.0	13677	149	30.0	yes	both	no	no	no
92234.49c	232.0300	uresa	B-VI.0	1978	300.0	161296	22539	20.0	no	both	no	no	yes
92234.50c	232.0300	endf5p	B-V.0	1978	293.6	89433	12430	20.0	no	tot	no	no	no
92234.50d	232.0300	dre5	B-V.0	1978	293.6	4833	263	20.0	no	tot	no	no	no
92234.51c	232.0300	rmccs	B-V.0	1978	293.6	6426	672	20.0	no	tot	no	no	no
92234.51d	232.0300	drmccs	B-V.0	1978	293.6	4833	263	20.0	no	tot	no	no	no
92234.60c	232.0300	endf60	B-VI.0	1978	293.6	77059	10660	17.5	no	both	no	no	no
92234.61c	232.0300	endf6dn	B-VI.0	1978	293.6	82047	10660	17.5	no	both	no	yes	no
92234.65c	232.0300	endf66e	B-VI.0	1978	3000.1	144201	16318	20.0	no	both	no	yes	yes
92234.66c	232.0300	endf66c	B-VI.0	1978	293.6	196273	22827	20.0	no	both	no	yes	yes
** U-235 **,													
92235.01c	233.0250	endfht	B-VI.2	1989	1.2e4	234381	18913	20.0	yes	both	no	no	no
92235.02c	233.0250	endfht	B-VI.2	1989	1.2e5	138369	8245	20.0	yes	both	no	no	no
92235.03c	233.0250	endfht	B-VI.2	1989	1.2e6	102567	4267	20.0	yes	both	no	no	no
92235.04c	233.0250	endfht	B-VI.2	1989	1.2e7	85917	2417	20.0	yes	both	no	no	no
92235.05c	233.0250	endfht	B-VI.2	1989	1.2e8	79635	1719	20.0	yes	both	no	no	no
92235.06c	233.0250	endfht	B-V.0	1977	1.2e4	47562	3712	20.0	yes	both	no	no	no
92235.07c	233.0250	endfht	B-V.0	1977	1.2e5	32721	2063	20.0	yes	both	no	no	no
92235.08c	233.0250	endfht	B-V.0	1977	1.2e6	28905	1639	20.0	yes	both	no	no	no
92235.09c	233.0250	endfht	B-V.0	1977	1.2e7	27627	1497	20.0	yes	both	no	no	no
92235.10c	233.0250	endfht	B-V.0	1977	1.2e8	27312	1462	20.0	yes	both	no	no	no

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92235.11c	233.0250	endf62mt	B-VI.2	1989	77.0	696398	78912	20.0	yes	both	no	no	no
92235.12c	233.0250	endf62mt	B-VI.2	1989	400.0	411854	43344	20.0	yes	both	no	no	no
92235.13c	233.0250	endf62mt	B-VI.2	1989	500.0	379726	39328	20.0	yes	both	no	no	no
92235.14c	233.0250	endf62mt	B-VI.2	1989	600.0	353678	36072	20.0	yes	both	no	no	no
92235.15c	233.0250	endf62mt	B-VI.2	1989	800.0	316622	31440	20.0	yes	both	no	no	no
92235.16c	233.0250	endf62mt	B-VI.2	1989	900.0	300278	29397	20.0	yes	both	no	no	no
92235.17c	233.0250	endf62mt	B-VI.2	1989	1200	269062	25495	20.0	yes	both	no	no	no
92235.42c	233.0248	endl92	LLNL	<1992	300.0	72790	5734	30.0	yes	both	no	no	no
92235.49c	233.0250	uresa	B-VI.4	1996	300.0	647347	72649	20.0	yes	both	no	no	yes
92235.50c	233.0250	rmccs	B-V.0	1977	293.6	60489	5725	20.0	yes	both	no	no	no
92235.50d	233.0250	drmccs	B-V.0	1977	293.6	11788	263	20.0	yes	both	no	no	no
92235.52c	233.0250	endf5mt[1]	B-V.0	1977	587.2	65286	6320	20.0	yes	both	no	no	no
92235.53c	233.0250	endf5mt[1]	B-V.0	1977	587.2	36120	2685	20.0	yes	both	no	no	no
92235.54c	233.0250	endf5mt[1]	B-V.0	1977	880.8	36008	2671	20.0	yes	both	no	no	no
92235.60c	233.0250	endf60	B-VI.2	1989	293.6	289975	28110	20.0	yes	both	no	no	no
92235.61c	233.0250	endf6dn	B-VI.2	1989	293.6	294963	28110	20.0	yes	both	no	yes	no
92235.64c	233.0250	endf66d	B-VI.5	1978	77.0	1115810	111154	20.0	no	both	no	yes	yes
92235.65c	233.0250	endf66e	B-VI.5	1978	3000.1	332639	24135	20.0	no	both	no	yes	yes
92235.66c	233.0250	endf66c	B-VI.5	1978	293.6	722105	67409	20.0	no	both	no	yes	yes
** U-236 **													
92236.42c	234.0178	endl92	LLNL	<1992	300.0	14595	311	30.0	yes	both	no	no	no
92236.49c	234.0180	uresa	B-VI.0	1989	300.0	159074	20865	20.0	no	both	no	no	yes
92236.50c	234.0180	endf5p	B-V.0	1978	293.6	138715	19473	20.0	no	tot	no	no	no
92236.50d	234.0180	dre5	B-V.0	1978	293.6	4838	263	20.0	no	tot	no	no	no
92236.51c	234.0180	rmccs	B-V.0	1978	293.6	7302	800	20.0	no	tot	no	no	no
92236.51d	234.0180	drmccs	B-V.0	1978	293.6	4838	263	20.0	no	tot	no	no	no
92236.60c	234.0180	endf60	B-VI.0	1989	293.6	82819	10454	20.0	no	both	no	no	no
92236.61c	234.0180	endf6dn	B-VI.0	1989	293.6	87807	10454	20.0	no	both	no	yes	no
92236.65c	234.0180	endf66e	B-VI.0	1989	3000.1	153474	15331	20.0	no	both	no	yes	yes
92236.66c	234.0180	endf66c	B-VI.0	1989	293.6	199786	21120	20.0	no	both	no	yes	yes
** U-237 **													
92237.42c	235.0123	endl92	LLNL	<1992	300.0	13465	210	30.0	yes	both	no	no	no
92237.50c	235.0120	endf5p	B-V.0	1976	293.6	32445	3293	20.0	yes	tot	no	no	no
92237.50d	235.0120	dre5	B-V.0	1976	293.6	8851	263	20.0	yes	tot	no	no	no
92237.51c	235.0120	rmccs	B-V.0	1976	293.6	10317	527	20.0	yes	tot	no	no	no
92237.51d	235.0120	drmccs	B-V.0	1976	293.6	8851	263	20.0	yes	tot	no	no	no
92237.65c	235.0120	endf66e	B-VI.2	1976	3000.1	72824	6381	20.0	no	both	no	yes	yes
92237.66c	235.0120	endf66c	B-VI.2	1976	293.6	87188	7977	20.0	no	both	no	yes	yes
** U-238 **													
92238.01c	236.0060	endfht	B-VI.2	1993	1.2e4	296788	30203	20.0	yes	both	no	no	no
92238.02c	236.0060	endfht	B-VI.2	1993	1.2e5	138937	12664	20.0	yes	both	no	no	no
92238.03c	236.0060	endfht	B-VI.2	1993	1.2e6	77638	5853	20.0	yes	both	no	no	no
92238.04c	236.0060	endfht	B-VI.2	1993	1.2e7	54625	3296	20.0	yes	both	no	no	no
92238.05c	236.0060	endfht	B-VI.2	1993	1.2e8	44356	2155	20.0	yes	both	no	no	no
92238.06c	236.0060	endfht	B-V.0	1979	1.2e4	185164	18732	20.0	yes	both	no	no	no
92238.07c	236.0060	endfht	B-V.0	1979	1.2e5	85705	7681	20.0	yes	both	no	no	no

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
92238.08c	236.0060	endfht	B-V.0	1979	1.2e6	46123	3283	20.0	yes	both	no	no	no
92238.09c	236.0060	endfht	B-V.0	1979	1.2e7	34774	2022	20.0	yes	both	no	no	no
92238.10c	236.0060	endfht	B-V.0	1979	1.2e8	30193	1513	20.0	yes	both	no	no	no
92238.11c	236.0060	endf62mt	B-VI.2	1993	77.0	621385	74481	20.0	yes	both	no	no	no
92238.12c	236.0060	endf62mt	B-VI.2	1993	400.0	456593	53882	20.0	yes	both	no	no	no
92238.13c	236.0060	endf62mt	B-VI.2	1993	500.0	433681	51018	20.0	yes	both	no	no	no
92238.14c	236.0060	endf62mt	B-VI.2	1993	600.0	414185	48581	20.0	yes	both	no	no	no
92238.15c	236.0060	endf62mt	B-VI.2	1993	800.0	386305	45096	20.0	yes	both	no	no	no
92238.16c	236.0060	endf62mt	B-VI.2	1993	900.0	372625	43386	20.0	yes	both	no	no	no
92238.17c	236.0060	endf62mt	B-VI.2	1993	1200.0	348137	40325	20.0	yes	both	no	no	no
92238.21c	236.0060	100xs[3]	LANL/T:X	1989	300.0	279245	30911	100.0	yes	both	no	no	no
92238.42c	236.0058	endl92	LLNL	<1992	300.0	107739	7477	30.0	yes	both	no	no	no
92238.48c	236.0060	uresa[16]	B-VI.2	1993	300.0	705623	85021	20.0	no	both	no	no	yes
92238.50c	236.0060	rmccs	B-V.0	1979	293.6	88998	9285	20.0	yes	both	no	no	no
92238.50d	236.0060	drmccs	B-V.0	1979	293.6	16815	263	20.0	yes	both	no	no	no
92238.52c	236.0060	endf5mt[1]	B-V.0	1979	587.2	123199	8454	20.0	yes	both	no	no	no
92238.53c	236.0060	endf5mt[1]	B-V.0	1979	587.2	160107	17876	20.0	yes	both	no	no	no
92238.54c	236.0060	endf5mt[1]	B-V.0	1979	880.8	160971	17984	20.0	yes	both	no	no	no
92238.60c	236.0060	endf60	B-VI.2	1993	293.6	206322	22600	20.0	yes	both	no	no	no
92238.61c	236.0060	endf6dn	B-VI.2	1993	293.6	211310	22600	20.0	yes	both	no	yes	no
92238.64c	236.0060	endf66d	B-VI.5	1993	77.0	976500	103602	20.0	no	both	no	yes	yes
92238.65c	236.0060	endf66e	B-VI.5	1993	3000.1	425088	42334	20.0	no	both	no	yes	yes
92238.66c	236.0060	endf66c	B-VI.5	1993	293.6	751905	78647	20.0	no	both	no	yes	yes
** U-239 **													
92239.35c	237.0007	rmccsa	LLNL	<1985	0.0	9809	394	20.0	yes	pr	no	no	no
92239.35d	237.0007	drmccs	LLNL	<1985	0.0	9286	263	20.0	yes	pr	no	no	no
92239.42c	237.0007	endl92	LLNL	<1992	300.0	14336	205	30.0	yes	both	no	no	no
** U-240 **													
92240.42c	237.9944	endl92	LLNL	<1992	300.0	14000	128	30.0	yes	both	no	no	no
Z = 93 ********** Neptunium **********													
** Np-235 **													
93235.42c	233.0249	endl92	LLNL	<1992	300.0	17717	660	30.0	yes	both	no	no	no
** Np-236 **													
93236.42c	234.0188	endl92	LLNL	<1992	300.0	13464	179	30.0	yes	both	no	no	no
** Np-237 **													
93237.42c	235.0118	endl92	LLNL	<1992	300.0	31966	2477	30.0	yes	both	no	no	no
93237.50c	235.0120	endf5p	B-V.0	1978	293.6	63223	8519	20.0	no	tot	no	no	no
93237.50d	235.0120	dre5	B-V.0	1978	293.6	5267	263	20.0	no	tot	no	no	no
93237.55c	235.0120	rmccsa	LANL/T:	1984	293.6	32558	1682	20.0	no	both	no	no	no
93237.55d	235.0120	drmccs	LANL/T	1984	293.6	20484	263	20.0	no	both	no	no	no
93237.60c	235.0118	endf60	B-VI.1	1990	293.6	105150	7218	20.0	yes	both	no	no	no
93237.61c	235.0118	endf6dn	B-VI.1	1990	293.6	110048	7218	20.0	yes	both	no	yes	no
93237.66c	235.0118	endf66c	B-VI.1	1990	293.6	255036	18967	20.0	yes	both	no	yes	no
** Np-238 **													
93238.42c	236.0060	endl92	LLNL	<1992	300.0	13445	165	30.0	yes	both	no	no	no

APPENDIX G

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
** Np-239 **													
93239.60c	236.9990	endf60	B-VI.0	1988	293.6	7406	562	20.0	no	tot	no	no	no
93239.66c	236.9990	endf66c	B-VI.0	1988	293.6	17349	1087	20.0	no	tot	no	no	no
Z = 94 ********** Plutonium **********													
** Pu-236 **													
94236.60c	234.0180	endf60	B-VI.0	1978	293.6	33448	4610	20.0	no	tot	no	no	no
94236.66c	234.0180	endf66c	B-VI.4	1995	293.6	25187	1537	20.0	no	both	no	no	no
** Pu-237 **													
94237.42c	235.0120	endl92	LLNL	<1992	300.0	17284	279	30.0	yes	both	no	no	no
94237.60c	235.0120	endf60	B-VI.0	1978	293.6	3524	257	20.0	no	tot	no	no	no
94237.66c	235.0120	endf66c	B-VI.0	1978	293.6	10982	718	20.0	no	tot	no	no	no
** Pu-238 **													
94238.42c	236.0046	endl92	LLNL	<1992	300.0	30572	2177	30.0	yes	both	no	no	no
94238.49c	236.0045	uresa	B-VI.0	1978	300.0	41814	5337	20.0	no	both	no	no	yes
94238.50c	236.1670	endf5p	B-V.0	1978	293.6	18763	2301	20.0	no	tot	no	no	no
94238.50d	236.1670	dre5	B-V.0	1978	293.6	5404	263	20.0	no	tot	no	no	no
94238.51c	236.1670	rmccs	B-V.0	1978	293.6	6067	537	20.0	no	tot	no	no	no
94238.51d	236.1670	drmccs	B-V.0	1978	293.6	5404	263	20.0	no	tot	no	no	no
94238.60c	236.0045	endf60	B-VI.0	1978	293.6	29054	3753	20.0	no	both	no	no	no
94238.61c	236.0045	endf6dn	B-VI.0	1978	293.6	33952	3753	20.0	no	both	no	yes	no
94238.65c	236.0045	endf66e	B-VI.0	1978	3000.1	50571	4565	20.0	no	both	no	yes	yes
94238.66c	236.0045	endf66c	B-VI.0	1978	293.6	58875	5603	20.0	no	both	no	yes	yes
** Pu-239 **													
94239.01c	236.9986	endfht	B-VI.2	1993	1.2e4	229878	18004	20.0	yes	both	no	no	no
94239.02c	236.9986	endfht	B-VI.2	1993	1.2e5	126018	6464	20.0	yes	both	no	no	no
94239.03c	236.9986	endfht	B-VI.2	1993	1.2e6	97362	3280	20.0	yes	both	no	no	no
94239.04c	236.9986	endfht	B-VI.2	1993	1.2e7	85788	1994	20.0	yes	both	no	no	no
94239.05c	236.9986	endfht	B-VI.2	1993	1.2e8	81423	1509	20.0	yes	both	no	no	no
94239.06c	236.9990	endfht	B-V.2	1983	1.2e4	76790	6005	20.0	yes	both	no	no	no
94239.07c	236.9990	endfht	B-V.2	1983	1.2e5	45461	2524	20.0	yes	both	no	no	no
94239.08c	236.9990	endfht	B-V.2	1983	1.2e6	36236	1499	20.0	yes	both	no	no	no
94239.09c	236.9990	endfht	B-V.2	1983	1.2e7	33797	1228	20.0	yes	both	no	no	no
94239.10c	236.9990	endfht	B-V.2	1983	1.2e8	33230	1165	20.0	yes	both	no	no	no
94239.11c	236.9986	endf62mt	B-VI.2	1993	77.0	568756	62522	20.0	yes	both	no	no	no
94239.12c	236.9986	endf62mt	B-VI.2	1993	400.0	418556	43747	20.0	yes	both	no	no	no
94239.13c	236.9986	endf62mt	B-VI.2	1993	500.0	395964	40923	20.0	yes	both	no	no	no
94239.14c	236.9986	endf62mt	B-VI.2	1993	600.0	377116	38567	20.0	yes	both	no	no	no
94239.15c	236.9986	endf62mt	B-VI.2	1993	800.0	350292	35214	20.0	yes	both	no	no	no
94239.16c	236.9986	endf62mt	B-VI.2	1993	900.0	338236	33707	20.0	yes	both	no	no	no
94239.17c	236.9986	endf62mt	B-VI.2	1993	1200.0	312572	30499	20	yes	both	no	no	no
94239.42c	236.9986	endl92	LLNL	<1992	300.0	93878	6827	30.0	yes	both	no	no	no
94239.49c	236.9986	uresa	B-VI.2	1993	300.0	595005	64841	20.0	yes	both	no	no	yes
94239.50c	236.9990	endf5p	B-V.0	1976	293.6	74049	7809	20.0	yes	both	no	no	no
94239.50d	236.9990	dre5	B-V.0	1976	293.6	12631	263	20.0	yes	both	no	no	no
94239.55c	236.9990	rmccs	B-V.2	1983	293.6	102099	10318	20.0	yes	both	no	no	no
94239.55d	236.9990	drmccs	B-V.2	1983	293.6	20727	263	20.0	yes	both	no	no	no

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
94239.60c	236.9986	endf60	B-VI.2	1993	293.6	283354	26847	20.0	yes	both	no	no	no
94239.61c	236.9986	endf6dn	B-VI.2	1993	293.6	288252	26847	20.0	yes	both	no	yes	no
94239.64c	236.9986	endf66d	B-VI.5	1997	77.0	866231	83969	20.0	yes	both	no	yes	yes
94239.65c	236.9986	endf66e	B-VI.5	1997	3000.1	374390	29320	20.0	yes	both	no	yes	yes
94239.66c	236.9986	endf66c	B-VI.5	1997	293.6	685322	63868	20.0	yes	both	no	yes	yes
** Pu-240 **													
94240.42c	237.9916	endl92	LLNL	<1992	300.0	198041	16626	30.0	yes	both	no	no	no
94240.49c	237.9920	uresa	B-VI.2	1986	300.0	341542	41596	20.0	yes	both	no	no	yes
94240.50c	237.9920	rmccs	B-V.0	1977	293.6	58917	6549	20.0	yes	both	no	no	no
94240.50d	237.9920	drmccs	B-V.0	1977	293.6	9569	263	20.0	yes	both	no	no	no
94240.60c	237.9920	endf60	B-VI.2	1986	293.6	133071	15676	20.0	yes	both	no	no	no
94240.61c	237.9920	endf6dn	B-VI.2	1986	293.6	137969	15676	20.0	yes	both	no	yes	no
94240.65c	237.9920	endf66e	B-VI.2	1986	3000.1	283740	29451	20.0	yes	both	no	yes	yes
94240.66c	237.9920	endf66c	B-VI.2	1986	293.6	395889	41912	20.0	yes	both	no	yes	yes
** Pu-241 **													
94241.42c	238.9860	endl92	LLNL	<1992	300.0	14108	203	30.0	yes	both	no	no	no
94241.49c	238.9780	uresa	B-VI.3	1994	300.0	155886	17753	20.0	yes	both	no	no	yes
94241.50c	238.9780	endf5p	B-V.0	1977	293.6	38601	3744	20.0	yes	both	no	no	no
94241.50d	238.9780	dre5	B-V.0	1977	293.6	11575	263	20.0	yes	both	no	no	no
94241.51c	238.9780	rmccs	B-V.0	1977	293.6	13403	623	20.0	yes	both	no	no	no
94241.51d	238.9780	drmccs	B-V.0	1977	293.6	11575	263	20.0	yes	both	no	no	no
94241.60c	238.9780	endf60	B-VI.1	1988	293.6	76453	8112	20.0	yes	both	no	no	no
94241.61c	238.9780	endf6dn	B-VI.1	1988	293.6	81351	8112	20.0	yes	both	no	yes	no
94241.65c	238.9780	endf66e	B-VI.3	1994	3000.1	104019	9145	20.0	yes	both	no	yes	yes
94241.66c	238.9780	endf66c	B-VI.3	1994	293.6	185478	18196	20.0	yes	both	no	yes	yes
** Pu-242 **													
94242.42c	239.9793	endl92	LLNL	<1992	300.0	48688	4287	30.0	yes	both	no	no	no
94242.49c	239.9790	uresa	B-VI.0	1978	300.0	130202	14922	20.0	yes	both	no	no	yes
94242.50c	239.9790	endf5p	B-V.0	1978	293.6	71429	7636	20.0	yes	both	no	no	no
94242.50d	239.9790	dre5	B-V.0	1978	293.6	12463	263	20.0	yes	both	no	no	no
94242.51c	239.9790	rmccs	B-V.0	1978	293.6	15702	728	20.0	yes	both	no	no	no
94242.51d	239.9790	drmccs	B-V.0	1978	293.6	12463	263	20.0	yes	both	no	no	no
94242.60c	239.9790	endf60	B-VI.0	1978	293.6	73725	7896	20.0	yes	both	no	no	no
94242.61c	239.9790	endf6dn	B-VI.0	1978	293.6	78623	7896	20.0	yes	both	no	yes	no
94242.65c	239.9790	endf66e	B-VI.0	1978	3000.1	123314	11409	20.0	yes	both	no	yes	yes
94242.66c	239.9790	endf66c	B-VI.0	1978	293.6	157136	15167	20.0	yes	both	no	yes	yes
** Pu-243 **													
94243.42c	240.9740	endl92	LLNL	<1992	300.0	20253	745	30.0	yes	both	no	no	no
94243.60c	240.9740	endf60	B-VI.2	1976	293.6	45142	4452	20.0	yes	tot	no	no	no
94243.65c	240.9740	endf66e	B-VI.2	1976	3000.1	123314	11409	20.0	yes	both	no	yes	yes
94243.66c	240.9740	endf66c	B-VI.2	1976	293.6	157136	15167	20.0	yes	both	no	yes	yes
** Pu-244 **													
94244.60c	241.9680	endf60	B-VI.0	1978	293.6	23654	3695	20.0	no	tot	no	no	no
94244.65c	241.9680	endf66e	B-VI.0	1978	3000.1	51446	6450	20.0	no	tot	no	no	yes
94244.66c	241.9680	endf66c	B-VI.0	1978	293.6	61726	7931	20.0	no	tot	no	no	yes

APPENDIX G

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
Z = 95 ********** Americium **********													
** Am-241 **													
95241.42c	238.9860	endl92	LLNL	<1992	300.0	32579	2011	30.0	yes	both	no	no	no
95241.50c	238.9860	endf5u	B-V.0	1978	293.6	42084	4420	20.0	yes	tot	no	no	no
95241.50d	238.9860	dre5	B-V.0	1978	293.6	9971	263	20.0	yes	tot	no	no	no
95241.51c	238.9860	rmccs	B-V.0	1978	293.6	12374	713	20.0	yes	tot	no	no	no
95241.51d	238.9860	drmccs	B-V.0	1978	293.6	9971	263	20.0	yes	tot	no	no	no
95241.60c	238.9860	endf60	LANL/T	1994	300.0	168924	13556	30.0	yes	both	no	no	no
95241.61c	238.9860	endf6dn	LANL/T	1994	300.0	173822	13556	30.0	yes	both	no	yes	no
95241.65c	238.9860	endf66e	B-VI.3:X	1994	3000.1	162566	8011	30.0	yes	both	no	yes	yes
95241.66c	238.9860	endf66c	B-VI.3:X	1994	293.6	267137	19630	30.0	yes	both	no	yes	yes
** Am-242 metastable **													
95242.42c	239.9801	endl92	LLNL	<1992	300.0	21828	1368	20.0	yes	both	no	no	no
95242.50c	239.9800	endf5u	B-V.0	1978	293.6	8593	323	20.0	yes	tot	no	no	no
95242.50d	239.9800	dre5	B-V.0	1978	293.6	9048	263	20.0	yes	tot	no	no	no
95242.51c	239.9800	rmccs	B-V.0	1978	293.6	8502	317	20.0	yes	tot	no	no	no
95242.51d	239.9800	drmccs	B-V.0	1978	293.6	9048	263	20.0	yes	tot	no	no	no
95242.65c	239.9800	endf66e	B-VI.1	1978	3000.1	27793	945	20.0	yes	both	no	yes	yes
95242.66c	239.9800	endf66c	B-VI.1	1978	293.6	27625	933	20.0	yes	both	no	yes	yes
** Am-243 **													
95243.42c	240.9733	endl92	LLNL	<1992	300.0	52074	4867	30.0	yes	both	no	no	no
95243.50c	240.9730	endf5u	B-V.0	1978	293.6	92015	11921	20.0	yes	tot	no	no	no
95243.50d	240.9730	dre5	B-V.0	1978	293.6	11742	263	20.0	yes	tot	no	no	no
95243.51c	240.9730	rmccs	B-V.0	1978	293.6	13684	757	20.0	yes	tot	no	no	no
95243.51d	240.9730	drmccs	B-V.0	1978	293.6	11742	263	20.0	yes	tot	no	no	no
95243.60c	240.9730	endf60	B-VI.0	1988	293.6	104257	11984	20.0	yes	both	no	no	no
95243.61c	240.9730	endf6dn	B-VI.0	1988	293.6	109155	11984	20.0	yes	both	no	yes	no
95243.65c	240.9730	endf66e	B-VI.5	1996	3000.1	160276	10268	30.0	yes	both	no	yes	yes
95243.66c	240.9730	endf66c	B-VI.5	1996	293.6	308812	26772	30.0	yes	both	no	yes	yes
Z = 96 ********** Curium **********													
** Cm-241 **													
96241.60c	238.9870	endf60	B-VI.0	1978	293.6	3132	278	20.0	no	tot	no	no	no
96241.66c	238.9870	endf66c	B-VI.0	1978	293.6	9515	598	20.0	no	tot	no	no	no
** Cm-242 **													
96242.42c	239.9794	endl92	LLNL	<1992	300.0	37766	3141	30.0	yes	both	no	no	no
96242.50c	239.9790	endf5u	B-V.0	1978	293.6	30897	3113	20.0	yes	tot	no	no	no
96242.50d	239.9790	dre5	B-V.0	1978	293.6	8903	263	20.0	yes	tot	no	no	no
96242.51c	239.9790	rmccs	B-V.0	1978	293.6	9767	472	20.0	yes	tot	no	no	no
96242.51d	239.9790	drmccs	B-V.0	1978	293.6	8903	263	20.0	yes	tot	no	no	no
96242.60c	239.9790	endf60	B-VI.0	1978	293.6	34374	3544	20.0	yes	both	no	no	no
96242.61c	239.9790	endf6dn	B-VI.0	1978	293.6	39269	3544	20.0	yes	both	no	yes	no
96242.65c	239.9790	endf66e	B-VI.0	1978	3000.1	54517	4410	20.0	yes	both	no	yes	yes
96242.66c	239.9790	endf66c	B-VI.0	1978	293.6	62059	5248	20.0	yes	both	no	yes	yes
** Cm-243 **													
96243.42c	240.9733	endl92	LLNL	<1992	300.0	21543	1099	30.0	yes	both	no	no	no

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
96243.60c	240.9730	endf60	B-VI.0	1978	293.6	18860	1445	20.0	yes	tot	no	no	no
96243.65c	240.9730	endf66e	B-VI.0	1978	3000.1	29796	1965	20.0	yes	tot	no	yes	yes
96243.66c	240.9730	endf66c	B-VI.0	1978	293.6	32793	2298	20.0	yes	tot	no	yes	yes
** Cm-244 **													
96244.42c	241.9661	endl92	LLNL	<1992	300.0	46590	4198	30.0	yes	both	no	no	no
96244.49c	241.9660	uresa	B-VI.0	1978	300.0	97975	11389	20.0	yes	pr	no	no	yes
96244.50c	241.9660	endf5u	B-V.0	1978	293.6	45991	4919	20.0	yes	tot	no	no	no
96244.50d	241.9660	dre5	B-V.0	1978	293.6	9509	263	20.0	yes	tot	no	no	no
96244.51c	241.9660	rmccs	B-V.0	1978	293.6	10847	566	20.0	yes	tot	no	no	no
96244.51d	241.9660	drmccs	B-V.0	1978	293.6	9509	263	20.0	yes	tot	no	no	no
96244.60c	241.9660	endf60	B-VI.0	1978	293.6	73001	8294	20.0	yes	tot	no	no	no
96244.65c	241.9660	endf66e	B-VI.0	1978	3000.1	91371	8861	20.0	yes	tot	no	yes	yes
96244.66c	241.9660	endf66c	B-VI.0	1978	293.6	116265	11627	20.0	yes	tot	no	yes	yes
** Cm-245 **													
96245.42c	242.9602	endl92	LLNL	<1992	300.0	25678	1564	30.0	yes	both	no	no	no
96245.60c	242.9600	endf60	B-VI.2	1979	293.6	29535	2636	20.0	yes	both	no	no	no
96245.61c	242.9600	endf6dn	B-VI.2	1979	293.6	34433	2636	20.0	yes	both	no	yes	no
96245.65c	242.9600	endf66e	B-VI.2	1979	3000.1	44920	3214	20.0	yes	both	no	yes	yes
96245.66c	242.9600	endf66c	B-VI.2	1979	293.6	52336	4038	20.0	yes	both	no	yes	yes
** Cm-246 **													
96246.42c	243.9534	endl92	LLNL	<1992	300.0	24550	1376	30.0	yes	both	no	no	no
96246.60c	243.9530	endf60	B-VI.2	1976	293.6	37948	3311	20.0	yes	tot	no	no	no
96246.66c	243.9530	endf66c	B-VI.2	1976	293.6	56186	4704	20.0	yes	tot	no	no	no
** Cm-247 **													
96247.42c	244.9479	endl92	LLNL	<1992	300.0	39971	3256	30.0	yes	both	no	no	no
96247.60c	244.9500	endf60	B-VI.2	1976	293.6	38800	3679	20.0	yes	tot	no	no	no
96247.65c	244.9500	endf66e	B-VI.2	1976	3000.1	49949	3849	20.0	yes	tot	no	no	yes
96247.66c	244.9500	endf66c	B-VI.2	1976	293.6	64799	5499	20.0	yes	tot	no	no	yes
** Cm-248 **													
96248.42c	245.9413	endl92	LLNL	<1992	300.0	40345	3355	30.0	yes	both	no	no	no
96248.60c	245.9410	endf60	B-VI.0	1978	293.6	83452	9706	20.0	yes	tot	no	no	no
96248.65c	245.9410	endf66e	B-VI.0	1978	3000.1	102038	10383	20.0	yes	tot	no	no	yes
96248.66c	245.9410	endf66c	B-VI.0	1978	293.6	130361	13530	20.0	yes	tot	no	no	yes
Z = 97 ********** Berkelium **********													
** Bk-249 **													
97249.42c	246.9353	endl92	LLNL	<1992	300.0	19573	809	30.0	yes	both	no	no	no
97249.60c	246.9400	endf60	B-VI:X	1986	293.6	50503	5268	20.0	no	both	no	no	no
97249.65c	246.9400	endf66e	B-VI.0	1986	3000.1	65384	5360	20.0	no	both	no	no	yes
97249.66c	246.9400	endf66c	B-VI.0	1986	293.6	85568	7883	20.0	no	both	no	no	yes
Z = 98 ********** Californium **********													
** Cf-249 **													
98249.42c	246.9352	endl92	LLNL	<1992	300.0	49615	4554	30.0	yes	both	no	no	no
98249.60c	246.9400	endf60	B-VI:X	1989	293.6	41271	4329	20	no	both	no	no	no
98249.61c	246.9400	endf6dn	B-VI:X	1989	293.6	46154	4329	20.0	no	both	no	yes	no
98249.65c	246.9400	endf66e	B-VI.0:X	1989	3000.1	62455	4376	20.0	no	both	no	yes	yes

ZAID	AWR	Library Name	Source	Eval Date	Temp (K)	Length words	NE	E_{max} (MeV)	GP D	$\bar{\nu}$	CP	DN	UR
98249.66c	246.9400	endf66c	B-VI.0:X	1989	293.6	78679	6404	20.0	no	both	no	yes	yes
** Cf-250 **													
98250.42c	247.9281	endl92	LLNL	<1992	300.0	17659	574	30.0	yes	both	no	no	no
98250.60c	247.9280	endf60	B-VI.2	1976	293.6	47758	5554	20.0	yes	tot	no	no	no
98250.65c	247.9280	endf66e	B-VI.2	1976	3000.1	66024	6701	20.0	yes	tot	no	no	yes
98250.66c	247.9280	endf66c	B-VI.2	1976	293.6	77434	8132	20.0	yes	tot	no	no	yes
** Cf-251 **													
98251.42c	248.9227	endl92	LLNL	<1992	300.0	17673	545	30.0	yes	both	no	no	no
98251.60c	248.9230	endf60	B-VI.2	1976	293.6	42817	4226	20.0	yes	both	no	no	no
98251.61c	248.9230	endf6dn	B-VI.2	1976	293.6	47715	4226	20.0	yes	both	no	yes	no
98251.65c	248.9230	endf66e	B-VI.2	1976	3000.1	64568	5257	20.0	yes	both	no	yes	yes
98251.66c	248.9230	endf66c	B-VI.2	1976	293.6	73253	6222	20.0	yes	both	no	yes	yes
** Cf-252 **													
98252.42c	249.9161	endl92	LLNL	<1992	300.0	21027	1210	30.0	yes	both	no	no	no
98252.60c	249.9160	endf60	B-VI.2	1976	293.6	49204	5250	20.0	yes	both	no	no	no
98252.65c	249.9160	endf66e	B-VI.2	1976	3000.1	66642	6250	20.0	yes	tot	no	no	yes
98252.66c	249.9160	endf66c	B-VI.2	1976	293.6	78378	7554	20.0	yes	tot	no	no	yes

NOTES

1. The data libraries previously known as EPRIXS and U600K are now a part of the data library ENDF5MT.
2. Data translated to ENDF/B-VI format with some modifications by LANL.
3. The 100XS data library contains data for 9 nuclides up to 100 MeV. Heating numbers on this data library are known to be incorrect, overestimating the energy deposition [LIT95].
4. Photon production data were added to the existing ENDF evaluation for ^{11}B in 1984. A complete new evaluation was performed in 1986.
5. The natural carbon data 6000.50c are repeated here with the ZAID of 6012.50c for the user's convenience. Both are based on the natural carbon ENDF/B-V.0 evaluation.
6. The delayed gamma ray at an energy of 1.7791 MeV from the reaction $n + {}^{27}\mathrm{Al} \rightarrow {}^{28}\mathrm{Al} \rightarrow {}^{28}\mathrm{Si} + \beta^- + \gamma$ has been included in the thermal-capture photon-production data form these two ZAIDs [FRA02].
7. The data libraries previously known as ARKRC, GDT2GP, IRNAT, MISCXS, TM169, and T2DDC are now a part of the data library MISC5XS.
8. Photon production added to ENDF/B-V.0 neutron files for argon and krypton by T-16, with the intent to roughly estimate photon heating [LIT82b].
9. Data for Br, Rb, I, and Cs were taken from incomplete fission-product evaluations [LIT82c].

10. This is ENDF/B-V.0 for ^{89}Y after modification by evaluator to get better agreement with ENDL85 [LIT85a, LIT85b].
11. The following files for Zr have been replaced by the indicated ZAID, eliminating the rare problem of having a secondary neutron energy greater than the incident neutron energy caused by an ENDF/B-V.0 evaluation problem [SEA92]. Note that this correction has been made for the ENDF/B-VI evaluation.

40000.50c	rmccs	→	40000.56c	misc5xs
40000.50d	drmccs	→	40000.56d	misc5xs
40000.51c	endf5p	→	40000.57c	misc5xs
40000.51d	dre5	→	40000.57d	misc5xs
40000.53c	eprixs	→	40000.58c	misc5xs

12. The ZAIDs for ENDL-based average-fission-product data files have been changed for the latest library, ENDL92, to 49120.42c and 49125.42c. Z is now set to 49 to ensure that the appropriate atomic fraction and photon transport library is used. You may need to update the atomic weight ratio table in your XSDIR file to include these entries [FRA95, FRA96a]. The ENDL92FP library is not publicly available.
13. The LANL/T-16 evaluation for I-127 was accepted for ENDF/B-VI.2 with modifications. These data are processed from the original LANL/T-16 evaluation.
14. Photon production data for Gd were added to the ENDF/B-V.0 neutron cross sections by T-16. These data are valid only to 1 MeV [LIT86a].
15. Photon production data for ^{233}U were added by LANL to original evaluation in 1981.
16. There was a processing problem for the URES library that affected the photon production data for ^{182}W, ^{183}W, ^{184}W, ^{186}W, ^{232}Th, and ^{238}U. The URESA library contains the same ACE files as the URES library except that photon-production data for the affected isotopes is zeroed. The IDs for the affected isotopes have been changed from"49c" to "48c". Heating numbers in the unresolved region are known to be incorrect.

G.4 MULTIGROUP DATA FOR MCNPX

Currently, only one coupled neutron-photon multigroup library is supported by the Data Team, MGXSNP [LIT87]. MGXSNP is comprised of 30-group neutron and 12-group photon data primarily based on ENDF/B-V for 95 nuclides. The MCNPX-compatible multigroup data library was produced from the original Sn multigroup libraries MENDF5 and MENDF5G using the code CRSRD in April 1987 [LIT86b, WAG94]. The original neutron data library MENDF5 was produced using the "TD-Division Weight Function," also called "CLAW" by the processing code NJOY [SEA76, SEA80, MAC94a]. This weight function is a combination of a Maxwellian thermal + $1/E$ + fission + fusion peak at 14.0 MeV. The data library contains no upscatter groups or self-shielding and is most

applicable for fast systems. All cross sections are for room temperature, 300K. P0 through P4 scattering matrices from the original library were processed by CRSRD into angular distributions for MCNPX using the Carter-Forest equiprobable bin treatment. When available, both total and prompt nubar data are provided. The edit reactions available for each ZAID are fully described in LIT87.

Table G-3 describes the MGXSNP data library. The ZAIDs used for this library correspond to the source evaluation in the same manner as the ZAID for the continuous-energy and discrete data; as an example, the same source evaluation for natural iron was used to produce 26000.55c, 26000.55d and 26000.55m. For coupled neutron-photon problems, specifying a particular isotope on a material card will invoke the neutron set for that isotope and the corresponding photon set for that element. For example, an entry of "1003" on a material card will cause MCNPX to use ZAID=1003.50m for neutron data and 1000.01g for photon data.

Table G-3. MGXSNP: A Coupled Neutron-Photon Multigroup Data Library

ZAID	Neutron AWR	Length	ZAID	Photon AWR	Length
1001.50m	0.999172	3249	1000.01g	0.999317	583
1002.55m	1.996810	3542			
1003.50m	2.990154	1927			
2003.50m	2.990134	1843	2000.01g	3.968217	583
2004.50m	3.968238	1629			
3006.50m	5.963479	3566	3000.01g	6.881312	583
3007.55m	6.955768	3555			
4007.35m	6.949815	1598	4000.01g	8.934763	557
4009.50m	8.934807	3014			
5010.50m	9.926970	3557	5000.01g	10.717168	583
5011.56m	10.914679	2795			
6000.50m [1]	11.896972	2933	6000.01g	11.907955	583
6012.50m [1]	11.896972	2933			
7014.50m	13.882849	3501	7000.01g	13.886438	583
7015.55m	14.871314	2743			
8016.50m	15.857588	3346	8000.01g	15.861942	583
9019.50m	18.835289	3261	9000.01g	18.835197	583
11023.50m	22.792388	2982	11000.01g	22.792275	583
12000.50m	24.096375	3802	12000.01g	24.096261	583
13027.50m	26.749887	3853	13000.01g	26.749756	583
14000.50m	27.844378	3266	14000.01g	27.844241	583
15031.50m	30.707833	2123	15000.01g	30.707682	583
16032.50m	31.697571	2185	16000.01g	31.788823	583
17000.50m	35.148355	2737	17000.01g	35.148180	583

ZAID	Neutron AWR	Length	ZAID	Photon AWR	Length
18000.35m	39.605021	2022	18000.01g	39.604489	557
19000.50m	38.762616	2833	19000.01g	38.762423	583
20000.50m	39.734053	3450	20000.01g	39.733857	583
22000.50m	47.455981	3015	22000.01g	47.455747	583
23000.50m	50.504104	2775	23000.01g	50.503856	583
24000.50m	51.549511	3924	24000.01g	51.549253	583
25055.50m	54.466367	2890	25000.01g	54.466099	583
26000.55m	55.366734	4304	26000.01g	55.366466	583
27059.50m	58.427218	2889	27000.01g	58.426930	583
28000.50m	58.182926	3373	28000.01g	58.182641	583
29000.50m	62.999465	2803	29000.01g	62.999157	583
31000.50m	69.124611	2084	31000.01g	69.124270	583
33075.35m	74.278340	2022	33000.01g	74.277979	557
36078.50m	77.251400	2108	36000.01g	83.080137	583
36080.50m	79.230241	2257			
36082.50m	81.210203	2312			
36083.50m	82.202262	2141			
36084.50m	83.191072	2460			
36086.50m	85.173016	2413			
40000.50m	90.440039	2466	40000.01g	90.439594	583
41093.50m	92.108717	2746	41000.01g	92.108263	583
42000.50m	95.107162	1991	42000.01g	95.106691	583
45103.50m	102.021993	2147	45000.01g	102.021490	583
45117.90m	115.544386	2709			
46119.90m	117.525231	2629	46000.01g	105.513949	557
47000.55m	106.941883	2693	47000.01g	106.941685	583
47107.50m	105.987245	2107			
47109.50m	107.969736	1924			
48000.50m	111.442911	1841	48000.01g	111.442363	583
50120.35m	115.995479	1929	50000.01g	117.667336	557
50998.99m	228.025301	1382			
50999.99m	228.025301	1413			
54000.35m	130.171713	1929	54000.01g	130.165202	557
56138.50m	136.721230	2115	56000.01g	136.146809	583
63000.35m	150.654333	1933	63000.01g	150.657141	557
63151.55m	149.623005	2976			
63153.55m	151.608005	2691			
64000.35m	155.898915	1929	64000.01g	155.900158	557
67165.55m	163.512997	2526	67000.01g	163.513493	583

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ZAID	Neutron AWR	Length	ZAID	Photon AWR	Length
73181.50m	179.394458	2787	73000.01g	179.393456	583
74000.55m	182.270446	4360	74000.01g	182.269548	583
74182.55m	180.386082	3687			
74183.55m	181.379499	3628			
74184.55m	182.371615	3664			
74186.55m	184.357838	3672			
75185.50m	183.365036	1968	75000.01g	184.607108	583
75187.50m	185.350629	2061			
78000.35m	193.415026	1929	78000.01g	193.404225	557
79197.56m	195.274027	3490	79000.01g	195.274513	583
82000.50m	205.437162	3384	82000.01g	205.436151	583
83209.50m	207.186158	2524	83000.01g	207.185136	583
90232.50m	230.045857	2896	90000.01g	230.044724	583
91233.50m	231.039442	1970	91000.01g	229.051160	479
92233.50m	231.038833	1988	92000.01g	235.984125	583
92234.50m	232.031554	2150			
92235.50m	233.025921	3164			
92236.50m	234.018959	2166			
92237.50m	235.013509	2174			
92238.50m	236.006966	3553			
92239.35m	236.997601	2147			
93237.55m	235.012957	2812	93000.01g	235.011799	479
94238.50m	236.005745	2442	94000.01g [2]	241.967559	583
94239.55m	236.999740	3038			
94240.50m	237.992791	3044			
94241.50m	238.987218	2856			
94242.50m	239.980508	2956			
95241.50m	238.987196	2535			
95242.50m	239.981303	2284			
95243.50m	240.974535	2480			
96242.50m	239.980599	1970			
96244.50m	241.967311	1950			

Note 1. The neutron transport data for ZAIDs 6012.50m and 6000.50m are the same.
Note 2. Photon transport data are not provided for Z>94.

G.5 PHOTOATOMIC DATA

There are four photon transport libraries maintained by X-Division and distributed with MCNPX: MCPLIB, MCPLIB02, MCPLIB03, and MCPLIB04. Their lineage is summarized below.

The official version of MCPLIB is unchanged since 1982 [LIT82a]. Versions of MCPLIB existed prior to 1982. MCPLIB contains data from several sources. For Z equal to 1 to 94 (excluding Z equal to 84, 85, 87, 88, 89, 91, and 93), the cross-section data for incident energies from 1 keV to 100 MeV and all form-factor data are from the ENDF/B-IV evaluation, which is available from RSICC as data package DLC-7e. The excluded elements are tabulated only on the energy range from 1 keV to 15 MeV and trace their cross-section data back to the Storm and Israel 1970 data compilation [STO70], which is available from RSICC as data package DLC-15. The form-factor data for the excluded elements is of forgotten origin. The fluorescence data were produced by Everett and Cashwell [EVE73] from the Storm and Israel 1970 data, supplemented as necessary. MCPLIB does not contain momentum profile (CDBD) data.

MCPLIB02 was officially released in 1993 [HUG96] and was created as an extension to MCPLIB. The form-factor and fluorescence data on MCPLIB and MCPLIB02 are identical. The cross-section data below 10 MeV are also identical. From the maximum energy on the original MCPLIB table up to 100 GeV, the cross-section data are derived from EPDL89 [CUL89]. Between 10 MeV and the highest energy of the MCNPLIB data, the data are smoothly transitioned. MCPLIB02 does not contain momentum profile (CDBD) data.

MCPLIB03 was officially released in 2002 [WHI02a] as another extension of the MCPLIB/MCPLIB02 data set. The cross-section, form-factor, and fluorescence data on MCPLIB02 and MCPLIB03 are identical. The only change is the addition of the momentum profile (CDBD) data, derived from the work of Biggs, Mendelsohn, and Mann [BIG75].

MCNPLIB04 was officially released in 2002 [WHI02b]. The cross-section, form-factor, and fluorescence data are all derived from the ENDF/B-VI.8 data library that was derived from EPDL97 [CUL97]. Cross-section data are given for incident photon energies from 1 keV to 1 GeV. Fluorescence data are derived from the atomic relaxation data available in ENDF/B-VI.8 but use the storage and sampling scheme defined by Everett and Cashwell [EVE73]. The momentum profile (CDBD) data are identical to the data found on MCPLIB03 [WHI02a].

The entries in each of the columns of Table G-4 are described as follows:

ZAID → The nuclide identification number with the form `ZZZAAA.abX` where
`ZZZ` is the atomic number,

AAAis always 000 for elemental photoatomic data,
ab is the unique alphanumeric table identifier, and
X=P for continuous-energy neutron tables.

Library → Name of the library that contains the data file for that ZAID.

Library Release Date → Date the library was officially released. This does not necessarily correspond to the source evaluation date; these tables contain data from many sources.

Length → The total length of a particular photoatomic table in words.

Number of Energies → The number of energy points (NE) on the grid used for the photoatomic cross sections for that data table. In general, a finer energy grid (or greater number of points) indicates a more accurate representation of the cross sections.

E_{max} → The maximum incident photon energy for that data table in GeV (multiply by 1000 to get the value in units of MeV). For all incident energies greater than E_{max}, MCNPX assumes the last cross-section value given.

Cross-Section Source → This entry indicates the source from which the cross-section data are derived. There are four sources for the cross-section data:

(1) S&I indicates data from the Storm and Israel 1970 compilation,
(2) B-IV indicates data from ENDF/B-IV,
(3) B-IV/89 indicates data from ENDF/B-IV merged with data from EPDL89, and
(4) B/VI.8 indicates data from ENDF/B-VI release 8.

Form-Factor Source → This entry indicates the source from which the form-factor data are derived. There are three sources for the form-factor data:

(1) Unknown indicates that data date back to unknown origins,
(2) B/IV indicates data from ENDF/B-IV, and
(3) B/VI.8 indicates data from ENDF/B-VI release 8.

Fluorescence Source → This entry indicates the source from which the fluorescence data are derived. There are two sources for the fluorescence data:

(1) E&C indicates data from Everett and Cashwell's original work, and
(2) B/VI.8 indicates data in the Everett and Cashwell format derived from ENDF/B-VI release 8.

CDBD Source → This entry indicates the source from which the momentum profile (CDBD) data for Doppler broadening of the Compton scattered energy are derived. Currently the only source for the CDBD data is Biggs, Mendelsohn, and Mann's 1975 compilation.

Table G-4. Continuous-Energy Photoatomic Data Libraries Maintained by X-Division

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 1 ********** Hydrogen **********									
1000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
1000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
1000.03p	mcplib03	2002	722	82	100	B-IV/89	B-IV	E&C	BM&M
1000.04p	mcplib04	2002	1898	278	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 2 ********** Helium **********									
2000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
2000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
2000.03p	mcplib03	2002	722	82	100	B-IV/89	B-IV	E&C	BM&M
2000.04p	mcplib04	2002	1970	290	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 3 ********** Lithium **********									
3000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
3000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
3000.03p	mcplib03	2002	821	82	100	B-IV/89	B-IV	E&C	BM&M
3000.04p	mcplib04	2002	2339	335	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 4 ********** Beryllium **********									
4000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
4000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
4000.03p	mcplib03	2002	821	82	100	B-IV/89	B-IV	E&C	BM&M
4000.04p	mcplib04	2002	2363	339	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 5 ********** Boron **********									
5000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
5000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
5000.03p	mcplib03	2002	920	82	100	B-IV/89	B-IV	E&C	BM&M
5000.04p	mcplib04	2002	3116	448	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 6 ********** Carbon **********									
6000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
6000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
6000.03p	mcplib03	2002	920	82	100	B-IV/89	B-IV	E&C	BM&M
6000.04p	mcplib04	2002	3152	454	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 7 ********** Nitrogen **********									
7000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
7000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
7000.03p	mcplib03	2002	920	82	100	B-IV/89	B-IV	E&C	BM&M
7000.04p	mcplib04	2002	3194	461	100	B-VI.8	B-VI.8	B-VI.8	BM&M

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ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 8 ********** Oxygen **********									
8000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
8000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
8000.03p	mcplib03	2002	920	82	100	B-IV/89	B-IV	E&C	BM&M
8000.04p	mcplib04	2002	3272	474	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 9 ********** Fluorine **********									
9000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
9000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
9000.03p	mcplib03	2002	920	82	100	B-IV/89	B-IV	E&C	BM&M
9000.04p	mcplib04	2002	3206	463	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 10 ********** Neon **********									
10000.01p	mcplib	1982	389	43	0.1	B-IV	B-IV	E&C	n/a
10000.02p	mcplib02	1993	623	82	100	B-IV/89	B-IV	E&C	n/a
10000.03p	mcplib03	2002	920	82	100	B-IV/89	B-IV	E&C	BM&M
10000.04p	mcplib04	2002	3278	475	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 11 ********** Sodium **********									
11000.01p	mcplib	1982	401	45	0.1	B-IV	B-IV	E&C	n/a
11000.02p	mcplib02	1993	635	84	100	B-IV/89	B-IV	E&C	n/a
11000.03p	mcplib03	2002	1031	84	100	B-IV/89	B-IV	E&C	BM&M
11000.04p	mcplib04	2002	3995	578	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 12 ********** Magnesium **********									
12000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
12000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
12000.03p	mcplib03	2002	1039	84	100	B-IV/89	B-IV	E&C	BM&M
12000.04p	mcplib04	2002	3781	541	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 13 ********** Aluminum **********									
13000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
13000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
13000.03p	mcplib03	2002	1138	84	100	B-IV/89	B-IV	E&C	BM&M
13000.04p	mcplib04	2002	4846	702	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 14 ********** Silicon **********									
14000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
14000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
14000.03p	mcplib03	2002	1138	84	100	B-IV/89	B-IV	E&C	BM&M
14000.04p	mcplib04	2002	4792	693	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 15 ********** Phosphorus **********									
15000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
15000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
15000.03p	mcplib03	2002	1138	84	100	B-IV/89	B-IV	E&C	BM&M
15000.04p	mcplib04	2002	4498	644	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 16 ********** Sulfur **********									
16000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
16000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
16000.03p	mcplib03	2002	1138	84	100	B-IV/89	B-IV	E&C	BM&M
16000.04p	mcplib04	2002	4654	670	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 17 ********** Chlorine **********									
17000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
17000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
17000.03p	mcplib03	2002	1138	84	100	B-IV/89	B-IV	E&C	BM&M
17000.04p	mcplib04	2002	4738	684	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 18 ********** Argon **********									
18000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
18000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
18000.03p	mcplib03	2002	1138	84	100	B-IV/89	B-IV	E&C	BM&M
18000.04p	mcplib04	2002	4696	677	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 19 ********** Potassium **********									
19000.01p	mcplib	1982	409	45	0.1	B-IV	B-IV	E&C	n/a
19000.02p	mcplib02	1993	643	84	100	B-IV/89	B-IV	E&C	n/a
19000.03p	mcplib03	2002	1237	84	100	B-IV/89	B-IV	E&C	BM&M
19000.04p	mcplib04	2002	5047	719	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 20 ********** Calcium **********									
20000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
20000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
20000.03p	mcplib03	2002	1245	84	100	B-IV/89	B-IV	E&C	BM&M
20000.04p	mcplib04	2002	5013	712	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 21 ********** Scandium **********									
21000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
21000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
21000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
21000.04p	mcplib04	2002	5532	782	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 22 ********** Titanium **********									
22000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
22000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
22000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
22000.04p	mcplib04	2002	5742	817	100	B-VI.8	B-VI.8	B-VI.8	BM&M

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ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 23 ********** Vanadium **********									
23000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
23000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
23000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
23000.04p	mcplib04	2002	5814	829	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 24 ********** Chromium **********									
24000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
24000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
24000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
24000.04p	mcplib04	2002	5682	807	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 25 ********** Manganese **********									
25000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
25000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
25000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
25000.04p	mcplib04	2002	5598	793	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 26 ********** Iron **********									
26000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
26000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
26000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
26000.04p	mcplib04	2002	5718	813	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 27 ********** Cobalt **********									
27000.01p	mcplib	1982	417	45	0.1	B-IV	B-IV	E&C	n/a
27000.02p	mcplib02	1993	651	84	100	B-IV/89	B-IV	E&C	n/a
27000.03p	mcplib03	2002	1344	84	100	B-IV/89	B-IV	E&C	BM&M
27000.04p	mcplib04	2002	5436	766	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 28 ********** Nickel **********									
28000.01p	mcplib	1982	429	47	0.1	B-IV	B-IV	E&C	n/a
28000.02p	mcplib02	1993	663	86	100	B-IV/89	B-IV	E&C	n/a
28000.03p	mcplib03	2002	1356	86	100	B-IV/89	B-IV	E&C	BM&M
28000.04p	mcplib04	2002	5826	831	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 29 ********** Copper **********									
29000.01p	mcplib	1982	429	47	0.1	B-IV	B-IV	E&C	n/a
29000.02p	mcplib02	1993	663	86	100	B-IV/89	B-IV	E&C	n/a
29000.03p	mcplib03	2002	1356	86	100	B-IV/89	B-IV	E&C	BM&M
29000.04p	mcplib04	2002	5754	819	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 30 ********** Zinc **********									
30000.01p	mcplib	1982	453	51	0.1	B-IV	B-IV	E&C	n/a
30000.02p	mcplib02	1993	687	90	100	B-IV/89	B-IV	E&C	n/a

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
30000.03p	mcplib03	2002	1380	90	100	B-IV/89	B-IV	E&C	BM&M
30000.04p	mcplib04	2002	6288	908	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 31 ********** Gallium **********									
31000.01p	mcplib	1982	457	51	0.1	B-IV	B-IV	E&C	n/a
31000.02p	mcplib02	1993	691	90	100	B-IV/89	B-IV	E&C	n/a
31000.03p	mcplib03	2002	1483	90	100	B-IV/89	B-IV	E&C	BM&M
31000.04p	mcplib04	2002	6787	974	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 32 ********** Germanium **********									
32000.01p	mcplib	1982	457	51	0.1	B-IV	B-IV	E&C	n/a
32000.02p	mcplib02	1993	691	90	100	B-IV/89	B-IV	E&C	n/a
32000.03p	mcplib03	2002	1483	90	100	B-IV/89	B-IV	E&C	BM&M
32000.04p	mcplib04	2002	7027	1014	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 33 ********** Arsenic **********									
33000.01p	mcplib	1982	457	51	0.1	B-IV	B-IV	E&C	n/a
33000.02p	mcplib02	1993	691	90	100	B-IV/89	B-IV	E&C	n/a
33000.03p	mcplib03	2002	1483	90	100	B-IV/89	B-IV	E&C	BM&M
33000.04p	mcplib04	2002	6595	942	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 34 ********** Selenium **********									
34000.01p	mcplib	1982	457	51	0.1	B-IV	B-IV	E&C	n/a
34000.02p	mcplib02	1993	691	90	100	B-IV/89	B-IV	E&C	n/a
34000.03p	mcplib03	2002	1483	90	100	B-IV/89	B-IV	E&C	BM&M
34000.04p	mcplib04	2002	6655	952	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 35 ********** Bromine **********									
35000.01p	mcplib	1982	457	51	0.1	B-IV	B-IV	E&C	n/a
35000.02p	mcplib02	1993	691	90	100	B-IV/89	B-IV	E&C	n/a
35000.03p	mcplib03	2002	1483	90	100	B-IV/89	B-IV	E&C	BM&M
35000.04p	mcplib04	2002	6853	985	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 36 ********** Krypton **********									
36000.01p	mcplib	1982	457	51	0.1	B-IV	B-IV	E&C	n/a
36000.02p	mcplib02	1993	691	90	100	B-IV/89	B-IV	E&C	n/a
36000.03p	mcplib03	2002	1879	90	100	B-IV/89	B-IV	E&C	BM&M
36000.04p	mcplib04	2002	7177	973	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 37 ********** Rubidium **********									
37000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
37000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
37000.03p	mcplib03	2002	1982	90	100	B-IV/89	B-IV	E&C	BM&M
37000.04p	mcplib04	2002	7364	987	100	B-VI.8	B-VI.8	B-VI.8	BM&M

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ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 38 ********** Strontium **********									
38000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
38000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
38000.03p	mcplib03	2002	1982	90	100	B-IV/89	B-IV	E&C	BM&M
38000.04p	mcplib04	2002	7256	969	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 39 ********** Yttrium **********									
39000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
39000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
39000.03p	mcplib03	2002	2081	90	100	B-IV/89	B-IV	E&C	BM&M
39000.04p	mcplib04	2002	7583	1007	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 40 ********** Zirconium **********									
40000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
40000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
40000.03p	mcplib03	2002	2081	90	100	B-IV/89	B-IV	E&C	BM&M
40000.04p	mcplib04	2002	7703	1027	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 41 ********** Niobium **********									
41000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
41000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
41000.03p	mcplib03	2002	2081	90	100	B-IV/89	B-IV	E&C	BM&M
41000.04p	mcplib04	2002	7667	1021	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 42 ********** Molybdenum **********									
42000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
42000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
42000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
42000.04p	mcplib04	2002	7592	992	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 43 ********** Technetium **********									
43000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
43000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
43000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
43000.04p	mcplib04	2002	7946	1051	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 44 ********** Ruthenium **********									
44000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
44000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
44000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
44000.04p	mcplib04	2002	7988	1058	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 45 ********** Rhodium **********									
45000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
45000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a

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45000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
45000.04p	mcplib04	2002	7856	1036	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 46 ********** Palladium **********									
46000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
46000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
46000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
46000.04p	mcplib04	2002	7595	1009	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 47 ********** Silver **********									
47000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
47000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
47000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
47000.04p	mcplib04	2002	7772	1022	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 48 ********** Cadmium **********									
48000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
48000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
48000.03p	mcplib03	2002	2180	90	100	B-IV/89	B-IV	E&C	BM&M
48000.04p	mcplib04	2002	7700	10010	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 49 ********** Indium **********									
49000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
49000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
49000.03p	mcplib03	2002	2279	90	100	B-IV/89	B-IV	E&C	BM&M
49000.04p	mcplib04	2002	8291	1092	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 50 ********** Tin **********									
50000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
50000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
50000.03p	mcplib03	2002	2279	90	100	B-IV/89	B-IV	E&C	BM&M
50000.04p	mcplib04	2002	8039	1050	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 51 ********** Antimony **********									
51000.01p	mcplib	1982	461	51	0.1	B-IV	B-IV	E&C	n/a
51000.02p	mcplib02	1993	695	90	100	B-IV/89	B-IV	E&C	n/a
51000.03p	mcplib03	2002	2378	90	100	B-IV/89	B-IV	E&C	BM&M
51000.04p	mcplib04	2002	8414	1096	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 52 ********** Tellurium **********									
52000.01p	mcplib	1982	473	53	0.1	B-IV	B-IV	E&C	n/a
52000.02p	mcplib02	1993	707	92	100	B-IV/89	B-IV	E&C	n/a
52000.03p	mcplib03	2002	2390	92	100	B-IV/89	B-IV	E&C	BM&M
52000.04p	mcplib04	2002	8162	1054	100	B-VI.8	B-VI.8	B-VI.8	BM&M

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ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 53 ********** Iodine **********									
53000.01p	mcplib	1982	473	53	0.1	B-IV	B-IV	E&C	n/a
53000.02p	mcplib02	1993	707	92	100	B-IV/89	B-IV	E&C	n/a
53000.03p	mcplib03	2002	2390	92	100	B-IV/89	B-IV	E&C	BM&M
53000.04p	mcplib04	2002	8492	1109	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 54 ********** Xenon **********									
54000.01p	mcplib	1982	473	53	0.1	B-IV	B-IV	E&C	n/a
54000.02p	mcplib02	1993	707	92	100	B-IV/89	B-IV	E&C	n/a
54000.03p	mcplib03	2002	2390	92	100	B-IV/89	B-IV	E&C	BM&M
54000.04p	mcplib04	2002	8324	1081	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 55 ********** Cesium **********									
55000.01p	mcplib	1982	497	57	0.1	B-IV	B-IV	E&C	n/a
55000.02p	mcplib02	1993	731	96	100	B-IV/89	B-IV	E&C	n/a
55000.03p	mcplib03	2002	2513	96	100	B-IV/89	B-IV	E&C	BM&M
55000.04p	mcplib04	2002	8417	1080	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 56 ********** Barium **********									
56000.01p	mcplib	1982	497	57	0.1	B-IV	B-IV	E&C	n/a
56000.02p	mcplib02	1993	731	96	100	B-IV/89	B-IV	E&C	n/a
56000.03p	mcplib03	2002	2513	96	100	B-IV/89	B-IV	E&C	BM&M
56000.04p	mcplib04	2002	8465	1088	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 57 ********** Lanthanum **********									
57000.01p	mcplib	1982	497	57	0.1	B-IV	B-IV	E&C	n/a
57000.02p	mcplib02	1993	731	96	100	B-IV/89	B-IV	E&C	n/a
57000.03p	mcplib03	2002	2612	96	100	B-IV/89	B-IV	E&C	BM&M
57000.04p	mcplib04	2002	8744	1118	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 58 ********** Cerium **********									
58000.01p	mcplib	1982	497	57	0.1	B-IV	B-IV	E&C	n/a
58000.02p	mcplib02	1993	731	96	100	B-IV/89	B-IV	E&C	n/a
58000.03p	mcplib03	2002	2711	96	100	B-IV/89	B-IV	E&C	BM&M
58000.04p	mcplib04	2002	9173	1173	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 59 ********** Praseodymium **********									
59000.01p	mcplib	1982	497	57	0.1	B-IV	B-IV	E&C	n/a
59000.02p	mcplib02	1993	731	96	100	B-IV/89	B-IV	E&C	n/a
59000.03p	mcplib03	2002	2612	96	100	B-IV/89	B-IV	E&C	BM&M
59000.04p	mcplib04	2002	8750	1119	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 60 ********** Praseodymium **********									
60000.01p	mcplib	1982	509	59	0.1	B-IV	B-IV	E&C	n/a
60000.02p	mcplib02	1993	743	98	100	B-IV/89	B-IV	E&C	n/a

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
60000.03p	mcplib03	2002	2624	98	100	B-IV/89	B-IV	E&C	BM&M
60000.04p	mcplib04	2002	9362	1221	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 61 ********** Neodymium **********									
61000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
61000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
61000.03p	mcplib03	2002	2636	100	100	B-IV/89	B-IV	E&C	BM&M
61000.04p	mcplib04	2002	9350	1219	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 62 ********** Samarium **********									
62000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
62000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
62000.03p	mcplib03	2002	2636	100	100	B-IV/89	B-IV	E&C	BM&M
62000.04p	mcplib04	2002	9374	1223	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 63 ********** Europium **********									
63000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
63000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
63000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
63000.04p	mcplib04	2002	9323	1198	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 64 ********** Gadolinium **********									
64000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
64000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
64000.03p	mcplib03	2002	2834	100	100	B-IV/89	B-IV	E&C	BM&M
64000.04p	mcplib04	2002	9560	1221	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 65 ********** Terbium **********									
65000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
65000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
65000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
65000.04p	mcplib04	2002	9143	1168	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 66 ********** Dysprosium **********									
66000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
66000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
66000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
66000.04p	mcplib04	2002	9479	1224	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 67 ********** Holmium **********									
67000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
67000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
67000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
67000.04p	mcplib04	2002	9419	1214	100	B-VI.8	B-VI.8	B-VI.8	BM&M

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ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 68 ********** Erbium **********									
68000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
68000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
68000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
68000.04p	mcplib04	2002	9233	1183	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 69 ********** Thulium **********									
69000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
69000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
69000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
69000.04p	mcplib04	2002	9473	1223	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 70 ********** Ytterbium **********									
70000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
70000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
70000.03p	mcplib03	2002	2735	100	100	B-IV/89	B-IV	E&C	BM&M
70000.04p	mcplib04	2002	9539	1234	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 71 ********** Lutetium **********									
71000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
71000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
71000.03p	mcplib03	2002	2834	100	100	B-IV/89	B-IV	E&C	BM&M
71000.04p	mcplib04	2002	9914	1280	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 72 ********** Hafnium **********									
72000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
72000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
72000.03p	mcplib03	2002	2834	100	100	B-IV/89	B-IV	E&C	BM&M
72000.04p	mcplib04	2002	9932	1283	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 73 ********** Tantalum **********									
73000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
73000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
73000.03p	mcplib03	2002	2834	100	100	B-IV/89	B-IV	E&C	BM&M
73000.04p	mcplib04	2002	9698	1244	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 74 ********** Tungsten **********									
74000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
74000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
74000.03p	mcplib03	2002	2834	100	100	B-IV/89	B-IV	E&C	BM&M
74000.04p	mcplib04	2002	9713	1247	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 75 ********** Rhenium **********									
75000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
75000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
75000.03p	mcplib03	2002	2933	100	100	B-IV/89	B-IV	E&C	BM&M
75000.04p	mcplib04	2002	9797	1244	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 76 ********** Osmium **********									
76000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
76000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
76000.03p	mcplib03	2002	2933	100	100	B-IV/89	B-IV	E&C	BM&M
76000.04p	mcplib04	2002	9977	1274	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 77 ********** Iridum **********									
77000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
77000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
77000.03p	mcplib03	2002	2933	100	100	B-IV/89	B-IV	E&C	BM&M
77000.04p	mcplib04	2002	9665	1222	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 78 ********** Platinum **********									
78000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
78000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
78000.03p	mcplib03	2002	2933	100	100	B-IV/89	B-IV	E&C	BM&M
78000.04p	mcplib04	2002	9377	1174	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 79 ********** Gold **********									
79000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
79000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
79000.03p	mcplib03	2002	2933	100	100	B-IV/89	B-IV	E&C	BM&M
79000.04p	mcplib04	2002	9881	1258	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 80 ********** Mercury **********									
80000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
80000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
80000.03p	mcplib03	2002	2933	100	100	B-IV/89	B-IV	E&C	BM&M
80000.04p	mcplib04	2002	9281	1158	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 81 ********** Thallium **********									
81000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
81000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
81000.03p	mcplib03	2002	3032	100	100	B-IV/89	B-IV	E&C	BM&M
81000.04p	mcplib04	2002	10142	1285	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 82 ********** Lead **********									
82000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
82000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
82000.03p	mcplib03	2002	3032	100	100	B-IV/89	B-IV	E&C	BM&M
82000.04p	mcplib04	2002	10010	1263	100	B-VI.8	B-VI.8	B-VI.8	BM&M

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ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 83 ********** Bismuth **********									
83000.01p	mcplib	1982	521	61	0.1	B-IV	B-IV	E&C	n/a
83000.02p	mcplib02	1993	755	100	100	B-IV/89	B-IV	E&C	n/a
83000.03p	mcplib03	2002	3131	100	100	B-IV/89	B-IV	E&C	BM&M
83000.04p	mcplib04	2002	10373	1307	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 84 ********** Polonium **********									
84000.01p	mcplib	1982	467	52	0.015	DLC-15	Unknown	E&C	n/a
84000.02p	mcplib02	1993	749	99	100	S&I/89	Unknown	E&C	n/a
84000.03p	mcplib03	2002	3125	99	100	S&I /89	Unknown	E&C	BM&M
84000.04p	mcplib04	2002	10247	1286	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 85 ********** Polonium **********									
85000.01p	mcplib	1982	479	54	0.015	DLC-15	Unknown	E&C	n/a
85000.02p	mcplib02	1993	761	101	100	S&I/89	Unknown	E&C	n/a
85000.03p	mcplib03	2002	3137	101	100	S&I /89	Unknown	E&C	BM&M
85000.04p	mcplib04	2002	10463	1322	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 86 ********** Radon **********									
86000.01p	mcplib	1982	533	63	0.1	B-IV	B-IV	E&C	n/a
86000.02p	mcplib02	1993	767	102	100	B-IV/89	B-IV	E&C	n/a
86000.03p	mcplib03	2002	3143	102	100	B-IV/89	B-IV	E&C	BM&M
86000.04p	mcplib04	2002	10325	1299	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 87 ********** Francium **********									
87000.01p	mcplib	1982	479	54	0.015	S&I	Unknown	E&C	n/a
87000.02p	mcplib02	1993	761	101	100	S&I/89	Unknown	E&C	n/a
87000.03p	mcplib03	2002	3236	101	100	S&I /89	Unknown	E&C	BM&M
87000.04p	mcplib04	2002	10532	1317	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 88 ********** Radium **********									
88000.01p	mcplib	1982	479	54	0.015	S&I	Unknown	E&C	n/a
88000.02p	mcplib02	1993	761	101	100	S&I/89	Unknown	E&C	n/a
88000.03p	mcplib03	2002	3236	101	100	S&I /89	Unknown	E&C	BM&M
88000.04p	mcplib04	2002	10346	1286	100	B-VI.8	B-VI.8	B-VI.8	BM&M

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 89 ********** Actinium **********									
89000.01p	mcplib	1982	479	54	0.015	S&I	Unknown	E&C	n/a
89000.02p	mcplib02	1993	761	101	100	S&I/89	Unknown	E&C	n/a
89000.03p	mcplib03	2002	3335	101	100	S&I /89	Unknown	E&C	BM&M
89000.04p	mcplib04	2002	10133	1234	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 90 ********** Thorium **********									
90000.01p	mcplib	1982	533	63	0.1	B-IV	B-IV	E&C	n/a
90000.02p	mcplib02	1993	767	102	100	B-IV/89	B-IV	E&C	n/a
90000.03p	mcplib03	2002	3341	102	100	B-IV/89	B-IV	E&C	BM&M
90000.04p	mcplib04	2002	10565	1306	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 91 ********** Protactinium **********									
91000.01p	mcplib	1982	479	54	0.015	S&I	Unknown	E&C	n/a
91000.02p	mcplib02	1993	761	101	100	S&I/89	Unknown	E&C	n/a
91000.03p	mcplib03	2002	3434	101	100	S&I /89	Unknown	E&C	BM&M
91000.04p	mcplib04	2002	10670	1307	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 92 ********** Uranium **********									
92000.01p	mcplib	1982	533	63	0.1	B-IV	B-IV	E&C	n/a
92000.02p	mcplib02	1993	767	102	100	B-IV/89	B-IV	E&C	n/a
92000.03p	mcplib03	2002	3440	102	100	B-IV/89	B-IV	E&C	BM&M
92000.04p	mcplib04	2002	10868	1330	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 93 ********** Neptunium **********									
93000.01p	mcplib	1982	479	54	0.015	S&I	Unknown	E&C	n/a
93000.02p	mcplib02	1993	761	101	100	S&I/89	Unknown	E&C	n/a
93000.03p	mcplib03	2002	3434	101	100	S&I /89	Unknown	E&C	BM&M
93000.04p	mcplib04	2002	11120	1382	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 94 ********** Plutonium **********									
94000.01p	mcplib	1982	533	63	0.1	B-IV	B-IV	E&C	n/a
94000.02p	mcplib02	1993	767	102	100	B-IV/89	B-IV	E&C	n/a
94000.03p	mcplib03	2002	3341	102	100	B-IV/89	B-IV	E&C	BM&M
94000.04p	mcplib04	2002	10451	1287	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 95 ********** Americium **********									
95000.04p	mcplib04	2002	10640	1302	100	B-VI.8	B-VI.8	B-VI.8	BM&M

ZAID	Library Name	Release Date	Length words	NE	E_{max} (GeV)	CS Source	FF Source	Fluor. Source	CDBD Source
Z = 96 ********** Curium **********									
96000.04p	mcplib04	2002	10421	1249	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 97 ********** Berkelium **********									
97000.04p	mcplib04	2002	10478	1275	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 98 ********** Californium **********									
98000.04p	mcplib04	2002	10634	1301	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 99 ********** Einsteinium **********									
99000.04p	mcplib04	2002	11126	1383	100	B-VI.8	B-VI.8	B-VI.8	BM&M
Z = 100 ********** Fermium **********									
100000.04p	mcplib04	2002	10916	1348	100	B-VI.8	B-VI.8	B-VI.8	BM&M

G.6 PHOTONUCLEAR DATA

LA150U is the only photonuclear data library supported by X-Division. It is derived from work done at Los Alamos National Laboratory in the Nuclear Physics Group (LANL/T-16).

The entries in each of the columns of Table G-5 are described as follows:

ZAID → The nuclide identification number with the form `ZZZAAA.abX` where
`ZZZ` is the atomic number,
`AAA` is the mass number (000 for elements),
`ab` is the unique alphanumeric table identifier, and
`X=U` for continuous-energy photonuclear tables.

Atomic Weight Ratio → The atomic weight ratio (AWR) is the ratio of the atomic mass of the nuclide to a neutron, as contained in the original evaluation and used in the NJOY processing of the evaluation.

Library → Name of the library that contains the data file for that ZAID.

Evaluation Date → Date the evaluation was officially released.

Source → The source from which the evaluated data was obtained. The abbreviation LANL/T-16 indicates that the data were produced by the Nuclear Physics Group (T-16) at Los Alamos National Laboratory.

Length → The total length of a particular photonuclear table in words.

Number of Energies → The number of energy points (NE) on the grid used for the photonuclear cross sections for that data table. In general, a finer energy grid with a greater number of points provides a more accurate representation of the cross sections.

E_{max} → The maximum incident photon energy in MeV for that data table. For all incident energies greater than E_{max}, MCNPX assumes the last cross-section value given.

CP → "YES" indicates that secondary charged-particle data are present; "NO" indicates that such data are not present.

Table G-5. Continuous-Energy Photonuclear Data Libraries Maintained by X-Division

ZAID	AWR	Library Name	Eval. Date	Source	Length (words)	NE	E_{max} (GeV)	CP
Z = 1 ********** Hydrogen **********								
** H-2 **								
1002.24u	1.9963	la150u	2001	LANL/T-16	3686	35	30	No
Z = 6 ********** Carbon **********								
** C-12 **								
6012.24u	11.89691	la150u	1999	LANL/T-16	50395	98	150	Yes
Z = 8 ********** Oxygen **********								
** O-16 **								
8016.24u	15.85316	la150u	1999	LANL/T-16	72930	95	150	Yes
Z = 13 ********** Aluminum **********								
** Al-27 **								
13027.24u	26.74975	la150u	1999	LANL/T-16	68599	52	150	Yes
Z = 14 ********** Silicon **********								
** Si-28 **								
14028.24u	27.737	la150u	1999	LANL/T-16	70693	60	150	Yes
Z = 20 ********** Calcium **********								
** Ca-40 **								
20040.24u	39.736	la150u	1998	LANL/T-16	67051	54	150	Yes
Z = 26 ********** Iron **********								
** Fe-56 **								
26056.24u	55.454	la150u	1998	LANL/T-16	64043	50	150	Yes

ZAID	AWR	Library Name	Eval. Date	Source	Length (words)	NE	E_{max} (GeV)	CP
Z = 29 ********** Copper **********								
** Cu-63 **								
29063.24u	62.389	la150u	1999	LANL/T-16	73548	57	150	Yes
Z = 73 ********** Tantalum **********								
** Ta-181 **								
73181.24u	179.4	la150u	1999	LANL/T-16	85094	50	150	Yes
Z = 74 ********** Tungsten **********								
** W-184 **								
74184.24u	182.3707	la150u	1998	LANL/T-16	78439	51	150	Yes
Z = 82 ********** Lead **********								
** Pb-206 **								
82206.24u	204.2	la150u	1998	LANL/T-16	78186	49	150	Yes
** Pb-207 **								
82207.24u	205.2	la150u	1998	LANL/T-16	78259	52	150	Yes
** Pb-208 **								
82208.24u	209.19	la150u	1998	LANL/T-16	77099	51	150	Yes

G.7 DOSIMETRY DATA FOR MCNPX

The tally multiplier (FM) feature in MCNPX allows users to calculate quantities of the form:

$$C\int \phi(E)R(E)dE$$

where C is a constant, $\phi(E)$ is the fluence (n/cm^2), and $R(E)$ is a response function. If $R(E)$is a cross section, and with the appropriate choice of units for C [atom/b·cm], the quantity calculated becomes the total number of some type of reaction per unit volume. If the tally is made over a finite time interval, it becomes a reaction rate per unit volume. In addition to using the standard reaction cross-section information available in our neutron transport libraries, dosimetry or activation reaction data may also be used as a response function. Often only dosimetry data is available for rare nuclides.

A full description of the use of dosimetry data can be found in reference LIT84. This memorandum also gives a listing of all reaction data that is available for each ZAID. There have been no major revisions of the LLNL/ACTL data since LLLDOS was produced. Users need to remember that dosimetry data libraries are appropriate only when used as a source of $R(E)$ for FM tally multipliers. Dosimetry data libraries cannot be used as a source of data for materials through which actual transport is required. Table

G-6 lists the available dosimetry data libraries for use with MCNPX, the evaluation source and date, and the length of the data in words.

Table G-6. Dosimetry Data Libraries for MCNPX Tallies

ZAID	AWR	Library	Source	Date	Length
Z = 1 ********** Hydrogen **********					
1001.30y	1.00782	llldos	LLNL/ACTL	<1983	209
1002.30y	2.01410	llldos	LLNL/ACTL	<1983	149
1003.30y	3.01605	llldos	LLNL/ACTL	<1983	27
Z = 2 ********** Helium **********					
2003.30y	3.01603	llldos	LLNL/ACTL	<1983	267
Z = 3 ********** Lithium **********					
3006.24y	5.96340	531dos	ENDF/B-V	1978	735
3006.26y	5.96340	532dos	ENDF/B-V	1977	713
3006.30y	6.01512	llldos	LLNL/ACTL	<1983	931
3007.26y	6.95570	532dos	ENDF/B-V	1972	733
3007.30y	7.01601	llldos	LLNL/ACTL	<1983	201
Z = 4 ********** Beryllium **********					
4007.30y	7.01693	llldos	LLNL/ACTL	<1983	253
4009.30y	9.01218	llldos	LLNL/ACTL	<1983	335
Z = 5 ********** Boron **********					
5010.24y	9.92690	531dos	ENDF/B-V	1979	769
5010.26y	9.92690	532dos	ENDF/B-V	1976	589
5010.30y	10.01290	llldos	LLNL/ACTL	<1983	381
5011.30y	11.00930	llldos	LLNL/ACTL	<1983	119
Z = 6 ********** Carbon **********					
6012.30y	12.00000	llldos	LLNL/ACTL	<1983	97
6013.30y	13.00340	llldos	LLNL/ACTL	<1983	479
6014.30y	14.00320	llldos	LLNL/ACTL	<1983	63
Z = 7 ********** Nitrogen **********					
7014.26y	13.88300	532dos	ENDF/B-V	1973	1013
7014.30y	14.00310	llldos	LLNL/ACTL	<1983	915

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ZAID	AWR	Library	Source	Date	Length
Z = 8 ********** Oxygen **********					
8016.26y	15.85800	532dos	ENDF/B-V	1973	95
8016.30y	15.99490	llldos	LLNL/ACTL	<1983	215
8017.30y	16.99910	llldos	LLNL/ACTL	<1983	239
Z = 9 ********** Fluorine **********					
9019.26y	18.83500	532dos	ENDF/B-V	1979	31
9019.30y	18.99840	llldos	LLNL/ACTL	<1983	517
Z = 11 ********** Sodium **********					
11023.30y	22.98980	llldos	LLNL/ACTL	<1983	621
Z = 12 ********** Magnesium **********					
12023.30y	22.99410	llldos	LLNL/ACTL	<1983	333
12024.26y	23.98500	532dos	ENDF/B-V	1979	165
12024.30y	23.98500	llldos	LLNL/ACTL	<1983	309
12025.30y	24.98580	llldos	LLNL/ACTL	<1983	309
12026.30y	25.98260	llldos	LLNL/ACTL	<1983	321
12027.30y	26.98430	llldos	LLNL/ACTL	<1983	309
Z = 13 ********** Aluminum **********					
13026.30y	25.98690	llldos	LLNL/ACTL	<1983	447
13027.24y	26.75000	531dos	ENDF/B-V	1973	1165
13027.26y	26.75000	532dos	ENDF/B-V	1973	1753
13027.30y	26.98150	llldos	LLNL/ACTL	<1983	491
Z = 14 ********** Silicon **********					
14027.30y	26.98670	llldos	LLNL/ACTL	<1983	401
14028.30y	27.97690	llldos	LLNL/ACTL	<1983	377
14029.30y	28.97650	llldos	LLNL/ACTL	<1983	389
14030.30y	29.97380	llldos	LLNL/ACTL	<1983	395
14031.30y	30.97540	llldos	LLNL/ACTL	<1983	337
Z = 15 ********** Phosphorus **********					
15031.26y	30.70800	532dos	ENDF/B-V	1977	65
15031.30y	30.97380	llldos	LLNL/ACTL	<1983	263
Z = 16 ********** Sulfur **********					
16031.30y	30.97960	llldos	LLNL/ACTL	<1983	393

ZAID	AWR	Library	Source	Date	Length
16032.24y	31.69740	531dos	ENDF/B-V	1979	145
16032.26y	31.69700	532dos	ENDF/B-V	1977	35
16032.30y	31.97210	llldos	LLNL/ACTL	<1983	417
16033.30y	32.97150	llldos	LLNL/ACTL	<1983	435
16034.30y	33.96790	llldos	LLNL/ACTL	<1983	437
16035.30y	34.96900	llldos	LLNL/ACTL	<1983	339
16036.30y	35.96710	llldos	LLNL/ACTL	<1983	293
16037.30y	36.97110	llldos	LLNL/ACTL	<1983	279
Z = 17 ********** Chlorine **********					
17034.30y	33.97380	llldos	LLNL/ACTL	<1983	401
17035.30y	34.96890	llldos	LLNL/ACTL	<1983	459
17036.30y	35.96830	llldos	LLNL/ACTL	<1983	563
17037.30y	36.96590	llldos	LLNL/ACTL	<1983	407
17038.30y	37.96800	llldos	LLNL/ACTL	<1983	33
Z = 18 ********** Argon **********					
18036.30y	35.96750	llldos	LLNL/ACTL	<1983	309
18037.30y	36.96680	llldos	LLNL/ACTL	<1983	311
18038.30y	37.96270	llldos	LLNL/ACTL	<1983	311
18039.30y	38.96430	llldos	LLNL/ACTL	<1983	337
18040.26y	39.61910	532dos	ENDF/B-V	1979	3861
18040.30y	39.96240	llldos	LLNL/ACTL	<1983	347
18041.30y	40.96450	llldos	LLNL/ACTL	<1983	317
18042.30y	41.96300	llldos	LLNL/ACTL	<1983	291
18043.30y	42.96570	llldos	LLNL/ACTL	<1983	295
Z = 19 ********** Potassium **********					
19038.30y	37.96910	llldos	LLNL/ACTL	<1983	603
19039.30y	38.96370	llldos	LLNL/ACTL	<1983	405
19040.30y	39.96400	llldos	LLNL/ACTL	<1983	675
19041.26y	40.60990	532dos	ENDF/B-V	1979	33
19041.30y	40.96180	llldos	LLNL/ACTL	<1983	369
19042.30y	41.96240	llldos	LLNL/ACTL	<1983	343
19043.30y	42.96070	llldos	LLNL/ACTL	<1983	277
19044.30y	43.96160	llldos	LLNL/ACTL	<1983	275
19045.30y	44.96070	llldos	LLNL/ACTL	<1983	283
19046.30y	45.96200	llldos	LLNL/ACTL	<1983	283

ZAID	AWR	Library	Source	Date	Length
Z = 20 ********** Calcium **********					
20039.30y	38.97070	llldos	LLNL/ACTL	<1983	601
20040.30y	39.96260	llldos	LLNL/ACTL	<1983	309
20041.30y	40.96230	llldos	LLNL/ACTL	<1983	313
20042.30y	41.95860	llldos	LLNL/ACTL	<1983	285
20043.30y	42.95880	llldos	LLNL/ACTL	<1983	295
20044.30y	43.95550	llldos	LLNL/ACTL	<1983	269
20045.30y	44.95620	llldos	LLNL/ACTL	<1983	271
20046.30y	45.95370	llldos	LLNL/ACTL	<1983	255
20047.30y	46.95450	llldos	LLNL/ACTL	<1983	243
20048.30y	47.95250	llldos	LLNL/ACTL	<1983	239
20049.30y	48.95570	llldos	LLNL/ACTL	<1983	229
Z = 21 ********** Scandium **********					
21044.30y	43.95940	llldos	LLNL/ACTL	<1983	313
21044.31y	43.95940	llldos	LLNL/ACTL	<1983	311
21045.24y	44.56790	531dos	ENDF/B-V	1979	20179
21045.26y	44.56790	532dos	ENDF/B-V	1979	20211
21045.30y	44.95590	llldos	LLNL/ACTL	<1983	547
21046.30y	45.95520	llldos	LLNL/ACTL	<1983	323
21046.31y	45.95520	llldos	LLNL/ACTL	<1983	323
21047.30y	46.95240	llldos	LLNL/ACTL	<1983	331
21048.30y	47.95220	llldos	LLNL/ACTL	<1983	325
Z = 22 ********** Titanium **********					
22045.30y	44.95810	llldos	LLNL/ACTL	<1983	449
22046.24y	45.55780	531dos	ENDF/B-V	1977	53
22046.26y	45.55780	532dos	ENDF/B-V	1977	53
22046.30y	45.95260	llldos	LLNL/ACTL	<1983	391
22047.24y	46.54800	531dos	ENDF/B-V	1977	209
22047.26y	46.54800	532dos	ENDF/B-V	1977	209
22047.30y	46.95180	llldos	LLNL/ACTL	<1983	419
22048.24y	47.53600	531dos	ENDF/B-V	1977	145
22048.26y	47.53600	532dos	ENDF/B-V	1977	177
22048.30y	47.94790	llldos	LLNL/ACTL	<1983	415
22049.30y	48.94790	llldos	LLNL/ACTL	<1983	409
22050.26y	49.57000	532dos	ENDF/B-V	1979	33
22050.30y	49.94480	llldos	LLNL/ACTL	<1983	345
22051.30y	50.94660	llldos	LLNL/ACTL	<1983	389

ZAID	AWR	Library	Source	Date	Length
Z = 23 ********** Vanadium **********					
23047.30y	46.95490	llldos	LLNL/ACTL	<1983	209
23048.30y	47.95230	llldos	LLNL/ACTL	<1983	399
23049.30y	48.94850	llldos	LLNL/ACTL	<1983	423
23050.30y	49.94720	llldos	LLNL/ACTL	<1983	407
23051.30y	50.94400	llldos	LLNL/ACTL	<1983	357
23052.30y	51.94480	llldos	LLNL/ACTL	<1983	401
Z = 24 ********** Chromium **********					
24049.30y	48.95130	llldos	LLNL/ACTL	<1983	377
24050.26y	49.51650	532dos	ENDF/B-V	1979	7405
24050.30y	49.94600	llldos	LLNL/ACTL	<1983	435
24051.30y	50.94480	llldos	LLNL/ACTL	<1983	377
24052.26y	51.49380	532dos	ENDF/B-V	1979	27
24052.30y	51.94050	llldos	LLNL/ACTL	<1983	417
24053.30y	52.94060	llldos	LLNL/ACTL	<1983	425
24054.30y	53.93890	llldos	LLNL/ACTL	<1983	461
24055.30y	54.94080	llldos	LLNL/ACTL	<1983	419
24056.30y	55.94070	llldos	LLNL/ACTL	<1983	297
Z = 25 ********** Manganese **********					
25051.30y	50.94820	llldos	LLNL/ACTL	<1983	417
25052.30y	51.94560	llldos	LLNL/ACTL	<1983	379
25053.30y	52.94130	llldos	LLNL/ACTL	<1983	425
25054.30y	53.94040	llldos	LLNL/ACTL	<1983	391
25055.24y	54.46610	531dos	ENDF/B-V	1977	119
25055.30y	54.93800	llldos	LLNL/ACTL	<1983	435
25056.30y	55.93890	llldos	LLNL/ACTL	<1983	423
25057.30y	56.93830	llldos	LLNL/ACTL	<1983	419
25058.30y	57.93970	llldos	LLNL/ACTL	<1983	285
Z = 26 ********** Iron **********					
26053.30y	52.94530	llldos	LLNL/ACTL	<1983	387
26054.24y	53.47620	531dos	ENDF/B-V	1979	517
26054.26y	53.47600	532dos	ENDF/B-V	1978	21563
26054.30y	53.93960	llldos	LLNL/ACTL	<1983	457
26055.30y	54.93830	llldos	LLNL/ACTL	<1983	373
26056.24y	55.45400	531dos	ENDF/B-V	1978	449
26056.26y	55.45400	532dos	ENDF/B-V	1978	581

ZAID	AWR	Library	Source	Date	Length
26056.30y	55.93490	llldos	LLNL/ACTL	<1983	415
26057.30y	56.93540	llldos	LLNL/ACTL	<1983	447
26058.24y	57.43560	531dos	ENDF/B-V	1979	7077
26058.26y	57.43560	532dos	ENDF/B-V	1979	7097
26058.30y	57.93330	llldos	LLNL/ACTL	<1983	431
26059.30y	58.93490	llldos	LLNL/ACTL	<1983	397
26060.30y	59.93400	llldos	LLNL/ACTL	<1983	285
Z = 27 ********** Cobalt **********					
27057.30y	56.93630	llldos	LLNL/ACTL	<1983	629
27058.30y	57.93580	llldos	LLNL/ACTL	<1983	531
27058.31y	57.93580	llldos	LLNL/ACTL	<1983	569
27059.30y	58.93320	llldos	LLNL/ACTL	<1983	657
27060.30y	59.93380	llldos	LLNL/ACTL	<1983	435
27060.31y	59.93380	llldos	LLNL/ACTL	<1983	499
27061.30y	60.93250	llldos	LLNL/ACTL	<1983	613
27062.30y	61.93400	llldos	LLNL/ACTL	<1983	463
27062.31y	61.93400	llldos	LLNL/ACTL	<1983	519
27063.30y	62.93360	llldos	LLNL/ACTL	<1983	339
27064.30y	63.93580	llldos	LLNL/ACTL	<1983	323
Z = 28 ********** Nickel **********					
28057.30y	56.93980	llldos	LLNL/ACTL	<1983	441
28058.24y	57.43760	531dos	ENDF/B-V	1977	411
28058.26y	57.43760	532dos	ENDF/B-V	1978	4079
28058.30y	57.93530	llldos	LLNL/ACTL	<1983	509
28059.30y	58.93430	llldos	LLNL/ACTL	<1983	513
28060.24y	59.41590	531dos	ENDF/B-V	1977	435
28060.26y	59.41590	532dos	ENDF/B-V	1978	479
28060.30y	59.93080	llldos	LLNL/ACTL	<1983	503
28061.30y	60.93110	llldos	LLNL/ACTL	<1983	489
28062.26y	61.39630	532dos	ENDF/B-V	1978	3847
8062.30y	61.92830	llldos	LLNL/ACTL	<1983	459
28063.30y	62.92970	llldos	LLNL/ACTL	<1983	375
28064.30y	63.92800	llldos	LLNL/ACTL	<1983	397
28065.30y	64.93010	llldos	LLNL/ACTL	<1983	345
Z = 29 ********** Copper **********					
29062.30y	61.93260	llldos	LLNL/ACTL	<1983	507
29063.24y	62.93000	531dos	ENDF/B-V	1978	3375

ZAID	AWR	Library	Source	Date	Length
29063.26y	62.93000	532dos	ENDF/B-V	1978	3615
29063.30y	62.92960	llldos	LLNL/ACTL	<1983	513
29064.30y	63.92980	llldos	LLNL/ACTL	<1983	437
29065.24y	64.92800	531dos	ENDF/B-V	1978	49
29065.26y	64.92800	532dos	ENDF/B-V	1978	49
29065.30y	64.92780	llldos	LLNL/ACTL	<1983	563
29066.30y	65.92890	llldos	LLNL/ACTL	<1983	397
Z = 30 ********** Zinc **********					
30064.30y	63.92910	llldos	LLNL/ACTL	<1983	555
30066.30y	65.92600	llldos	LLNL/ACTL	<1983	561
30067.30y	66.92710	llldos	LLNL/ACTL	<1983	411
30068.30y	67.92480	llldos	LLNL/ACTL	<1983	643
30070.30y	69.92530	llldos	LLNL/ACTL	<1983	619
Z = 31 ********** Gallium **********					
31069.30y	68.92560	llldos	LLNL/ACTL	<1983	197
31071.30y	70.92470	llldos	LLNL/ACTL	<1983	419
Z = 32 ********** Germanium **********					
32070.30y	69.92420	llldos	LLNL/ACTL	<1983	405
32072.30y	71.92210	llldos	LLNL/ACTL	<1983	423
32073.30y	72.92350	llldos	LLNL/ACTL	<1983	431
32074.30y	73.92120	llldos	LLNL/ACTL	<1983	629
32076.30y	75.92140	llldos	LLNL/ACTL	<1983	623
Z = 33 ********** Arsenic **********					
33075.30y	74.92160	llldos	LLNL/ACTL	<1983	987
Z = 34 ********** Selenium **********					
34074.30y	73.92250	llldos	LLNL/ACTL	<1983	159
34076.30y	75.91920	llldos	LLNL/ACTL	<1983	177
34080.30y	79.91650	llldos	LLNL/ACTL	<1983	205
34082.30y	81.91670	llldos	LLNL/ACTL	<1983	223
Z = 35 ********** Bromine **********					
35079.30y	78.91830	llldos	LLNL/ACTL	<1983	263
35081.30y	80.91630	llldos	LLNL/ACTL	<1983	695

ZAID	AWR	Library	Source	Date	Length
Z = 37 ********** Rubidium **********					
37085.30y	84.91180	llldos	LLNL/ACTL	<1983	193
37087.30y	86.90920	llldos	LLNL/ACTL	<1983	199
Z = 38 ********** Strontium **********					
38084.30y	83.91340	llldos	LLNL/ACTL	<1983	163
38086.30y	85.90930	llldos	LLNL/ACTL	<1983	33
Z = 39 ********** Yttrium **********					
39086.70y	85.177000	super			457
39087.70y	86.164000	super			697
39087.71y	86.164000	super			701
39088.70y	87.154000	super			747
39088.71y	87.154000	super			727
39088.72y	87.154000	super			727
39089.30y	88.90590	llldos	LLNL/ACTL	<1983	419
39089.70y	88.142000	super			565
39089.71y	88.142000	super			607
39090.70y	89.135000	super			433
39091.70y	90.126000	super			411
39092.70y	91.120000	super			311
Z = 40 ********** Zirconium **********					
40089.30y	88.90890	llldos	LLNL/ACTL	<1983	321
40090.26y	89.13200	532dos	ENDF/B-V	1976	37
40090.30y	89.90470	llldos	LLNL/ACTL	<1983	385
40091.30y	90.90560	llldos	LLNL/ACTL	<1983	407
40092.26y	91.11200	532dos	ENDF/B-V	1976	3821
40092.30y	91.90500	llldos	LLNL/ACTL	<1983	431
40093.30y	92.90650	llldos	LLNL/ACTL	<1983	371
40094.26y	93.09600	532dos	ENDF/B-V	1976	5255
40094.30y	93.90630	llldos	LLNL/ACTL	<1983	417
40095.30y	94.90800	llldos	LLNL/ACTL	<1983	375
40096.30y	95.90830	llldos	LLNL/ACTL	<1983	57
40097.30y	96.91090	llldos	LLNL/ACTL	<1983	339
Z = 41 ********** Niobium **********					
41091.30y	90.90700	llldos	LLNL/ACTL	<1983	491
41091.31y	90.90700	llldos	LLNL/ACTL	<1983	491

ZAID	AWR	Library	Source	Date	Length
41092.30y	91.90720	llldos	LLNL/ACTL	<1983	285
41092.31y	91.90720	llldos	LLNL/ACTL	<1983	285
41093.30y	92.90640	llldos	LLNL/ACTL	<1983	493
41094.30y	93.90730	llldos	LLNL/ACTL	<1983	331
41095.30y	94.90680	llldos	LLNL/ACTL	<1983	333
41096.30y	95.90810	llldos	LLNL/ACTL	<1983	335
41097.30y	96.90810	llldos	LLNL/ACTL	<1983	339
41098.30y	97.91030	llldos	LLNL/ACTL	<1983	341
41100.30y	99.91420	llldos	LLNL/ACTL	<1983	349
Z = 42 ********** Molybdenum **********					
42090.30y	89.91390	llldos	LLNL/ACTL	<1983	261
42091.30y	90.91180	llldos	LLNL/ACTL	<1983	281
42092.26y	91.21000	532dos	ENDF/B-V	1980	7815
42092.30y	91.90680	llldos	LLNL/ACTL	<1983	537
42093.30y	92.90680	llldos	LLNL/ACTL	<1983	429
42093.31y	92.90680	llldos	LLNL/ACTL	<1983	461
42094.30y	93.90510	llldos	LLNL/ACTL	<1983	443
42095.30y	94.90580	llldos	LLNL/ACTL	<1983	523
42096.30y	95.90470	llldos	LLNL/ACTL	<1983	501
42097.30y	96.90600	llldos	LLNL/ACTL	<1983	427
42098.26y	97.06440	532dos	ENDF/B-V	1980	6489
42098.30y	97.90540	llldos	LLNL/ACTL	<1983	421
42099.30y	98.90770	llldos	LLNL/ACTL	<1983	445
42100.26y	99.04920	532dos	ENDF/B-V	1980	4971
42100.30y	99.90750	llldos	LLNL/ACTL	<1983	427
42101.30y	100.91000	llldos	LLNL/ACTL	<1983	447
Z = 43 ********** Technetium **********					
43099.30y	98.90620	llldos	LLNL/ACTL	<1983	469
43099.31y	98.90620	llldos	LLNL/ACTL	<1983	469
Z = 45 ********** Rhodium **********					
45103.30y	102.90600	llldos	LLNL/ACTL	<1983	275
Z = 46 ********** Palladium **********					
46110.30y	109.90500	llldos	LLNL/ACTL	<1983	417
Z = 47 ********** Silver **********					
47106.30y	105.90700	llldos	LLNL/ACTL	<1983	263

ZAID	AWR	Library	Source	Date	Length
47106.31y	105.90700	llldos	LLNL/ACTL	<1983	265
47107.30y	106.90500	llldos	LLNL/ACTL	<1983	517
47108.30y	107.90600	llldos	LLNL/ACTL	<1983	275
47108.31y	107.90600	llldos	LLNL/ACTL	<1983	275
47109.30y	108.90500	llldos	LLNL/ACTL	<1983	583
47110.30y	109.90600	llldos	LLNL/ACTL	<1983	277
47110.31y	109.90600	llldos	LLNL/ACTL	<1983	281
Z = 48 ********** Cadmium **********					
48106.30y	105.90600	llldos	LLNL/ACTL	<1983	177
48111.30y	110.90400	llldos	LLNL/ACTL	<1983	317
48112.30y	111.90300	llldos	LLNL/ACTL	<1983	221
48116.30y	115.90500	llldos	LLNL/ACTL	<1983	231
Z = 49 ********** Indium **********					
49113.30y	112.90400	llldos	LLNL/ACTL	<1983	861
49115.24y	113.92000	531dos	ENDF/B-V	1978	26009
49115.26y	113.92000	532dos	ENDF/B-V	1978	26009
49115.30y	114.90400	llldos	LLNL/ACTL	<1983	1265
Z = 50 ********** Tin **********					
50112.30y	111.90500	llldos	LLNL/ACTL	<1983	789
50114.30y	113.90300	llldos	LLNL/ACTL	<1983	435
50115.30y	114.90300	llldos	LLNL/ACTL	<1983	389
50116.30y	115.90200	llldos	LLNL/ACTL	<1983	603
50117.30y	116.90300	llldos	LLNL/ACTL	<1983	313
50118.30y	117.90200	llldos	LLNL/ACTL	<1983	745
50119.30y	118.90300	llldos	LLNL/ACTL	<1983	311
50120.26y	118.87200	532dos	ENDF/B-V	1974	12881
50120.30y	119.90200	llldos	LLNL/ACTL	<1983	309
50122.26y	120.85600	532dos	ENDF/B-V	1974	1891
50122.30y	121.90300	llldos	LLNL/ACTL	<1983	275
50124.26y	122.84100	532dos	ENDF/B-V	1974	1693
50124.30y	123.90500	llldos	LLNL/ACTL	<1983	485
Z = 51 ********** Antimony **********					
51121.30y	120.90400	llldos	LLNL/ACTL	<1983	811
51123.30y	122.90400	llldos	LLNL/ACTL	<1983	1013

ZAID	AWR	Library	Source	Date	Length
Z = 53 ********** Iodine **********					
53127.24y	125.81400	531dos	ENDF/B-V	1972	115
53127.26y	125.81400	532dos	ENDF/B-V	1980	14145
53127.30y	126.90400	llldos	LLNL/ACTL	<1983	221
Z = 55 ********** Cesium **********					
55133.30y	132.90500	llldos	LLNL/ACTL	<1983	215
Z = 57 ********** Lanthanum **********					
57139.26y	137.71300	532dos	ENDF/B-V	1980	15475
Z = 58 ********** Cerium **********					
58140.30y	139.90500	llldos	LLNL/ACTL	<1983	427
58142.30y	141.90900	llldos	LLNL/ACTL	<1983	265
Z = 59 ********** Praseodymium **********					
59141.30y	140.90800	llldos	LLNL/ACTL	<1983	215
Z = 60 ********** Neodymium **********					
60142.30y	141.90800	llldos	LLNL/ACTL	<1983	207
60148.30y	147.91700	llldos	LLNL/ACTL	<1983	255
60150.30y	149.92100	llldos	LLNL/ACTL	<1983	259
Z = 62 ********** Samarium **********					
62144.30y	143.91200	llldos	LLNL/ACTL	<1983	189
62148.30y	147.91500	llldos	LLNL/ACTL	<1983	245
62152.30y	151.92000	llldos	LLNL/ACTL	<1983	237
62154.30y	153.92200	llldos	LLNL/ACTL	<1983	247
Z = 63 ********** Europium **********					
63151.30y	150.92000	llldos	LLNL/ACTL	<1983	731
63153.30y	152.92100	llldos	LLNL/ACTL	<1983	565
Z = 64 ********** Gadolinium **********					
64150.30y	149.91900	llldos	LLNL/ACTL	<1983	237
64151.30y	150.92000	llldos	LLNL/ACTL	<1983	241
Z = 66 ********** Dysprosium **********					
66164.26y	162.52000	532dos	ENDF/B-V	1967	581

ZAID	AWR	Library	Source	Date	Length
Z = 67 ********** Holmium **********					
67163.30y	162.92900	llldos	LLNL/ACTL	<1983	533
67164.30y	163.93000	llldos	LLNL/ACTL	<1983	327
67164.31y	163.93000	llldos	LLNL/ACTL	<1983	327
67165.30y	164.93000	llldos	LLNL/ACTL	<1983	589
67166.30y	165.93200	llldos	LLNL/ACTL	<1983	333
67166.31y	165.93200	llldos	LLNL/ACTL	<1983	333
Z = 69 ********** Thulium **********					
69166.70y	164.510000	super			95
69167.70y	165.500000	super			105
69169.70y	166.490000	super			107
69169.30y	168.93400	llldos	LLNL/ACTL	<1983	453
69169.70y	167.480000	super			105
69170.70y	168.480000	super			105
69171.70y	169.470000	super			103
69172.70y	170.460000	super			107
69173.70y	171.450000	super			105
Z = 71 ********** Lutetium **********					
71173.30y	172.93900	llldos	LLNL/ACTL	<1983	587
71174.30y	173.94000	llldos	LLNL/ACTL	<1983	417
71174.31y	173.94000	llldos	LLNL/ACTL	<1983	465
71175.30y	174.94100	llldos	LLNL/ACTL	<1983	559
71176.30y	175.94300	llldos	LLNL/ACTL	<1983	621
71176.31y	175.94300	llldos	LLNL/ACTL	<1983	637
71177.30y	176.94400	llldos	LLNL/ACTL	<1983	573
71177.31y	176.94400	llldos	LLNL/ACTL	<1983	573
Z = 72 ********** Hafnium **********					
72174.30y	173.94000	llldos	LLNL/ACTL	<1983	147
72175.30y	174.94100	llldos	LLNL/ACTL	<1983	121
72176.30y	175.94100	llldos	LLNL/ACTL	<1983	153
72177.30y	176.94300	llldos	LLNL/ACTL	<1983	157
72178.30y	177.94400	llldos	LLNL/ACTL	<1983	153
72179.30y	178.94600	llldos	LLNL/ACTL	<1983	433
72180.30y	179.94700	llldos	LLNL/ACTL	<1983	409
72181.30y	180.94900	llldos	LLNL/ACTL	<1983	365
72183.30y	182.95400	llldos	LLNL/ACTL	<1983	373

ZAID	AWR	Library	Source	Date	Length
Z = 73 ********** Tantalum **********					
73179.30y	178.94600	llldos	LLNL/ACTL	<1983	629
73180.30y	179.94700	llldos	LLNL/ACTL	<1983	523
73180.31y	179.94700	llldos	LLNL/ACTL	<1983	435
73181.30y	180.94800	llldos	LLNL/ACTL	<1983	715
73182.30y	181.95000	llldos	LLNL/ACTL	<1983	435
73182.31y	181.95000	llldos	LLNL/ACTL	<1983	447
73183.30y	182.95100	llldos	LLNL/ACTL	<1983	425
73184.30y	183.95400	llldos	LLNL/ACTL	<1983	371
73186.30y	185.95900	llldos	LLNL/ACTL	<1983	377
Z = 74 ********** Tungsten **********					
74179.30y	178.94700	llldos	LLNL/ACTL	<1983	263
74180.30y	179.94700	llldos	LLNL/ACTL	<1983	397
74181.30y	180.94800	llldos	LLNL/ACTL	<1983	263
74182.30y	181.94800	llldos	LLNL/ACTL	<1983	415
74183.30y	182.95000	llldos	LLNL/ACTL	<1983	499
74184.30y	183.95100	llldos	LLNL/ACTL	<1983	443
74185.30y	184.95300	llldos	LLNL/ACTL	<1983	267
74186.30y	185.95400	llldos	LLNL/ACTL	<1983	413
74187.30y	186.95700	llldos	LLNL/ACTL	<1983	279
74188.30y	187.95800	llldos	LLNL/ACTL	<1983	271
Z = 75 ********** Rhenium **********					
75184.30y	183.95300	llldos	LLNL/ACTL	<1983	331
75184.31y	183.95300	llldos	LLNL/ACTL	<1983	335
75185.30y	184.95300	llldos	LLNL/ACTL	<1983	373
75186.30y	185.95500	llldos	LLNL/ACTL	<1983	381
75187.30y	186.95600	llldos	LLNL/ACTL	<1983	547
75188.30y	187.95800	llldos	LLNL/ACTL	<1983	339
75188.31y	187.95800	llldos	LLNL/ACTL	<1983	341
Z = 77 ********** Iridium **********					
77188.70y	186.340000	super			319
77189.70y	187.330000	super			335
77190.70y	188.330000	super			381
77191.30y	190.96100	llldos	LLNL/ACTL	<1983	237
77191.70y	189.320100	super			393
77192.70y	191.310000	super			525

ZAID	AWR	Library	Source	Date	Length
77193.30y	192.96300	llldos	LLNL/ACTL	<1983	243
77193.70y	191.310000	super			367
77193.71y	191.350000	super			471
77194.30y	193.96500	llldos	LLNL/ACTL	<1983	421
77194.70y	192.300000	super			401
77195.70y	193.290000	super			385
Z = 78 ********** Platinum **********					
78190.30y	189.96000	llldos	LLNL/ACTL	<1983	151
78192.30y	191.96100	llldos	LLNL/ACTL	<1983	153
78193.30y	192.96300	llldos	LLNL/ACTL	<1983	123
78193.31y	192.96300	llldos	LLNL/ACTL	<1983	123
78194.30y	193.96300	llldos	LLNL/ACTL	<1983	211
78195.30y	194.96500	llldos	LLNL/ACTL	<1983	157
78196.30y	195.96500	llldos	LLNL/ACTL	<1983	157
78197.30y	196.96700	llldos	LLNL/ACTL	<1983	427
78197.31y	196.96700	llldos	LLNL/ACTL	<1983	129
78198.30y	197.96800	llldos	LLNL/ACTL	<1983	183
78199.30y	198.97100	llldos	LLNL/ACTL	<1983	99
78199.31y	198.97100	llldos	LLNL/ACTL	<1983	99
Z = 79 ********** Gold **********					
79193.30y	192.96400	llldos	LLNL/ACTL	<1983	209
79194.30y	193.96500	llldos	LLNL/ACTL	<1983	261
79195.30y	194.96500	llldos	LLNL/ACTL	<1983	261
79196.30y	195.96700	llldos	LLNL/ACTL	<1983	265
79196.31y	195.96700	llldos	LLNL/ACTL	<1983	265
79197.30y	196.96700	llldos	LLNL/ACTL	<1983	307
79198.30y	197.96800	llldos	LLNL/ACTL	<1983	265
79199.30y	198.96900	llldos	LLNL/ACTL	<1983	269
79200.30y	199.97100	llldos	LLNL/ACTL	<1983	39
Z = 80 ********** Mercury **********					
80202.30y	201.97100	llldos	LLNL/ACTL	<1983	381
80203.30y	202.97300	llldos	LLNL/ACTL	<1983	379
80204.30y	203.97300	llldos	LLNL/ACTL	<1983	365
Z = 81 ********** Thallium **********					
81202.30y	201.97200	llldos	LLNL/ACTL	<1983	377
81203.30y	202.97200	llldos	LLNL/ACTL	<1983	375

ZAID	AWR	Library	Source	Date	Length
81204.30y	203.97400	llldos	LLNL/ACTL	<1983	373
81205.30y	204.97400	llldos	LLNL/ACTL	<1983	369
Z = 82 ********** Lead **********					
82203.30y	202.97300	llldos	LLNL/ACTL	<1983	257
82204.30y	203.97300	llldos	LLNL/ACTL	<1983	405
82205.30y	204.97400	llldos	LLNL/ACTL	<1983	257
82206.30y	205.97400	llldos	LLNL/ACTL	<1983	347
82207.30y	206.97600	llldos	LLNL/ACTL	<1983	333
82208.30y	207.97700	llldos	LLNL/ACTL	<1983	263
82209.30y	208.98100	llldos	LLNL/ACTL	<1983	279
82210.30y	209.98400	llldos	LLNL/ACTL	<1983	351
Z = 83 ********** Bismuth **********					
83208.30y	207.98000	llldos	LLNL/ACTL	<1983	409
83209.30y	208.98000	llldos	LLNL/ACTL	<1983	551
83210.30y	209.98400	llldos	LLNL/ACTL	<1983	421
83210.31y	209.98400	llldos	LLNL/ACTL	<1983	421
Z = 84 ********** Polonium **********					
84210.30y	209.98300	llldos	LLNL/ACTL	<1983	441
Z = 90 ********** Thorium **********					
90230.30y	230.03300	llldos	LLNL/ACTL	<1983	209
90231.30y	231.03600	llldos	LLNL/ACTL	<1983	599
90232.30y	232.03800	llldos	LLNL/ACTL	<1983	347
90233.30y	233.04200	llldos	LLNL/ACTL	<1983	561
90234.30y	234.04400	llldos	LLNL/ACTL	<1983	37
Z = 91 ********** Protactinium **********					
91231.26y	229.05000	532dos	ENDF/B-V	1978	2861
91233.26y	231.03800	532dos	ENDF/B-V	1978	73
91233.30y	233.04000	llldos	LLNL/ACTL	<1983	361
Z = 92 ********** Uranium **********					
92233.26y	231.04300	532dos	ENDF/B-V	1978	75
92233.30y	233.04000	llldos	LLNL/ACTL	<1983	461
92234.30y	234.04100	llldos	LLNL/ACTL	<1983	393
92235.30y	235.04400	llldos	LLNL/ACTL	<1983	4629
92236.30y	236.04600	llldos	LLNL/ACTL	<1983	395

ZAID	AWR	Library	Source	Date	Length
92237.30y	237.04900	llldos	LLNL/ACTL	<1983	609
92238.30y	238.05100	llldos	LLNL/ACTL	<1983	3103
92239.30y	239.05400	llldos	LLNL/ACTL	<1983	825
92240.30y	240.05700	llldos	LLNL/ACTL	<1983	389
Z = 93 ********** Neptunium **********					
93237.30y	237.04800	llldos	LLNL/ACTL	<1983	629
Z = 94 ********** Plutonium **********					
94237.30y	237.04800	llldos	LLNL/ACTL	<1983	487
94238.30y	238.05000	llldos	LLNL/ACTL	<1983	459
94239.30y	239.05200	llldos	LLNL/ACTL	<1983	497
94240.30y	240.05400	llldos	LLNL/ACTL	<1983	479
94241.30y	241.05700	llldos	LLNL/ACTL	<1983	559
94242.30y	242.05900	llldos	LLNL/ACTL	<1983	505
94243.30y	243.06200	llldos	LLNL/ACTL	<1983	511
Z = 95 ********** Americium **********					
95241.30y	241.05700	llldos	LLNL/ACTL	<1983	673
95242.30y	242.06000	llldos	LLNL/ACTL	<1983	473
95243.30y	243.06100	llldos	LLNL/ACTL	<1983	431
Z = 96 ********** Curium **********					
96242.30y	242.05900	llldos	LLNL/ACTL	<1983	467
96243.30y	243.06100	llldos	LLNL/ACTL	<1983	465
96244.30y	244.06300	llldos	LLNL/ACTL	<1983	483
96245.30y	245.06500	llldos	LLNL/ACTL	<1983	465
96246.30y	246.06700	llldos	LLNL/ACTL	<1983	491
96247.30y	247.07000	llldos	LLNL/ACTL	<1983	491
96248.30y	248.07200	llldos	LLNL/ACTL	<1983	495
Z = 97 ********** Berkelium **********					
97249.30y	249.07500	llldos	LLNL/ACTL	<1983	545
Z = 98 ********** Californium **********					
98249.30y	249.07500	llldos	LLNL/ACTL	<1983	491
98250.30y	250.07600	llldos	LLNL/ACTL	<1983	335
98251.30y	251.08000	llldos	LLNL/ACTL	<1983	485
98252.30y	252.08200	llldos	LLNL/ACTL	<1983	467

G.8 ELECTRON DATA

ZAID	Electron AWR	Library Name	Length words	ZAID	Electron AWR	Library Name	Length words
Z = 1 ***** Hydrogen *****				Z = 51 ***** Antimony *****			
1000.01e	0.999317	el	478	51000.01e	120.712028	el	478
1000.03e	0.999317	el03	2329	51000.03e	120.712028	el03	2359
Z = 2 ***** Helium *****				Z = 52 ***** Tellurium *****			
2000.01e	3.968217	el	478	52000.01e	126.527819	el	478
2000.03e	3.968217	el03	2329	52000.03e	126.527819	el03	2359
Z = 3 ***** Lithium *****				Z = 53 ***** Iodine *****			
3000.01e	6.881312	el	478	53000.01e	125.814300	el	478
3000.03e	6.881312	el03	2331	53000.03e	125.814300	el03	2359
Z = 4 ***** Beryllium *****				Z = 54 ***** Xenon *****			
4000.01e	8.934763	el	478	54000.01e	130.165202	el	478
4000.03e	8.934763	el03	2331	54000.03e	130.165202	el03	2361
Z = 5 ***** Boron *****				Z = 55 ***** Cesium *****			
5000.01e	10.717168	el	478	55000.01e	131.763705	el	478
5000.03e	10.717168	el03	2331	55000.03e	131.763705	el03	2363
Z = 6 ***** Carbon *****				Z = 56 ***** Barium *****			
6000.01e	11.907955	el	478	56000.01e	136.146809	el	478
6000.03e	11.907955	el03	2333	56000.03e	136.146809	el03	2363
Z = 7 ***** Nitrogen *****				Z = 57 ***** Lanthanum *****			
7000.01e	13.886438	el	478	57000.01e	137.712194	el	478
7000.03e	13.886438	el03	2333	57000.03e	137.712194	el03	2363
Z = 8 ***** Oxygen *****				Z = 58 ***** Cerium *****			
8000.01e	15.861942	el	478	58000.01e	138.911207	el	478
8000.03e	15.861942	el03	2333	58000.03e	138.911207	el03	2365
Z = 9 ***** Fluorine *****				Z = 59 ***** Praseodymium *****			
9000.01e	18.835197	el	478	59000.01e	139.697185	el	478
9000.03e	18.835197	el03	2333	59000.03e	139.697185	el03	2365

ZAID	Electron AWR	Library Name	Length words	ZAID	Electron AWR	Library Name	Length words
Z = 10 ***** Neon *****				Z = 60 ***** Praseodymium *****			
10000.01e	20.006093	el	478	60000.01e	142.997075	el	478
10000.03e	20.006093	el03	2335	60000.03e	142.997075	el03	2365
Z = 11 ***** Sodium *****				Z = 61 ***** Neodymium *****			
11000.01e	22.792275	el	478	61000.01e	143.667877	el	478
11000.03e	22.792275	el03	2337	61000.03e	143.667877	el03	2365
Z = 12 ***** Magnesium *****				Z = 62 ***** Samarium *****			
12000.01e	24.096261	el	478	62000.01e	149.060207	el	478
12000.03e	24.096261	el03	2337	62000.03e	149.060207	el03	2365
Z = 13 ***** Aluminum *****				Z = 63 ***** Europium *****			
13000.01e	26.749756	el	478	63000.01e	150.657141	el	478
13000.03e	26.749756	el03	2337	63000.03e	150.657141	el03	2365
Z = 14 ***** Silicon *****				Z = 64 ***** Gadolinium *****			
14000.01e	27.844241	el	478	64000.01e	155.900158	el	478
14000.03e	27.844241	el03	2339	64000.03e	155.900158	el03	2365
Z = 15 ***** Phosphorus *****				Z = 65 ***** Terbium *****			
15000.01e	30.707682	el	478	65000.01e	157.560097	el	478
15000.03e	30.707682	el03	2339	65000.03e	157.560097	el03	2365
Z = 16 ***** Sulfur *****				Z = 66 ***** Dysprosium *****			
16000.01e	31.788823	el	478	66000.01e	161.098819	el	478
16000.03e	31.788823	el03	2339	66000.03e	161.098819	el03	2365
Z = 17 ***** Chlorine *****				Z = 67 ***** Holmium *****			
17000.01e	35.148180	el	478	67000.01e	163.513493	el	478
17000.03e	35.148180	el03	2339	67000.03e	163.513493	el03	2365
Z = 18 ***** Argon *****				Z = 68 ***** Erbium *****			
18000.01e	39.604489	el	478	68000.01e	165.825350	el	478
18000.03e	39.604489	el03	2341	68000.03e	165.825350	el03	2365
Z = 19 ***** Potassium *****				Z = 69 ***** Thulium *****			
19000.01e	38.762423	el	478	69000.01e	167.482990	el	478
19000.03e	38.762423	el03	2343	69000.03e	167.482990	el03	2365

ZAID	Electron AWR	Library Name	Length words	ZAID	Electron AWR	Library Name	Length words
Z = 20 ***** Calcium *****				Z = 70 ***** Ytterbium *****			
20000.01e	39.733857	el	478	70000.01e	171.537027	el	478
20000.03e	39.733857	el03	2343	70000.03e	171.537027	el03	2367
Z = 21 ***** Scandium *****				Z = 71 ***** Lutetium *****			
21000.01e	44.569718	el	478	71000.01e	173.463777	el	478
21000.03e	44.569718	el03	2343	71000.03e	173.463777	el03	2367
Z = 22 ***** Titanium *****				Z = 72 ***** Hafnium *****			
22000.01e	47.455747	el	478	72000.01e	176.956288	el	478
22000.03e	47.455747	el03	2345	72000.03e	176.956288	el03	2367
Z = 23 ***** Vanadium *****				Z = 73 ***** Tantalum *****			
23000.01e	50.503856	el	478	73000.01e	179.393456	el	478
23000.03e	50.503856	el03	2345	73000.03e	179.393456	el03	2367
Z = 24 ***** Chromium *****				Z = 74 ***** Tungsten *****			
24000.01e	51.549253	el	478	74000.01e	182.269548	el	478
24000.03e	51.549253	el03	2345	74000.03e	182.269548	el03	2367
Z = 25 ***** Manganese *****				Z = 75 ***** Rhenium *****			
25000.01e	54.466099	el	478	75000.01e	184.607108	el	478
25000.03e	54.466099	el03	2345	75000.03e	184.607108	el03	2369
Z = 26 ***** Iron *****				Z = 76 ***** Osmium *****			
26000.01e	55.366466	el	478	76000.01e	188.605651	el	478
26000.03e	55.366466	el03	2345	76000.03e	188.605651	el03	2369
Z = 27 ***** Cobalt *****				Z = 77 ***** Iridum *****			
27000.01e	58.426930	el	478	77000.01e	190.564832	el	478
27000.03e	58.426930	el03	2345	77000.03e	190.564832	el03	2369
Z = 28 ***** Nickel *****				Z = 78 ***** Platinum *****			
28000.01e	58.182641	el	478	78000.01e	193.404225	el	478
28000.03e	58.182641	el03	2347	78000.03e	193.404225	el03	2369
Z = 29 ***** Copper *****				Z = 79 ***** Gold *****			
29000.01e	62.999157	el	478	79000.01e	195.274513	el	478
29000.03e	62.999157	el03	2347	79000.03e	195.274513	el03	2371

APPENDIX G

ZAID	Electron AWR	Library Name	Length words	ZAID	Electron AWR	Library Name	Length words
Z = 30 ***** Zinc *****				Z = 80 ***** Mercury *****			
30000.01e	64.835472	el	478	80000.01e	198.875705	el	478
30000.03e	64.835472	el03	2347	80000.03e	198.875705	el03	2371
Z = 31 ***** Gallium *****				Z = 81 ***** Thallium *****			
31000.01e	69.124270	el	478	81000.01e	202.628033	el	478
31000.03e	69.124270	el03	2347	81000.03e	202.628033	el03	2373
Z = 32 ***** Germanium *****				Z = 82 ***** Lead *****			
32000.01e	72.008301	el	478	82000.01e	205.436151	el	478
32000.03e	72.008301	el03	2349	82000.03e	205.436151	el03	2373
Z = 33 ***** Arsenic *****				Z = 83 ***** Bismuth *****			
33000.01e	74.277979	el	478	83000.01e	207.185136	el	478
33000.03e	74.277979	el03	2349	83000.03e	207.185136	el03	2373
Z = 34 ***** Selenium *****				Z = 84 ***** Polonium *****			
34000.01e	78.310715	el	478	84000.01e	207.187152	el	478
34000.03e	78.310715	el03	2349	84000.03e	207.187152	el03	2373
Z = 35 ***** Bromine *****				Z = 85 ***** Polonium *****			
35000.01e	79.217113	el	478	85000.01e	208.183242	el	478
35000.03e	79.217113	el03	2349	85000.03e	208.183242	el03	2375
Z = 36 ***** Krypton *****				Z = 86 ***** Radon *****			
36000.01e	83.080137	el	478	86000.01e	220.110325	el	478
36000.03e	83.080137	el03	2351	86000.03e	220.110325	el03	2375
Z = 37 ***** Rubidium *****				Z = 87 ***** Francium *****			
37000.01e	84.733459	el	478	87000.01e	221.103876	el	478
37000.03e	84.733459	el03	2353	87000.03e	221.103876	el03	2377
Z = 38 ***** Strontium *****				Z = 88 ***** Radium *****			
38000.01e	86.864279	el	478	88000.01e	224.083728	el	478
38000.03e	86.864379	el03	2353	88000.03e	224.083728	el03	2377
Z = 39 ***** Yttrium *****				Z = 89 ***** Actinium *****			
39000.01e	88.142108	el	478	89000.01e	225.077462	el	478
39000.03e	88.142108	el03	2353	89000.03e	225.077462	el03	2377

ZAID	Electron AWR	Library Name	Length words	ZAID	Electron AWR	Library Name	Length words
Z = 40 ***** Zirconium *****				Z = 90 ***** Thorium *****			
40000.01e	90.439594	el	478	90000.01e	230.044724	el	478
40000.03e	90.439594	el03	2353	90000.03e	230.044724	el03	2377
Z = 41 ***** Niobium *****				Z = 91 ***** Protactinium *****			
41000.01e	92.108263	el	478	91000.01e	229.051160	el	478
41000.03e	92.108263	el03	2355	91000.03e	229.051160	el03	2379
Z = 42 ***** Molybdenum *****				Z = 92 ***** Uranium *****			
42000.01e	95.106691	el	478	92000.01e	235.984125	el	478
42000.03e	95.106691	el03	2353	92000.03e	235.984125	el03	2379
Z = 43 ***** Technetium *****				Z = 93 ***** Neptunium *****			
43000.01e	96.073885	el	478	93000.01e	235.011799	el	478
43000.03e	96.073885	el03	2355	93000.03e	235.011799	el03	2379
Z = 44 ***** Ruthenium *****				Z = 94 ***** Plutonium *****			
44000.01e	100.201894	el	478	94000.01e	241.967559	el	478
44000.03e	100.201894	el03	2355	94000.03e	241.967559	el03	2379
Z = 45 ***** Rhodium *****				Z = 95 ***** Americium *****			
45000.01e	102.021490	el	478				
45000.03e	102.021490	el03	2355	95000.03e	240.972982	el03	2379
Z = 46 ***** Palladium *****				Z = 96 ***** Curium *****			
46000.01e	105.513949	el	478				
46000.03e	150.513949	el03	2355	96000.03e	244.947545	el03	2379
Z = 47 ***** Silver *****				Z = 97 ***** Berkelium *****			
47000.01e	160.941685	el	478				
47000.03e	106.941685	el03	2357	97000.03e	244.947545	el03	2379
Z = 48 ***** Cadmium *****				Z = 98 ***** Californium *****			
48000.01e	111.442363	el	478				
48000.03	111.442363	el03	2357	98000.03e	248.923092	el03	2379
Z = 49 ***** Indium *****				Z = 99 ***** Einsteinium *****			
49000.01e	113.831536	el	478				
49000.03e	113.831536	el03	2357	99000.03e	249.91766	el03	2379

ZAID	Electron AWR	Library Name	Length words	ZAID	Electron AWR	Library Name	Length words
Z = 50 ***** Tin *****				Z = 100 ***** Fermium *****			
50000.01e	117.667336	el	478				
50000.03e	117.667336	el03	2359	100000.03e	254.88641	el03	2379

G.9 PROTON DATA

ZAID	Proton AWR	Library Name	Length words
Z = 1 ***** Hydrogen *****			
1001.24h	0.999170	la150h	15895
1002.24h	1.996800	la150h	5824
Z = 6 ***** Carbon *****			
6012.24h	11.896910	la150h	51762
Z = 7 ***** Nitrogen *****			
7014.24h	13.882780	la150h	71369
Z = 8 ***** Oxygen *****			
8016.24h	15.857510	la150h	54535
Z = 13 ***** Aluminum *****			
13027.24h	26.749770	la150h	86202
Z = 14 ***** Silicon *****			
14028.24h	27.736590	la150h	71809
14029.24h	28.727570	la150h	82243
14030.24h	29.716280	la150h	85018
Z = 15 ***** Phosphorus *****			
15031.24h	30.707680	la150h	85621
Z = 20 ***** Calcium *****			
20040.24h	36.619290	la150h	69252
Z = 24 ***** Chromium *****			
24050.24h	49.516990	la150h	108001

ZAID	Proton AWR	Library Name	Length words
24052.24h	51.494320	la150h	111226
24053.24h	52.485870	la150h	117028
24054.24h	53.475520	la150h	117594
Z = 26 ***** Iron *****			
26054.24h	53.476240	la150h	76355
26056.24h	55.454430	la150h	82212
26057.24h	56.446300	la150h	87558
Z = 28 ***** Nickel *****			
28058.24h	57.437650	la150h	109097
28060.24h	59.415960	la150h	112315
28061.24h	60.407630	la150h	117868
28062.24h	61.396360	la150h	115649
28064.24h	63.378800	la150h	118364
Z = 29 ***** Copper *****			
29063.24h	62.389000	la150h	91451
29065.24h	64.370030	la150h	96860
Z = 41 ***** Niobium *****			
41093.24h	92.108270	la150h	105451
Z = 74 ***** Tungsten *****			
74182.24h	180.385200	la150h	91147
74183.24h	181.378600	la150h	93696
74184.24h	182.370700	la150h	93014
74186.24h	187.356900	la150h	94210
Z = 80 ***** Mercury *****			
80196.24h	194.282000	la150h	116823
80198.24h	196.266000	la150h	118093
80199.24h	197.259000	la150h	119757
80200.24h	198.250000	la150h	118676
80201.24h	199.244000	la150h	120944
80202.24h	200.236000	la150h	119844
80204.24h	202.22100	la150h	119892
Z = 82 ***** Lead *****			
82206.24h	204.20500	la150h	89428

ZAID	Proton AWR	Library Name	Length words
82207.24h	205.197800	la150h	90779
82208.24h	206.190000	la150h	89961
Z = 83 ***** Bismuth *****			
83209.24h	207.185000	la150h	95609

G.10 REFERENCES

ADA00 K. J. Adams, "Electron Upgrade for MCNP4B," Los Alamos National Laboratory internal memorandum, X-5-RN(U)-00-14 (May 25, 2000).

BIG75 F. Biggs, L. B. Mendelsohn, and J. B. Mann, "Hartree-Fock Compton Profiles for the Elements," *Atomic Data and Nuclear Data Tables*, Volume 16, pp. 201–309 (1975).

CUL89 D. E. Cullen, M. H. Chen, J. H. Hubbell, S. T. Perkins, E. F. Plechaty, J. A. Rathkopf, and J. H. Scofield, "Tables and Graphs of Photon Interaction Cross Sections from 10 eV to 100 GeV Derived from the LLNL Evaluated Photon Data Library (EPDL)," Lawrence Livermore National Laboratory report UCRL-50400, Volume 6, Rev. 4, Part A: Z = 1 to 50 and Part B: Z = 51 to 100 (1989).

CUL97 D. E. Cullen, J. H. Hubbell, and L. D. Kissel, "EPDL97: The Evaluated Photon Data Library, '97 Version," Lawrence Livermore National Laboratory report, UCRL-50400, Volume 6, Rev. 5 (1997).

EVE73 C. J. Everett and E. D. Cashwell, "MCP Code Fluorescence Routine Discussion," Los Alamos National Laboratory report LA-5240-MS (1973).

FRA95 S. C. Frankle, "ENDL Fission Products, ENDL85 and ENDL92," LANL internal memorandum, XTM:95-254 (1995).

FRA96a S. C. Frankle, "Summary Documentation for the ENDL92 Continuous-Energy Neutron Data Library (Release 1)," LANL Unclassified Release, XTM:96-05 and LA-UR-96-327 (1996).

FRA96b S. C. Frankle, "ENDF62MT: A Multitemperature Neutron Library for MCNP (Rev. 0)," LANL internal memorandum XTM:SCF-96-153 (1996).

FRA96c S. C. Frankle and R. C. Little, "Cross-section and Reaction Nomenclature for MCNP Continuous-energy Libraries and DANTSYS Multigroup Libraries," LANL internal memorandum, XTM:96-313 (July 15, 1996).

FRA02 S. C. Frankle, R. C. Reedy, and P. G. Young, "ACTI—A MCNP Continuous-Energy Neutron Data Library for Prompt Gamma-Ray Spectroscopy," Los Alamos National Laboratory report LA-UR-02-7783 (December 2002).

HAL92 J. A. Halbleib, R. P. Kensek, G. D. Valdez, T. A. Mehlhorn, S. M. Seltzer, and M. J. Berger, "ITS Version 3.0: The Integrated TIGER Series of Coupled Electron/Photon Monte Carlo Transport Codes," *IEEE Transactions on Nuclear Science*, Volume 39, pp. 1025–1030 (1992). Sandia National Laboratories report SAND91-1634 (March 1992).

HUG96 H. G. Hughes, "Information on the Photon Library MCPLIB02," LANL internal memorandum X-6:HGH-93-77 (revised 1996).

KOP78 J. U. Koppel and D. H. Houston, "Reference Manual for ENDF Thermal Neutron Scattering Data," General Atomics report GA-8774. (Also revised and reissued as ENDF-269 by the National Nuclear Data Center at the Brookhaven National Laboratory) (July 1978).

LIT82a R. C. Little, "New Photon Library from ENDF Data," LANL internal memorandum to Buck Thompson (February 26, 1982).

LIT82b R. C. Little, "Argon and Krypton Cross-section Files," LANL internal memorandum (June 30, 1982).

LIT82c R. C. Little, "Cross Sections in ACE Format for Various IP Target Materials," LANL internal memorandum (August 19, 1982).

LIT84 R. C. Little and R. E. Seamon, "Dosimetry/Activiation Cross Sections for MCNP," LANL internal memorandum (March 13, 1984).

LIT85a R. C. Little, "Y-89 cross sections for MCNP," LANL internal memorandum X-6:RCL-85- 419 (1985).

LIT85b R. C. Little, "Modified ENDF/B-V.0 Y-89 cross sections for MCNP," LANL internal memorandum X-6:RCL-85-443 (1985).

LIT86a R. Little and R. Seamon, "ENDF/B-V.0 Gd Cross Sections with Photon Production," LANL internal memorandum X-6:RCL-87-132 (1986).

LIT86b R. C. Little and R. E. Seamon, "New MENDF5 and MENDF5G," LANL internal memoradum X-6:RCL-86-412 (1986).

LIT87 R. C. Little, "Neutron and Photon Multigroup Data Tables for MCNP3B," LANL internal memorandum X-6:RCL-87-225 (1987).

LIT95 R. C. Little, "Summary Documentation for the 100XS Neutron Cross Section Library (Release 1)," LANL internal memorandum XTM:RCL-95-259 and report LA-UR-96-24 (1995).

MAC88 Robert E. MacFarlane, "Cold Moderator Scattering Kernals," *Advanced Neutron Sources 1988, Proceedings of the 10th Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-X)* held at Los Alamos, 3–7 October 1988, Institute of Physics Conferences Series Number 97, p. 15,7 Institute of Physics, Bristol and New York (1988).

MAC91 R. E. MacFarlane, "Cold Moderator Scattering Kernals," International Workshop on Cold Neutron Sources, March 5–8, 1990, Los Alamos, New Mexico, Los Alamos National Laboratory report LA-12146-C (August 1991).

MAC94a R. E. MacFarlane and D. W. Muir, "The NJOY Nuclear Data Processing System," LANL report LA-12740 (1994).

MAC94b R. E. MacFarland, "New Thermal Neutron Scattering Files for ENDF/B-VI Release 2," Los Alamos National Laboratory report LA-12639-MS. (Also released as ENDF-356 by the National Nuclear Data Center at the Brookhaven National Laboratory) (August 1994).

MCL95 V. McLane, C. L. Dunford, and P.F. Rose, ed., "ENDF-102: Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6," BNL report, BNL-NCS-44945 (revised 1995).

SEA76 R. E. Seamon, "Weight Functions for the Isotopes on Permfile THIRTY2," LANL Internal memorandum, TD-6 (July 23, 1976).

SEA80 R. E. Seamon, "Plots of the TD Weight Function," LANL internal memorandum, X-6:RES- 91-80 (1980).

SEA92 R. E. Seamon, "Revised ENDF/B-V Zirconium Cross Sections," LANL internal memorandum X-6:RES-92-324 (1992).

STO70 E. Storm and H. I. Israel, "Photon Cross Sections from 1 keV to 100 MeV for Elements Z=1 to Z=100," *Nuclear Data Tables*, Volume A7, pp. 565–681 (1970).

WAG94 J. C. Wagner et al., "MCNP: Multigroup/Adjoint Capabilities," LANL report LA-12704 (1994).

WHI02a M. C. White, "Photoatomic Data Library MCPLIB03: An Update to MCPLIB02 Containing New Compton Doppler Broadening Data," Los Alamos National Laboratory internal memorandum X-5:MCW-02-110 (2002).

WHI02b M. C. White, "Photoatomic Data Library MCPLIB04: A New Photoatomic Library Based on Data from ENDF/B-VI Release 8," Los Alamos National Laboratory internal memorandum X-5:MCW-02-111 (2002).

APPENDIX H FISSION SPECTRA CONSTANTS AND FLUX-TO-DOSE FACTORS

This appendix is divided into two sections: fission spectra constants to be used with the SP input card and ANSI standard flux-to-dose conversion factors to be used with the DE and DF input cards.

H.1 CONSTANTS FOR FISSION SPECTRA

The following is a list of recommended parameters for use with the MCNPX source fission spectra and the SP input card described in Section 5.5.1.2. The constants for neutron-induced fission are taken directly from the ENDF/B-V library. For each fissionable isotope, constants are given for either the Maxwell spectrum or the Watt spectrum, but not both. The Watt fission spectrum is preferred to the Maxwell fission spectrum. The constants for spontaneously fissioning isotopes are supplied by Madland of Group T-16. If you desire constants for isotopes other than those listed below, contact X-Division. Note that both the Watt and Maxwell fission spectra are approximations. A more accurate representation has been developed by Madland in T-16. If you are interested in this spectrum, contact X-Division.

H.1.1 Constants for the Maxwell Fission Spectrum (neutron-induced)

$$f(E) = CE^{1/2}\exp(-E/a)$$

	Incident Neutron Energy (MeV)	a (MeV)
n + ^{233}Pa	Thermal	1.3294
	1	1.3294
	14	1.3294
n + ^{234}U	Thermal	1.2955
	1	1.3086
	14	1.4792
n + ^{236}U	Thermal	1.2955
	1	1.3086
	14	1.4792

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	Incident Neutron Energy (MeV)	a (MeV)
n + ^{237}U	Thermal	1.2996
	1	1.3162
	14	1.5063
n + ^{237}Np	Thermal	1.315
	1	1.315
	14	1.315
n + ^{238}Pu	Thermal	1.330
	1	1.330
	14	1.330
n + ^{240}Pu	Thermal	1.346
	1	1.3615
	14	1.547
n + ^{241}Pu	Thermal	1.3597
	1	1.3752
	14	1.5323
n + ^{242}Pu	Thermal	1.337
	1	1.354
	14	1.552
n + ^{241}Am	Thermal	1.330
	1	1.330
	14	1.330
n + ^{242}*m*Pu	Thermal	1.330
	1	1.330
	14	1.330
n + ^{243}Am	Thermal	1.330
	1	1.330
	14	1.330
n + ^{242}Cm	Thermal	1.330
	1	1.330
	14	1.330
n + ^{244}Cm	Thermal	1.330
	1	1.330
	14	1.330
n + ^{245}Cm	Thermal	1.4501
	1	1.4687
	14	1.6844
n + ^{246}Cm	Thermal	1.3624
	1	1.4075
	14	1.6412

H.1.2 Constants for the Watt Fission Spectrum

$$f(E) = C\exp(-E/a)\sinh(bE)^{1/2}$$

H.1.2.1 NEUTRON-INDUCED FISSION

	Incident Neutron Energy (MeV)	*a* (MeV)	*b* (MeV^{-1})
n + ^{232}Th	Thermal	1.0888	1.6871
	1	1.1096	1.6316
	14	1.1700	1.4610
n + ^{233}U	Thermal	0.977	2.546
	1	0.977	2.546
	14	1.0036	2.6377
n + ^{235}U	Thermal	0.988	2.249
	1	0.988	2.249
	14	1.028	2.084
n + ^{238}U	Thermal	0.88111	3.4005
	1	0.89506	3.2953
	14	0.96534	2.8330
n + ^{239}Pu	Thermal	0.966	2.842
	1	0.966	2.842
	14	1.055	2.383

H.1.2.2 SPONTANEOUS FISSION

	a (MeV)	b (MeV^{-1})
^{232}Th	0.800000	4.00000
^{232}U	0.892204	3.72278
^{233}U	0.854803	4.03210
^{234}U	0.771241	4.92449
^{235}U	0.774713	4.85231
^{236}U	0.735166	5.35746
^{238}U	0.648318	6.81057
^{237}Np	0.833438	4.24147
^{238}Pu	0.847833	4.16933
^{239}Pu	0.885247	3.80269
^{240}Pu	0.794930	4.68927
^{241}Pu	0.842472	4.15150
^{242}Pu	0.819150	4.36668
^{241}Am	0.933020	3.46195
^{242}Cm	0.887353	3.89176
^{244}Cm	0.902523	3.72033
^{249}Bk	0.891281	3.79405
^{252}Cf	1.180000	1.03419

H.2 FLUX-TO-DOSE CONVERSION FACTORS

This section presents several flux-to-dose rate conversion factor sets for use on the DE and DF tally cards to convert from calculated particle flux to human biological dose equivalent rate. These sets of conversion factors are not the only ones in existence, nor are they recommended by this publication. Rather, they are presented for convenience should you decide that one is appropriate for your use. The original publication cited or other sources should be consulted to determine if they are appropriate for your application.

Although the various conversion factor sets differ from one another, it seems to be the consensus of the health physics community that they do not differ significantly from most health physics applications where accuracies of ±20% are generally acceptable. Some of the differences in the various sets are attributable to different assumptions about source directionality, phantom geometry, and depth of penetration. The neutron quality factors, derived primarily from animal experiments, are also somewhat different.

Be aware that conversion factor sets are subject to change based on the actions of various national and international organizations such as the National Council on

Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), the International Commission on Radiation Units and Measurements (ICRU), the American National Standards Institute (ANSI), and the American Nuclear Society (ANS). Changes may be based on the re-evaluation of existing data and calculations or on the availability of new information. Currently, a revision of the 1977 ANSI/ANS [ANS77] conversion factors is under way and the ICRP and NCRP are considering an increase in the neutron quality factors by a factor of 2 to 2.5.

In addition to biological dose factors, a reference is given for silicon displacement kerma factors for potential use in radiation effects assessment of electronic semiconductor devices. The use of these factors is subject to the same caveats stated above for biological dose rates.

H.2.1 Biological Dose Equivalent Rate Factors

In the following discussions, dose rate will be used interchangeably with biological dose equivalent rate. In all cases the conversion factors will contain the quality factors used to convert the absorbed dose in rads to rem. The neutron quality factors implicit in the conversion factors are also tabulated for information. For consistency, all conversion factors are given in units of rem/h per unit flux (particles/cm^2-s) rather than in the units given by the original publication. The interpolation mode chosen should correspond to that recommended by the reference. For example, the ANSI/ANS publication recommends log-log interpolation; significant differences at interpolated energies can result if a different interpolation scheme is used.

H.2.1.1 NEUTRONS

The NCRP-38 [NCR71] and ICRP-21 [ICR71] neutron flux-to-dose rate conversion factors and quality factors are listed in Table H-1. Note that the 1977 ANSI/ANS factors referred to earlier were taken from NCRP-38 and therefore are not listed separately.

H.2.1.2 PHOTONS

The 1977 ANSI/ANS [ANS77] and the ICRP-21 [ICR71] photon flux-to-dose rate conversion factors are given in Table H-2. No tabulated set of photon conversion factors have been provided by the NCRP as far as can be determined. Note that the 1977 ANSI/ANS and the ICRP-21 conversion factor sets differ significantly (>20%) below approximately 0.7 MeV with maximum disagreement occurring at ~0.06 MeV, where the ANSI/ANS value is about 2.3 times larger than the ICRP value.

H.2.2 Silicon Displacement Kerma Factors

Radiation damage to or effects on electronic components are often of interest in radiation fields. Of particular interest are the absorbed dose in rads and silicon displacement kerma factors. The absorbed dose may be calculated for a specific material by using the FM tally card discussed in Section 5.6.7 with an appropriate constant C to convert from the MCNPX default units to rads. The silicon displacement kermas, however, are given as a function of energy, similar to the biological conversion factors. Therefore, they may be implemented on the DE and DF cards. One source of these kerma factors and a discussion of their significance and use can be found in AST80.

Table H-1. Neutron Flux-to-Dose Rate Conversion Factors and Quality Factors

	NCRP-38, ANSI/ANS-6.1.1-1977†		ICRP-21	
Energy, E (MeV)	DF(E) (rem/hr)/(n/cm^2-s)	Quality Factor	DF(E) (rem/hr)/(n/cm^2-s)	Quality Factor
2.5E-08	3.67E-06	2.0	3.85E-06	2.3
1.0E-07	3.67E-06	2.0	4.17E-06	2.0
1.0E-06	4.46E-06	2.0	4.55E-06	2.0
1.0E-05	4.54E-06	2.0	4.35E-06	2.0
1.0E-04	4.18E-06	2.0	4.17E-06	2.0
1.0E-03	3.76E-06	2.0	3.70E-06	2.0
1.0E-02	3.56E-06	2.5	3.57E-06	2.0
1.0E-01	2.17E-05	7.5	2.08E-05	7.4
5.0E-01	9.26E-05	11.0	7.14E-05	11.0
1.0	1.32E-04	11.0	1.18E-04	10.6
2.0			1.43E-04	9.3
2.5	1.25E-04	9.0		
5.0	1.56E-04	8.0	1.47E-04	7.8
7.0	1.47E-04	7.0		
10.0	1.47E-04	6.5	1.47E-04	6.8
14.0	2.08E-04	7.5		
20.0	2.27E-04	8.0	1.54E-04	6.0

† Extracted from American National Standard ANSI/ANS-6.1.1-1977 with permission of the publisher, the American Nuclear Society.

Table H-2. Photon Flux-to-Dose Rate Conversion Factors

ANSI/ANS6.1.11977		ICRP-21	
Energy, E (MeV)	DF(E) (rem/hr)/(p/cm^2-s)	Energy, E (MeV)	DF(E) (rem/hr)/(p/cm^2-s)
0.01	3.96E-06	0.01	2.78E-06
0.03	5.82E-07	0.015	1.11E-06
0.05	2.90E-07	0.02	5.88E-07
0.07	2.58E-07	0.03	2.56E-07
0.1	2.83E-07	0.04	1.56E-07
0.15	3.79E-07	0.05	1.20E-07
0.2	5.01E-07	0.06	1.11E-07
0.25	6.31E-07	0.08	1.20E-07
0.3	7.59E-07	0.1	1.47E-07
0.35	8.78E-07	0.15	2.38E-07
0.4	9.85E-07	0.2	3.45E-07
0.45	1.08E-06	0.3	5.56E-07
0.5	1.17E-06	0.4	7.69E-07
0.55	1.27E-06	0.5	9.09E-07
0.6	1.36E-06	0.6	1.14E-06
0.65	1.44E-06	0.8	1.47E-06
0.7	1.52E-06	1.	1.79E-06
0.8	1.68E-06	1.5	2.44E-06
1.0	1.98E-06	2.	3.03E-06
1.4	2.51E-06	3.	4.00E-06
1.8	2.99E-06	4.	4.76E-06
2.2	3.42E-06	5.	5.56E-06
2.6	3.82E-06	6.	6.25E-06
2.8	4.01E-06	8.	7.69E-06
3.25	4.41E-06	10.	9.09E-06
3.75	4.83E-06		
4.25	5.23E-06		
4.75	5.60E-06		
5.0	5.80E-06		
5.25	6.01E-06		
5.75	6.37E-06		
6.25	6.74E-06		
6.75	7.11E-06		
7.5	7.66E-06		
9.0	8.77E-06		
11.0	1.03E-05		

ANSI/ANS6.1.11977		ICRP-21	
Energy, E (MeV)	**DF(E) (rem/hr)/(p/cm^2-s)**	**Energy, E (MeV)**	**DF(E) (rem/hr)/(p/cm^2-s)**
13.0	1.18E-05		
15.0	1.33E-05		

H.3 REFERENCES

ANS77 ANS-6.1.1 Working Group, M. E. Battat (Chairman), ''American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors,'' ANSI/ANS-6.1.1-1977 (N666), American Nuclear Society, LaGrange Park, Illinois (1977).

AST80 ASTM Committee E-10 on Nuclear Technology and Applications, ''Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics,'' American Society for Testing and Materials Standard E722-80, Annual Book of ASTM Standards (1980).

ICR71 ICRP Committee 3 Task Group, P. Grande and M. C. O'Riordan, chairmen, ''Data for Protection Against Ionizing Radiation from External Sources: Supplement to ICRP Publication 15,'' ICRP-21, International Commission on Radiological Protection, Pergamon Press (April 1971).

NCR71 NCRP Scientific Committee 4 on Heavy Particles, H. H. Rossi, chairman, ''Protection Against Neutron Radiation,'' NCRP-38, National Council on Radiation Protection and Measurements (January 1971).

APPENDIX I PTRAC TABLES

Table I-1 presents the format of the PTRAC output file. Table I-2 through 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 MCNPX FORTRAN variables (except where noted) and are defined in the developer's guide, which is not yet released.

Table I-1. Format of the PTRAC Output File

Format	ASCII		Binary Record
	Line	Format	
-1	1	(i5)	1
KOD, VER, LODDAT, IDTM	2	(a8,a5,a8,a19)	2
AID	3	(a80)	3
m n_1 V_1^2 V_2^2 … V_{n1}^2 …	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).		

Format		ASCII		Binary Record
		Line	Format	
$I_1^2\ I_2^2\ \ldots\ I_{N1}^2$		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 ($I_1\ I_2\ \ldots$).			
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.			
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.			
$L_1^1\ L_2^1\ \ldots\ L_{N2+N3}^1$	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_1^1	NPS.			
I_2^1	Event type of the 1st event for this history (see Table I-5).			
I_3^1	Cell number if cell filtered, otherwise omitted.			

Format	ASCII		Binary Record
	Line	Format	
I_4^1	Surface number if surface filtered, otherwise omitted.		
I_5^1	Tally number if tally filtered, otherwise omitted.		
I_6^1	TFC bin tally if tally filtered, otherwise omitted.		
See Table I-3 for definitions of J_1^1, J_2^1, ..., and P_1^1, P_2^1, ...			

Table I-2. PTRAC Input Format

$m\ n_1\ V_1^1\ V_2^1\ \ldots\ V_{n1}^1 \qquad n_2\ V_1^2\ V_2^2\ \ldots\ V_{n2}^2 \qquad \ldots \qquad n_{13}\ V_1^{13}\ V_2^{13}\ \ldots\ V_{n1}^{13}$

where 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)†

Index	Type 1		Type 2		Type 3		Type 4	
	$N_{12}\neq0$ WRITE=pos		$N_{12}=0$ WRITE=pos		$N_{12}\neq0$ WRITE=all		$N_{12}=0$ WRITE=all	
	$N_2=5$ $N_3=3$	$N_{4,6,8,10}=6$ $N_{5,7,9,11}=3$	$N_2=6$ $N_3=3$	$N_{4,6,8,10}=7$ $N_{5,7,9,11}=3$	$N_2=6$ $N_3=9$	$N_{4,6,8,10}=7$ $N_{5,7,9,11}=9$	$N_2=7$ $N_3=9$	$N_{4,6,8,10}=8$ $N_{5,7,9,11}=9$
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
J_6		18	18	17	19	18	18	17
J_7				18		19	19	18

Index	Type 1		Type 2		Type 3		Type 4	
	$N_{12}\neq0$ WRITE=pos		$N_{12}=0$ WRITE=pos		$N_{12}\neq0$ WRITE=all		$N_{12}=0$ WRITE=all	
	$N_2=5$ $N_3=3$	$N_{4,6,8,10}=6$ $N_{5,7,9,11}=3$	$N_2=6$ $N_3=3$	$N_{4,6,8,10}=7$ $N_{5,7,9,11}=3$	$N_2=6$ $N_3=9$	$N_{4,6,8,10}=7$ $N_{5,7,9,11}=9$	$N_2=7$ $N_3=9$	$N_{4,6,8,10}=8$ $N_{5,7,9,11}=9$
J_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 $J_1 \ldots J_4 = 7,8,10,11$
For a "sur" event (N_6, N_7), interpret $J_1 \ldots J_4 = 7,8,12,13$
For a "col" event (N_8, N_9), interpret $J_1 \ldots J_4 = 7,8,10,11$
For a "ter" event (N_{10}, N_{11}), interpret $J_1 \ldots J_4 = 7,8,14,15$

Table I-4. Description of Variable IDs

Variable ID	MCNPX Name	Description
NPS LINE		
1	NPS	See the developer's guide*
2	---	Event type of 1st event (see Table I-5)
3	NCL(ICL)	See the developer's guide*
4	NSF(JSU)	See the developer's guide*
5	JPTAL(1,ITAL)	See the developer's guide*
6	TAL(JPTAL(7,ITAL))	See the developer's guide*
EVENT LINE		
7		Event type of next event (see Table I-5)
8	NODE	See the developer's guide*
9	NSR	See the developer's guide*
10	NXS(2,IEX)	See the developer's guide*
11	NTYN/MTP	Reaction type (see Table I-7). NTYN for bank event; MTP for collision event
12	NSF(JSU)	Surface number

Variable ID	MCNPX Name	Description
13		Angle with surface normal (degrees)
14	NTER	Termination type (see Table I-7)
15		Branch number for this history
16	IPT	See the developer's guide*
17	NCL(ICL)	See the developer's guide*
18	MAT(ICL)	See the developer's guide*
19	NCP	See the developer's guide*
20	XXX	See the developer's guide*
21	YYY	See the developer's guide*
22	ZZZ	See the developer's guide*
23	UUU	See the developer's guide*
24	VVV	See the developer's guide*
25	WWW	See the developer's guide*
26	ERG	See the developer's guide*
27	WGT	See the developer's guide*
28	TME	See the developer's guide*

* The MCNPX developer's guide is not yet released.

Table I-5. Event Type Description

Location	Variable ID	Event Type					Flag†
		src	bnk‡	sur	col	ter	
I_2 or J_1	7	1000	±(2000+L)	3000	4000	5000	9000

† When I_2 or J_1 = 9000, this event is the last event for this history.
‡ When I_2 or 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	MCNPX Subroutine	NXS & 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

L Value	Description	MCNPX Subroutine	NXS & NTYN Provided
7	Neutron from Neutron (n,xn) (n,f) and Secondary Particles from Library Protons	COLIDN	Y
8	Photon from Neutron	ACEGAM	Y
9	Photon from Double Fluorescence	COLIDP	Y
10	Photon from Annihilation	COLIDP	N
		ELECTR	
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	N
		BREMS	
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	Photo from Photon - Multigroup	MGCOLN	Y
23	Adjoint Weight Split - Multigroup	MGACOL	N
24	Weight-Window Pseudo-Collision Split	WTWNDO	N
25	Secondary Particles from Photonuclear	COLLPN	Y
30	Light Ions from Neutrons	ACECP / LRECOIL / ACEION	Y
31	Light Ions from Protons	LRECOIL	Y
32	Library Neutrons from Model Neutrons	INTRCT	N
33	Secondary Particles from Inelastic Nuclear Interactions	UPDAT1	N
34	Secondary Particles from Elastic Nuclear Interactions	UPDATE	N

Table I-7. NTER and NTYN/MTP Variable Descriptions

NTER	Description	MTP	NTYN	Description
1	Escape	**NEUTRON**		
2	Energy cutoff	4	1	Inelastic $S(\alpha,\beta)$
3	Time cutoff	2	2	Elastic $S(\alpha,\beta)$
4	Weight window	>0	-99	Elastic scatter / Inelastic scatter
5	Cell importance		>5	ENDF Reaction ID
6	Weight cutoff			
7	Energy importance			
8	DXTRAN	**PHOTON**		
9	Forced collision	-1	1	Incoherent scatter
10	Exponential transform	-2	2	Coherent scatter
NEUTRON		-3	3	Fluorescence
11	Downscattering	-4	4	Pair production
12	Capture			
13	Loss to (*n*,x*n*)			
14	Loss to fission			
15	Nuclear interactions			
16	Particle decay			
17	Tabular boundary			
PHOTON				
11	Compton scatter			
12	Capture			
13	Pair production			
14	Photonuclear			
ELECTRON				
11	Scattering			
12	Bremsstrahlung			
16	Interaction or decay			
GENERIC NEUTRAL PARTICLES				
11	Nuclear interactions			
12	Elastic scatter			
13	Particle decay			
GENERIC CHARGED PARTICLES				
11	Multiple scatter			
12	Bremsstrahlung			
13	Nuclear interactions			
14	Elastic scatter			
15	Particle decay			
16	Capture			
17	Tabular sampling			

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 and time group numbers, and basic mesh information. Block 2 contains the mesh geometry. Block 3 contains the energy and 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 three-dimensional array of fine mesh cells is stored by assigning an index number to each cell. The three dimensions are x, y, and z for rectangular meshes, r, z, and θ for cylindrical meshes, and r, φ, and θ for spherical meshes. These may be indexed as *i, j, k,* with a total of I, J, K meshes in each coordinate direction. The assignment of mesh cells is illustrated in Figure J-1 for an x,y,z mesh. The cell index number is related to the fine mesh number in each coordinate direction through the following formula:

cell index number = $i + (j - 1)*I + (k - 1)*I*J$.

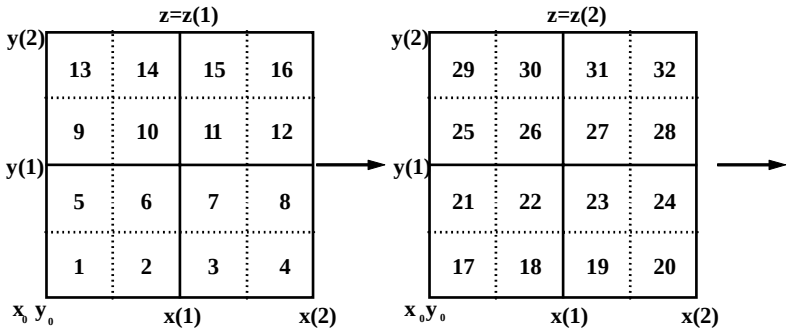

Figure J-1. Superimposed mesh cell indexing.

Table J-1. Format of the Mesh-Based WWINP, WWOUT and WWONE Files

FORMAT	VARIABLE LIST
BLOCK 1	
4i10, 20x, a19	*if iv ni nr probid*
7i10	*nt*(1) ... *nt*(*ni*) [if *iv*=2]
7i10	*ne*(1) ... *ne*(*ni*)
6g13.5	*nfx nfy nfz* x_0 y_0 z_0
6g13.5	*ncx ncy ncz nwg* [if *nr*=10]
6g13.5	*ncx ncy ncz* x_1 y_1 z_1 [if *nr*=16]
6g13.5	x_2 y_2 z_2 *nwg* [if *nr*=16]
BLOCK 2	
6g13.5	x_0 (*qx*(*i*), *px*(*i*), *sx*(*i*), *i*=1,*ncx*)
6g13.5	y_0 (*qy*(*i*), *py*(*i*), *sy*(*i*), *i*=1,*ncy*)
6g13.5	z_0 (*qz*(*i*), *pz*(*i*), *sz*(*i*), *i*=1,*ncz*)
BLOCK 3 (for each particle)	
6g13.5	*t*(*i*,1) ... *t*(*i*,*nt*(*i*)) [if *nt*(*i*)>1]
6g13.5	*e*(*i*,1) ... *e*(*i*,*ne*(*i*))
6g13.5	(((*w*(*i*,*j*,*k*,*l*,1) *j*=1,*nft*), *k*=1,*ne*(*i*)), *l*=1,*nt*(*i*))

Table J-2. Explanations of Variables from Table J-1

VARIABLE	NAME	DESCRIPTION
if	IF	File type. Only 1 is supported. Unused.
iv	IV	Time-dependent windows flag (1 / 2 = no / yes)
ni	NI	Number of particle types
nr	NR	= 10 / 16 / 16 for rectangular / cylindrical / spherical = number of words to describe mesh
probid	PROBID	Problem identification description
i	KP	Particle type
nt(*i*)	NWW(KP)	Number of time bins for particle type *i*
ne(*i*)	NGWW(KP)	Number of energy bins for particle type *i*
nfx, nfy, nfz	WWM(1:3)	Total number of fine (x,y,z), (r,z,θ), or (r,φ,θ) mesh bins

VARIABLE	NAME	DESCRIPTION
x_0, y_0, z_0	WWM(4:6)	Corner of (x,y,z) Cartesian geometry, bottom center of (r,z,θ) cylindrical geometry, or center of (r,φ,θ) spherical geometry
ncx, *ncy*, *ncz*	WWM(7:9)	Number of coarse (x,y,z), (r,z,θ), or (r,φ,θ) mesh bins
x_1, y_1, z_1	WWN (10:12)	Vector from x_0 y_0 z_0 to x_1 y_1 z_1 defines (r,z,θ) cylinder or (r,φ,θ) polar axis
x_2, y_2, z_2	WWN(13:15)	Vector from x_0 y_0 z_0 to x_2 y_2 z_2 defines (r,z,θ) cylinder or (r,φ,θ) azimuthal axis
nwg	WWM(NR)	Geometry type 1 / 2 / 3 = (x,y,z) / (r,z,θ) / (r,φ,θ)
px(*i*), *py*(*i*), *pz*(*i*)	WGM(*k*)	Coarse mesh coordinates for (x,y,z), (r,z,θ), or (r,φ,θ)
qx(*i*), *qy*(*i*), *qz*(*i*)	WGM(*k*)	Fine mesh ratio (presently = 1 always) in each coarse mesh for (x,y,z), (r,z,θ), or (r,φ,θ)
sx(*i*), *sy*(*i*), *sz*(*i*)	WGM(*k*)	Number of fine meshes in each coarse mesh for (x,y,z), (r,z,θ), or (r,φ,θ)
t(*i*,*j*)	WWT1(KP,*j*)	Upper time bounds for particle *i*, bin *j* (given only if *nt*(*i*)>1)
e(*i*,*j*)	WWE1(KP,*j*)	Upper energy bounds for particle *i*, bin *j*
nft	NWWM	Total number of fine meshes (*nfx*∗*nfy*∗*nfz*)
w(*i*,*j*,*k*,*l*,1)	WWF(KP,*j*,*k*,*l*,1)	Weight-window lower bounds. These are written in blocks of *j*=1:NWWMA geometry meshes for each energy *k*=1,NGWW(KP) and for each time *l*=1,MWWTG(KP)

Table J-3. Correspondence of Variable Names

WWINP	WWOUT / WWONE	DESCRIPTION
ip	*ip*	Particle type
ic	*ic*	Mesh cell index
ie	*ie*	Energy index
it	*it*	Time index
ia	*ia*	Angle index (for multigroup)
im	*im*	Multitasking index
NWGM	NWGMA	Length of WGM/WGMA
NWWM	NWWMA	Total number of fine meshes
MWWTF(*ip*)	MWWTG(*ip*)	Time bins
NWW(*ip*)	NGWW(*ip*)	Energy bins

WWINP	WWOUT / WWONE	DESCRIPTION
WWM(26)	WWMA(26)	Geometry description
WGM(*i*)	WGMA(*i*)	Geometry boundaries, fine
WWE1(*ip,ie*)	WWGE(*ip,ie*)	Energy bounds
WWT1(*ip,it*)	WWGT(*ip,it*)	Time bounds
WWF(*ip,ic,ie,it,ia*)	WWFA(*ip,ic,ie,it,im*	Weight-window lower bounds

Example:

Input file mesh description:

```
mesh geom=rzt ref= -4.2419 4.2419 -2
     origin 0 0 -9.0001
     imesh  3.02  6.0001
     iints  3  5
     jmesh 8.008 14.002
     jints  4  3
     kmesh .25 .50 .75  1
     kints  2   1   2   3
```

Resultant WWINP, WWOUT and WWONE file:

```
         1         1         1        16
         1
   6.0000       7.0000       8.0000       0.0000       0.0000      -9.0001
   2.0000       2.0000       4.0000       0.0000       0.0000       5.0001
   6.0001       0.0000      -9.0001       2.0000
   0.0000       3.0000       3.0200       1.0000       5.0000       6.0001
   1.0000
   0.0000       4.0000       8.0080       1.0000       3.0000       14.002
   1.0000
   0.0000       2.0000      0.25000       1.0000       1.0000      0.50000
   1.0000       2.0000      0.75000       1.0000       3.0000       1.0000
   1.0000
   100.00
   0.0000       0.0000       1.1924      0.48566      0.60746       1.0653
  0.10454       0.9993      0.11065      0.16738      0.37556      0.94980
...
...
```

APPENDIX K SUPPLEMENTAL PHYSICS INFORMATION

Table K-1 identifies those heavy ions that may be transported.

Table K-1. Heavy Ions Available for Transport

Z = 2 ***** Helium *****									
2005	2006	2007	2008						
Z = 3 ***** Lithium *****									
3005	3006	3007	3008	3009	3010	3011			
Z = 4 ***** Beryllium *****									
4006	4007	4008	4009	4010	4011	4012	4013	4014	
Z = 5 ***** Boron *****									
5008	5009	5010	5011	5012	5013	5014	5015	5016	5017
Z = 6 ***** Carbon *****									
6008	6009	6010	6011	6012	6013	6014	6015	6016	6017
6018	6019	6020							
Z = 7 ***** Nitrogen *****									
7011	7012	7013	7014	7015	7016	7017	7018	7019	7020
7021	7022	7023							
Z = 8 ***** Oxygen *****									
8013	8014	8015	8016	8017	8018	8019	8020	8021	8022
8023	8024								
Z = 9 ***** Fluorine *****									
9015	9016	9017	9018	9019	9020	9021	9022	9023	9024
9025	9026	9027							
Z = 10 ***** Neon *****									
10017	10018	10019	10020	10021	10022	10023	10024	10025	10026
10027	10028								

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Z = 11 ***** Sodium *****									
11019	11020	11021	11022	11023	11024	11025	11026	11027	11028
11029	11030	11031	11032	11033	11034	11035			
Z = 12 ***** Magnesium *****									
12020	12021	12022	12023	12024	12025	12026	12027	12028	12029
12030	12031	12032	12033	12034					
Z = 13 ***** Aluminum *****									
13022	13023	13024	13025	13026	13027	13028	13029	13030	13031
13032	13033	13034	13035						
Z = 14 ***** Silicon *****									
14024	14025	14026	14027	14028	14029	14030	14031	14032	14033
14034	14035	14036	14037	14038	14039				
Z = 15 ***** Phosphorus *****									
15026	15027	15028	15029	15030	15031	15032	15033	15034	15035
15036	15037	15038	15039	15040	15041	15042			
Z = 16 ***** Sulfur *****									
16029	16030	16031	16032	16033	16034	16035	16036	16037	16038
16039	16040	16041	16042	16043	16044				
Z = 17 ***** Chlorine *****									
17031	17032	17033	17034	17035	17036	17037	17038	17039	17040
17041	17042	17043	17044	17045					
Z = 18 ***** Argon *****									
18032	18033	18034	18035	18036	18037	18038	18039	18040	18041
18042	18043	18044	18045	18046					
Z = 19 ***** Potassium *****									
19035	19036	19037	19038	19039	19040	19041	19042	19043	19044
19045	19046	19047	19048	19049	19050	19051			
Z = 20 ***** Calcium *****									
20036	20037	20038	20039	20040	20041	20042	20043	20044	20045
20046	20047	20048	20049	20050	20051				

Z = 21 ***** Scandium *****									
21040	21041	21042	21043	21044	21045	21046	21047	21048	21049
21050	21051								
Z = 22 ***** Titanium *****									
22041	22042	22043	22044	22045	22046	22047	22048	22049	22050
22051	22052	22053	22054						
Z = 23 ***** Vanadium *****									
23044	23045	23046	23047	23048	23049	23050	23051	23052	23053
23054	23055	23056							
Z = 24 ***** Chromium *****									
24045	24046	24047	24048	24049	24050	24051	24052	24053	24054
24055	24056	24057	24058	24059					
Z = 25 ***** Manganese *****									
25049	25050	25051	25052	25053	25054	25055	25056	25057	25058
25059	25060	25061	25062						
Z = 26 ***** Iron *****									
26049	26050	26051	26052	26053	26054	26055	26056	26057	26058
26059	26060	26061	26062	26063	26064				
Z = 27 ***** Cobalt *****									
27053	27054	27055	27056	27057	27058	27059	27060	27061	27062
27063	27064								
Z = 28 ***** Nickel *****									
28053	28054	28055	28056	28057	28058	28059	28060	28061	28062
28063	28064	28065	28066	28067	28068				
Z = 29 ***** Copper *****									
29057	29058	29059	29060	29061	29062	29063	29064	29065	29066
29067	29068	29069	29070	29071	29072	29073			
Z = 30 ***** Zinc *****									
30057	30058	30059	30060	30061	30062	30063	30064	30065	30066
30067	30068	30069	30070	30071	30072	30073	30074	30075	30076
30077	30078								

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Z = 31 ***** Gallium *****									
31062	31063	31064	31065	311066	31067	31068	31069	31070	31071
31072	31073	31074	31075	31076	31077	31078	31079	31080	31081
31082	31083								
Z = 32 ***** Germanium *****									
32061	32062	32063	32064	32065	32066	32067	32068	32069	32070
32071	32072	32073	32074	32075	32076	32077	32078	32079	32080
32081	32082	32083	32084						
Z = 33 ***** Arsenic *****									
33066	33067	33068	33069	33070	33071	33072	33073	33074	33075
33076	33077	33078	33079	33080	33081	33082	33083	33084	33085
33086	33087								
Z = 34 ***** Selenium *****									
34068	34069	34070	34071	34072	34073	34074	34075	34076	34077
34078	34079	34080	34081	34082	34083	34084	31085	34086	34087
34088	34089	34090	34091						
Z = 35 ***** Bromine *****									
35070	35071	35072	35073	35074	35075	35076	35077	35078	35079
35080	35081	35082	35083	35084	35085	35086	35087	35088	35089
35090	35091	35092							
Z = 36 ***** Krypton *****									
36071	36072	36073	36074	36075	36076	36077	36078	36079	36080
36081	36082	36083	36084	36085	36086	36087	36088	36089	36090
36091	39092	36093	36094	36095	36096	36097			
Z = 37 ***** Rubidium *****									
37074	37075	37076	37077	37078	37079	37080	37081	37082	37083
37084	37085	37086	37087	37088	37089	37090	37091	37092	37093
37094	37095	37096	37097	37098	37099	37100			
Z = 38 ***** Strontium *****									
38077	38078	38079	38080	38081	38082	38083	38084	38085	38086
38087	38088	38089	38090	38091	38092	38093	38094	38095	38096
38097	38098	38099	38100						

Z = 39 ***** Yttrium *****									
39080	39081	39082	39083	39084	39085	39086	39087	39088	39089
39090	39091	39092	39093	39094	39095	39096	39097	39098	39099
39100	39101	39102							
Z = 40 ***** Zirconium *****									
40081	40082	40083	40084	40085	40086	40087	40088	40089	40090
40091	40092	40093	40094	40095	40096	40097	40098	40099	40100
40101	40102								
Z = 41 ***** Niobium *****									
41084	41085	41086	41087	41088	41089	41090	41091	41092	41093
41094	41095	41096	41097	41098	41099	41100	41101	41102	41103
41104	41105	41106							
Z = 42 ***** Molybdenum *****									
42087	42088	42089	42090	42091	42092	42093	42094	42095	42096
42097	42098	42099	42100	42101	42102	42103	42104	42105	42106
42107	42108								
Z = 43 ***** Technetium *****									
43090	43091	43092	43093	43094	43095	43096	43097	43098	43099
43100	43101	43102	43103	43104	43105	43106	43107	43108	43109
43110									
Z = 44 ***** Ruthenium *****									
44092	44093	44094	44095	44096	44097	44098	44099	44100	44101
44102	44103	44104	44105	44106	44107	44108	44109	44110	44111
44112	44113								
Z = 45 ***** Rhodium *****									
45094	45095	45096	45097	45098	45099	45100	45101	45102	45103
45104	45105	45106	45107	45108	45109	45110	45111	45112	45113
45114									
Z = 46 ***** Palladium *****									
46096	46097	46098	46099	46100	46101	46102	46103	46104	46105
46106	46107	46108	46109	46110	46111	46112	46113	46114	46115
46116	46117	46118							

Z = 47 ***** Silver *****									
47096	47097	47098	47099	47100	47101	47102	47103	47104	47105
47106	47107	47108	47109	47110	47111	47112	47113	47114	47115
47116	47117	47118	47119	47120	47121	47122	47123		
Z = 48 ***** Cadmium *****									
48097	48098	48099	48100	48101	48102	48103	48104	48105	48106
48107	48108	48109	48110	48111	48112	48113	48114	48115	48116
48117	48118	48119	48120	48121	48122	48123	48124	48125	48126
Z = 49 ***** Indium *****									
49100	49101	49102	49103	49104	49105	49106	49107	49108	49109
49110	49111	49112	49113	49114	49115	49116	49117	49118	49119
49120	49121	49122	49123	49124	49125	49126	49127	49128	49129
49130	49131	49132							
Z = 50 ***** Tin *****									
50103	50104	50105	50106	50107	50108	50109	50110	50111	50112
50113	50114	50115	50116	50117	50118	50119	50120	50121	50122
50123	50124	50125	50126	50127	50128	50129	50130	50131	50132
50133	50134								
Z = 51 ***** Antimony *****									
51108	51109	51110	51111	51112	51113	51114	51115	51116	51117
51118	51119	51120	51121	51122	51123	51124	51125	51126	51127
51128	51129	51130	51131	51132	51133	51134	51135	51136	
Z = 52 ***** Tellurium *****									
52106	52107	52108	520109	52110	52111	52112	52113	52114	52115
52116	52117	52118	52119	52120	52121	52122	52123	52124	52125
52126	52127	52128	52129	52130	52131	52132	52133	52134	52135
52136	52137	52138							
Z = 53 ***** Iodine *****									
53110	53111	53112	53113	53114	53115	53116	53117	53118	53119
53120	53121	53122	53123	53124	53125	53126	53127	53128	53129
53130	53131	53132	53133	53134	53135	53136	53137	53138	53139
53140	53141	53142							

Z = 54 ***** Xenon *****									
54110	54111	54112	54113	54114	54115	54116	54117	54118	54119
54120	54121	54122	54123	54124	54125	54126	54127	54128	54129
54130	54131	54132	54133	54134	54135	54136	54137	54138	54139
54140	54141	54142	54143	54144	54145				
Z = 55 ***** Cesium *****									
55114	55115	55116	55117	55118	55119	55120	55121	55122	55123
55124	55125	55126	55127	55128	55129	55130	55131	55132	55133
55134	55135	55136	55137	55138	55139	55140	55141	55142	55143
55144	55145	55146	55147	55148					
Z = 55 ***** Cesium *****									
55114	55115	55116	55117	55118	55119	55120	55121	55122	55123
55124	55125	55126	55127	55128	55129	55130	55131	55132	55133
55134	55135	55136	55137	55138	55139	55140	55141	55142	55143
55144	55145	55146	55147	55148					
Z = 56 ***** Barium *****									
56117	56118	56119	56120	56121	56122	56123	56124	56125	56126
56127	56128	56129	56130	56131	56132	56133	56134	56135	56136
56137	56138	56139	56140	56141	56142	56143	56144	56145	56146
56147	56148								
Z = 57 ***** Lanthanum *****									
57123	57124	57125	57126	57127	57128	57129	57130	57131	57132
57133	57134	57135	57136	57137	57138	57139	57140	57141	57142
57143	57144	57145	57146	57147	57148	57149			
Z = 58 ***** Cerium *****									
58124	58125	58126	58127	58128	58129	58130	58131	58132	58133
58134	58135	58136	58137	58138	58139	58140	58141	58142	58143
58144	58145	58146	58147	58148	58149	58150	58151		
Z = 59 ***** Praseodymium *****									
59129	59130	59131	59132	59133	59134	59135	59136	59137	59138
59139	59140	59141	59142	59143	59144	59145	59146	59147	59148
59149	59150	59151	59152						

Z = 60 ***** Neodymium *****									
60129	60130	60131	60132	60133	60134	60135	60136	60137	60138
60139	60140	60141	60142	60143	60144	60145	60146	60147	60148
60149	60150	60151	60152	60153	60154				
Z = 61 ***** Promethium *****									
61132	61133	61134	61135	61136	61137	61138	61139	61140	61141
61142	61143	61144	61145	61146	61147	61148	61149	61150	61151
61152	61153	61154	61155						
Z = 62 ***** Samarium *****									
62133	62134	62135	62136	62137	62138	62139	62140	62141	62142
62143	62144	62145	62146	62147	62148	62149	62150	62151	62151
62153	62154	62155	62156	62157	62158				
Z = 63 ***** Europium *****									
63138	63139	63140	63141	63142	63143	63144	63145	63146	63147
63148	63149	63150	63151	63152	63153	63154	63155	63156	63157
63158	63159	63160							
Z = 64 ***** Gadolinium *****									
64142	64143	64144	64145	64146	64147	64148	64149	64150	64151
64152	64153	64154	64155	64156	64157	64158	64159	64160	64161
64162	64163								
Z = 65 ***** Terbium *****									
65144	65145	65146	65147	65148	65149	65150	65151	65152	65153
65154	65155	65156	65157	65158	65159	65160	65161	65162	65163
65164	65165								
Z = 66 ***** Dysprosium *****									
66145	66146	66147	66148	66149	66150	66151	66152	66153	66154
66155	66156	66157	66158	66159	66160	66161	66162	66163	66164
66165	66166	66167	66168						
Z = 67 ***** Holmium *****									
67147	67148	67149	67150	67151	67152	67153	67154	67155	67156
67157	67158	67159	67160	67161	67162	67163	67164	67165	67166
67167	67168	67169	67170						

Z = 68 ***** Erbium *****									
68147	68148	68149	68150	68151	68152	68153	68154	68155	68156
68157	68158	68159	68160	68161	68162	68163	68164	68165	68166
68167	68168	68169	68170	68171	68172	68173			
Z = 69 ***** Thulium *****									
69151	69152	69153	69154	69155	69156	69157	69158	69159	69160
69161	69162	69163	69164	69165	69166	69167	69168	69169	69170
69171	69172	69173	69174	69175	69176				
Z = 70 ***** Ytterbium *****									
70153	70154	70155	70156	70157	70158	70159	70160	70161	70162
70163	70164	70165	70166	70167	70168	70169	70170	70171	70172
70173	70174	70175	70176	70177	70178	70179			
Z = 71 ***** Lutetium *****									
71151	71152	71153	71154	71155	71156	71157	71158	71159	71160
71161	71162	71163	71164	71165	71166	71167	71168	71169	71170
71171	71172	71173	71174	71175	71176	71177	71178	71179	71180
71181	71182	71183							
Z = 72 ***** Hafnium *****									
72154	72155	72156	72157	72158	72159	72160	72161	72162	72163
72164	72165	72166	72167	72168	72169	72170	72171	72172	72173
72174	72175	72176	72177	72178	72179	72180	72181	72182	72183
72184									
Z = 73 ***** Tantalum *****									
73157	73158	73159	73160	73161	73162	73163	73164	73165	73166
73167	73168	73169	73170	73171	73172	73173	73174	73175	73176
73177	73178	73179	73180	73181	73182	73183	73184	73185	73186
Z = 74 ***** Tungsten *****									
74158	74159	74160	74161	74162	74163	74164	74165	74166	74167
74168	74169	74170	74171	74172	74173	74174	74175	74176	74177
74178	74179	74180	74181	74182	74183	74184	74185	74186	74187
74188	74189	74190							

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Z = 75 ***** Rhenium *****									
75161	75162	75163	75164	75165	75166	75167	75168	75169	75170
75171	75172	75173	75174	75175	75176	75177	75178	75179	75180
75181	75182	75183	75184	75185	75186	75187	75188	75189	75190
75191	75192								
Z = 76 ***** Osmium *****									
76163	76164	76165	76166	76167	76168	76169	76170	76171	76172
76173	76174	76175	76176	76177	76178	76179	76180	76181	76182
76183	76184	76185	76186	76187	76188	76189	76190	76191	76192
76193	76194	76195	76196						
Z = 77 ***** Iridium *****									
77166	77167	77168	77169	77170	77171	77172	77173	77174	77175
77176	77177	77178	77179	77180	77181	77182	77183	77184	77185
77186	77187	77188	77189	77190	77191	77192	77193	77194	77195
77196	77197	77198							
Z = 78 ***** Platinum *****									
78168	78169	78170	78171	78172	78173	78174	78175	78176	78177
78178	78179	78180	78181	78182	78183	78184	78185	78186	78187
78188	78189	78190	78191	78192	78193	78194	78195	78196	78197
78198	78199	78200	78201						
Z = 79 ***** Gold *****									
79175	79176	79177	79178	79179	79180	79181	79182	79183	79184
79185	79186	79187	79188	79189	79190	79191	79192	79193	79194
79195	79196	79197	79198	79199	79200	79201	79202	79203	79204
Z = 80 ***** Mercury *****									
80177	80178	80179	80180	80181	80182	80183	80184	80185	80186
80187	80188	80189	80190	80191	80192	80193	80194	80195	80196
80197	80198	80199	80200	80201	80202	80203	80204	80205	80206
Z = 81 ***** Thallium *****									
81184	81185	81186	81187	81188	81189	81190	81191	81192	81193
81194	81195	81196	81197	81198	91199	81200	81201	81202	81203
81204	81205	81206	81207	81208	81209	81210			

Z = 82 ***** Lead *****									
82183	82184	82185	82186	82187	82188	82189	82190	82191	82192
82193	82194	82195	82196	82197	82198	82199	82200	82201	82202
82203	82204	82205	82206	82207	82208	82209	82210	82211	82212
82213	82214								
Z = 83 ***** Bismuth *****									
83188	83189	83190	83191	83192	83193	83194	83195	83196	83197
83198	83199	83200	83201	83202	83203	83204	83205	83206	83207
83208	83209	83210	83211	83212	83213	83214	83215		
Z = 84 ***** Polonium *****									
84192	84193	94194	84195	84196	84197	84198	84199	84200	84201
84202	84203	84204	84205	84206	84207	84208	84209	84210	84211
84212	84213	84214	84215	84216	84217	84218			
Z = 85 ***** Astatine *****									
85196	85497	85198	85199	85200	85201	85202	85203	85204	85205
85206	85207	85208	85209	85210	85211	85212	85213	85214	85215
85216	85217	85218	85219						
Z = 86 ***** Radon *****									
86199	86200	86201	86202	86203	86204	86205	86206	86207	86208
86209	86210	86211	86212	86213	86214	86215	86216	86217	86218
86219	86220	86221	86222	86223	86224	86225	86226		
Z = 87 ***** Francium *****									
87201	87202	87203	87204	87205	87206	87207	87208	87209	87210
87211	87212	87213	87214	87215	87216	87217	87218	87219	87220
87221	87222	87223	87224	87225	87226	87227	87228	87229	
Z = 88 ***** Radium *****									
88206	88207	88208	88209	88210	88211	88212	88213	88214	88215
88216	88217	88218	88219	88220	88221	88222	88223	88224	88225
88226	88227	88228	88229	88230					
Z = 89 ***** Actinium *****									
89209	89210	89211	89212	89213	89214	89215	89216	89217	89218
89219	89220	89221	89222	89223	89224	89225	89226	89227	89228
89229	89230	89231	89232						

Z = 90 ***** Thorium *****									
90212	90213	90214	90215	90216	90217	90218	90219	90220	90221
90222	90223	90224	90225	90226	90227	90228	90229	90230	90231
90232	90233	90234	90235	90236					
Z = 91 ***** Protactinium *****									
91215	91216	91217	91218	91219	91220	91221	91222	91223	91224
91225	91226	91227	91228	91229	91230	91231	91232	91233	91234
91235	91236	91237	91238						
Z = 92 ***** Uranium *****									
92222	92223	92224	92225	92226	92227	92228	92229	92230	92231
92232	92233	92234	92235	92236	92237	92238	92239	92240	92241
92242									
Z = 93 ***** Neptunium *****									
93227	93228	93229	93230	93231	93232	93233	93234	93235	93236
93237	93238	93239	93240	93241	93242				
Z = 94 ***** Plutonium *****									
94232	94233	94234	94235	94236	94237	94238	94239	94240	94241
94242	94243	94244	94245	94246					
Z = 95 ***** Americium *****									
95232	95233	95234	95235	95236	95237	95238	95239	95240	95241
95242	95243	95244	95245	95246	95247				
Z = 96 ***** Curium *****									
96238	96239	96240	96241	96242	96243	96244	96245	96246	96247
96248	96249	96250	96251						
Z = 97 ***** Berkelium *****									
97240	97241	9742	97243	97244	97245	97246	97247	97248	97249
97250	97251								
Z = 98 ***** Californium *****									
98239	98240	98241	98242	98243	98244	98245	98246	98247	98248
98249	98250	98251	98252	98253	98254	98255	98256		

Z = 99 ***** Einsteinium *****									
99243	99244	99245	99246	99247	99248	99249	99250	99251	99252
99253	99254	99255	99256						
Z = 100 ***** Fermium *****									
100242	100243	100244	100245	100246	100247	100248	100249	100250	100251
100252	100253	100254	100255	100256	100257	100258	100259		