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FLUKA: A Multi-Particle Transport Code

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Fluka:

a multi-particle transport code

(Program version 2005)

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GENEVA
2005

Preface

The INFN–CERN Collaboration Agreement for the Maintenance and Development of the Fluka

Acknowledgements

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The Fluka Collaboration:

Any portion of FLUKA so integrated, whether modified or unmodified shall continue to be subject to these license conditions.

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Part I

A summary description of FLUKA

Chapter 1

Introduction

1.2.1 Physics

1.2.1.1 Hadron inelastic nuclear interactions

The Fluka hadron-nucleon interaction models are based on resonance production and decay below a few GeV, and on the Dual Parton model above. Two models are used also in hadron-nucleus interactions. At momenta below 3–5 GeV/c the Peanut package includes a very detailed Generalised Intra-Nuclear Cascade (GINC) and a preequilibrium stage, while at high energies the Gribov-Glauber multiple collision mechanism is included in a less refined GINC. Both modules are followed by equilibrium processes: evaporation, fission, Fermi break-up, gamma deexcitation.

1.2.1.4 Transport of charged hadrons and muons

An original treatment of multiple Coulomb scattering and of ionisation fluctuations allows the code to handle accurately some challenging problems such as electron backscattering and energy deposition in thin layers even in the few keV energy range.

Energy loss:

- Bethe-Bloch theory [19–21, 29, 30]
-

1.2.1.6 Electrons

1.2.1.9 Neutrinos

–

Transport limits:

	Secondary particles	Primary particles
charged hadrons	1 keV–20 TeV ( )	100 keV–20 Te81.1V (
neutrons	the81.1rm81.1al–20 Te81.1V (	Thermal–20 TeV ( )
antineutrons	1 keV–20 TeV (	

A quick look at

transmutation, neutrino physics, shielding of free-electron lasers, calculation of tritium production at electron accelerators, energy amplifiers, maze design for medical accelerators, etc.

The recent addition of the simulation of heavy ion interactions allows also for applications to hadrotherapy.

Chapter 2

A FLUKA beginner's guide

2.1

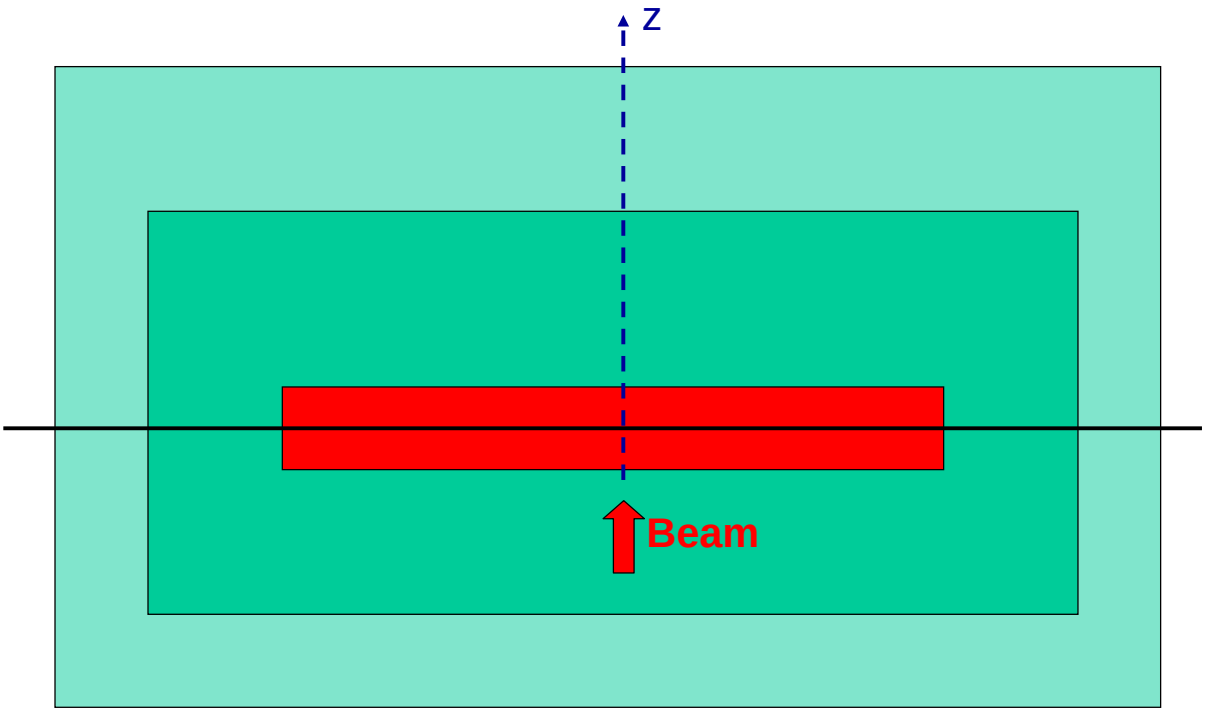
2.3 Building a FLUKA input

2.3.1 Generalities about FLUKA input

injection, the direction, etc., must be coherent with the geometrical description of the set-up, as discussed in the following section.

2.6 The geometry

SKETCH OF THE GEOMETRY (not to scale!)



allowed, but is not necessary (except for region 2) because a region is blackhole by default unless another material has been associated to it. (Region 2, if not assigned a material, is COPPER by default).

The table entitled `Regions: materials and fields`, in the standard output, can be consulted to check that material assignment has been done as desired.

supplied by the user at the end of the geometry description (see 8.2.2). All other columns are normalised

giving in input the “volume” or “area” value multiplied or divided by those factors. Options USRTRACK, USRCOLL and USRBDX can also calculate energy fluence, if the “particle” type is set = 208.0 (energy) or 211.0 (electron and photon energy).

independent runs (at least 4 or 5), each with a different independent initialisation, using the seeds written by the program at the end of each run. The `rfluka` script provided with the code on UNIX and LINUX platforms takes care of this task, provided the following card is issued in the input file:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
RANDOMIZE        1.0       0.0
```

The seeds of the random number generator are printed on a special file in hexadecimal form at the end of each group of histories (the size of a group depends on the number of histories requested in the START card).

```
GEOEND
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
MATERIAL         4.0    9.0122     1.848       5.0                     BERYLLIU
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
*  Be target, 1st and 2nd half
ASSIGNMAT        5.0       3.0       4.0
*  External Black Hole
ASSIGNMAT        1.0       1.0
*  Vacuum
ASSIGNMAT        2.0       2.0
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
* e+e- and gamma production threshold set at 10 MeV
EMFCUT        -0.010     0.010       1.0       5.0                     PROD-CUT
* score in each region energy deposition and stars produced by primaries
SCORE          208.0     210.0
* Boundary crossing fluence in the middle of the target (log intervals, one-way)
USRBDX          99.0     209.0     -47.0       3.0       4.0     400. piFluenUD
```

```
2789: old priority 0, new priority 10

Initial seed already existing

Running fluka in /home/user/flukawork/fluka_2789

============================== Running FLUKA for cycle # 1 ============================
```

At the end of each cycle the output files will be copied onto the running directory, the temporary

```
================================ Running FLUKA for cycle # 5 ===================

Removing links

Removing temporary files

Saving output and random number seed

Saving additional files generated
    Moving fort.47 to /home/fasso/Fluka/test/example005_fort.47
    Moving fort.48 to /home/fasso/Fluka/test/example005_fort.48
    Moving fort.49 to /home/fasso/Fluka/test/example005_fort.49
    Moving fort.50 to /home/fasso/Fluka/test/example005_fort.50
    Moving fort.51 to /home/fasso/Fluka/test/example005_fort.51

End of FLUKA run
```

At this time, in the working directory, the following new O014les exist:

```
example001_fort.47   example002_fort.47   ....   example005_fort.47
example001_fort.48   example002_fort.48   ....   example005_fort.48
example001_fort.49   example002_fort.49   ....   example005_fort.49
example001_fort.50   example002_fort.50   ....   example005_fort.50
example001_fort.51   example002_fort.51   ....   example005_fort.51
example001.out       example002.out       ....   example005.out
example001.err       example002.err       ....   example005.err
```

In Chapter 9 the user can O014nd a comprehensive description of the content of the Fluka standard output. For the purpose of this beginner's guide, it can just be pointed out that, according to the content of the USRBDX command, the O014les with extension fort.47

For each estimator file the program will show the content of the TITLE card of the Fuka input file,

```
Detector n:  1( 1)  piFluenUD
   (Area:         400. cmq,
    distr. scored: 209   ,
    from reg. 3 to  4,
    one way scoring,
    fluence scoring)

   Tot. resp. (Part/cmq/pr)  8.6904905E-04  +/-  0.6976866     %
   ( -->      (Part/pr)      0.3476196      +/-  0.6976866     % )
```

```
 1.5672133E-04 +/-    44.01294     %   2.1093644E-04 +/-    34.72458     %
 7.4201569E-05 +/-    33.68359     %   7.2452240E-05 +/-    33.54827     %
 8.6934262E-05 +/-    62.03180     %   1.0245090E-04 +/-    99.00000     %
 1.6312006E-04 +/-    82.06016     %   1.3002084E-04 +/-    52.15991     %
```

Soon after, the cumulative fluence distribution as a function of energy is also given:

```
**** Cumulative Fluxes as a function of energy ****
****      (integrated over solid angle)        ****


Energy boundaries (GeV):

 49.99992       40.27077       32.43475       26.12349       21.04029
 16.94620       13.64875       10.99293       8.853892       7.131072
```

```
**** Double diff. Fluxes as a function of energy ****

Solid angle minimum value (sr):   0.000000
```

2.14.3 Binning estimator

To analyse the binary output from USRBIN

2.16 Biasing

Although able to perform fully analogue particle transport calculations (i.e., to reproduce faithfully actual particle histories), in many cases of very non-uniform radiation fields, such as those encountered in shielding design, only a very small fraction of all the histories contributes to the desired response (dose, fluence) in the regions of interest, for instaalst,

Chapter 3

Installation

The Fluka

If the source code is present, the `INCLUDE` files needed to compile the program may be grouped into three files `emfadd.add`, `flukaadd.add` and `lowneuadd.add`.

A Makefile and a number of auxiliary programs split these files into individual routines and `INCLUDE` files, which are placed in 30+1 separate directories and compiled. The object files are inserted in a FLUKA library `libflukahp.a`. A shell script `lfluka` links all routines into an executable `flukahp` (the name is the leswhide29(i)14amwhir,a exet

Chapter 4

FLUKA modules (Fortran files)

Since several years, the Fluka

User oriented routines (see description in Chap. 12):

The "FLUKA User Routines" mentioned at point 3) in the FLUKA User License are those (and only those) contained in the directory `usermvax`, both in the source and binary versions of the code.

`ABSCFF` : absorption coe□cient (for optical photons)
`COMSCW` :

Table 5.2: Fluka generalised particles (to be used only for scoring)

Fluka name	Fluka number	Description
—	40	Low-energy neutrons (used only in some input options)
ALL-PART	201	All transportable particles
ALL-CHAR	202	All charged particles
ALL-NEUT	203	All neutral particles
ALL-NEGA	204	All negative particles
ALL-POSI	205	All positive particles
NUCLEONS	206	Protons and neutrons
NUC&PI+-	207	

5.2 Pre-defined materials

Materials can be easily defined by option MATERIAL (p. 142

Chapter 6

General features of FLUKA input

The input of Fluka consists of a text file containing a sequence of option lines (often called “cards”) which

```
    -100.0       0.0  -21200.0     100.0       0.0  -20800.0
STOP
#endif
```

Chapter 7

Description 9f FLUKA input options

There are more than 70 option keywords available for input in Fluka. A summary is given in Section 7.1,

EVENTBIN

ROT–DEFIni	defines rotations/translations to be applied to user-defined binnings
ROTPRBIN	sets the storage precision (single or double) and assigns possible rotations/translations for a given user-defined binning (USRBIN or EVENTBIN)
RQMD	defines some I/O parameters relevant to the heavy ion event generator Rqmd
SCORE	defines the (generalised) particles to be scored by region
SOURCE	tells Fluka to call a user-written source routine
START	defines the number of primary particles to follow, gets a primary particle from a beam or from a source, starts the transport and repeats until the predetermined number of primaries is reached
STEPSIZE	sets the maximum step size in cm (by region) for transport of charged particles
STERNHEIme	allows users to input their own values of the density effect parameters
STOP	stops input reading
TCQUENCH	sets scoring time cut-offs and/or Birks quenching parameters
THRESHOLd	defines the energy threshold for star density scoring, and sets thresholds for elastic and inelastic hadron reactions
TIME-CUT	sets transport time cut-offs
TITLE	gives the title of the run
USERDUMP	requests a collision file and defines the events to be written

For what concerns item 4, the user has a choice of several options to request the estimation of various radiometric quantities. Of course, there is no much point in running the program without requesting any result, but in a phase of input preparation it is quite common to have a few runs without any scoring commands. A typical minimum input containing only specifications for the above items 1, 2 and 3 will still produce some useful information. Looking at the standard Fluka output, the user can do several consistency checks, and can get some better insight into the problem from the final statistics and energy

and needs to read its own input, as explained in 7.56.

7.1.3.2 General setting options

The di□cult task of choosing the best settings for a calculation problem is made much easier by existence of

In early Monte Carlo programs results could depend critically on the size of the step, mainly due to

1.1.3.6 Time cut-o s

For time-dependent calculations, two time cut-o options are available: one for particle transport, TIME–CUT,

particle type input via the BEAM command can only be a generic heavy ion.

counter of crossings, not weighted by inverse cosine: but despite a widespread credence, current is only

7.1.6.1 Simple biasing options

7.1.8 Miscellaneous

Option COMMENT (7.8) isnot often used. Itsmainfunction istoinsert acertain number of commentlines

7.2 ASSIGNMAt

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....
MATERIAL        13.0      27.0       2.7      10.0       0.0      0.0 ALUMINUM
ASSIGNMA        10.0       1.0      15.0       0.0       1.0      0.0
ASSIGNMA         2.0       5.0      17.0       6.0      -1.0      0.0
ASSIGNMA         2.0      16.0      18.0       2.0       0.0      0.0
*       The above definitions mean that all regions from 1 to 15 are
*       aluminium with a magnetic field, except regions 5 and 11 which are
*       vacuum without any magnetic field. Regions 16, 17 and 18 are also
*       vacuum without field.
*       Note that in the above example material 10 has been defined
*       overriding the pre-defined FLUKA aluminium material, but keeping
```

Example:

```
*         The following BEAM card refers to a 100 keV pencil-like
*         electron beam:
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAM          -1.E-4       0.0       0.0       0.0       0.0      1.0 ELECTRON
*         The next option card describes a parallel proton beam with a
*         momentum of 10.0 +/- 0.2 GeV/c, with a gaussian profile in
*         the x-direction and in the y-direction described by standard
*         deviations sigma_x = 1. cm (FWHM = 2.36 cm) and sigma_y = 0.5
*         cm (FWHM = 1.18 cm).
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAM            10.0       0.2       0.0     -2.36     -1.18      1.0 PROTON
*         The next example concerns a negative muon beam of 2 GeV
*         kinetic energy, with a divergence of 3 mrad.
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAM            -2.0       0.0       3.0       0.0       0.0      1.0 MUON-
*         The next BEAM card describes a 137-Cs isotropic source
BEAM       -661.7E-6       0.0      1.E4       0.0       0.0      1.0 PHOTON
```

7.4 BEAMAXES

7.5 BEAMPOS

3. Beam divergence and transversal profile defined by option BEAM (p. 7.3), as well as polarisation defined by option POLARIZAti (p. 7.57), are meaningful only if the beam direction is along the positive z-axis, unless a command BEAMAXES is issued to establish a beam reference frame different from the geometry frame (see p. 7.4).

Examples:

```
*         A beam parallel to the x-axis starting at a point of
*         coordinates -0.1, 5.0, 5.0 :
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7...
BEAMPOS         -0.1       5.0       5.0       1.0       0.0       0.0

*         A beam perpendicular to the x-axis, with director cosines
*         0., 1/sqrt(2), -1/sqrt(2) with respect to x, y and z,
*         starting at point 0.0, 0.0, 0.0 :
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAMPOS          0.0       0.0       0.0       0.0 0.7071068      0.0 NEGATIVE
```

7.6 BIASING

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BIASING          2.0       0.0      10.0       7.0      11.0      2.0
BIASING          2.0       0.0      15.0       8.0       9.0      0.0
BIASING         -1.0       0.0       3.0       4.0       0.0      0.0
BIASING          1.0       0.7       0.4       3.0       8.0      0.0PRINT
```

7.8 COMMENT

Examples:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
COMMENT          3.0
```

7.9 COMPOUND

Defines a compound or mixture, made of several materials, or even a mixture of di erent isotopes

See also LOW–MAT, MATERIAL, MAT–PROP

neutron data set is identified either by name (if equal to a Fluka

7.11 DCYSCORE

Associates selected scoring detectors of given estimator type with user-

7.12 DCYTIMES

7.13 DEFAULTS

Sets Fluka *defaults suitable for a specified kind of problems. Starting from* Fluka99.5 *(June 2000) the standard defaults are those described under NEW–DEFAults below. That is, if no DEFAULTS card is issued the code behaves as if a card with NEW–DEFAults was given. be given.*

See also GLOBAL

4.

Notes

7.15 DETECT

Note: if no trigger region is given (i.e., no region with negative sign), a simple event-by-, a sigNote7.2-11.9552870tak

7.16 DISCARD

7.17 DPMJET

Defines some I/O parameters relevant to the heavy ion event generator Dpmjet.

See also BME, EVENTYPE, MYRQMD, PHYSICS, RQMD

Option DPMJET

7.18 ELCFIELD

7.19 EMF

7.20 EMF–BIAS

WHAT(5) = upper bound of the region indices where the selected leading particle biasing has to be played

7.21 EMFCUT

Sets the energy thresholds for electron and photon production in different materials, and electron and photon transport cut-offs in selected regions.

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7...
MATERIAL         13.    26.98     2.6989        3.        0.       0. ALUMINUM
MATERIAL         82.   207.20      11.35        4.        0.       0. LEAD
MATERIAL         29.    63.546      8.96       12.        0.       0. COPPER
MATERIAL          6.    12.000      2.00       26.        0.       0. CARBON
MATERIAL          7.    14.000    0.0012       27.        0.       0. NITROGEN
MATERIAL          8.    16.000    0.0014       28.        0.       0. OXYGEN
MATERIAL          1.     1.000    0.0001       29.        0.       1. HYDROGEN
MATERIAL          0.       0.0    1.0000       30.        0.       0. TISSUE
COMPOUND     5.57E-3      26.0  1.118E-3       27.  2.868E-2      28. TISSUE
COMPOUND    6.082E-2      29.0         0.        0.        0.       0. TISSUE
EMFFIX            3.      0.15        4.      0.15       12.     0.15
EMFFIX           30.      0.05        0.        0.        0.       0. PRINT
*    In this example, a maximum energy loss per step of 15% is requested
*    for aluminium, copper and lead, while a more accurate 5% is requested
*    for tissue
```

7.23 EMFFLUO

Activates a detailed treatment of photoelectric interactions and of the fol-

7.24 EMFRAY

Activates Rayleigh (coherent) scattering and Compton binding corrections

WHAT(1) ≥ 1.0:

7.25 EVENTBIN

Example 1:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....
EVENTBIN        10.0208.0      25.0150.0200.0180. Firstscore
EVENTBIN      -150.0100.0-20.0      75.0      50.020.0  &
*   In the above example, the user requests an event-by-event scoring of
*   energy deposition (generalised75.566Tfarticlthe 25(le,)-52iionaf
*thests =heaf
* -1ts don-15(le,)-522he -1tsan01ts dof
* 25(le,)-525(don)-5210he on1(1ts)-52biistsan don 15(.of)]TJ0-10.959Td[(*)-157T(the)-52resultstsr 20.theaf
* theFirstsco".1:
```

7.26 EVENTDAT

For calorimetry only.

```
      WRITE(8,'(A80)') RUNTIT
      WRITE(8,'(A32)') RUNTIM
      WRITE(8,'(A,I6,5X,A,A,I4)') 'Number of regions: ', NREGS,
     &           ' Number of scored quantities: ', NSCO
      WRITE(8,'(A,4I6)') 'The scored quantities are: ',
```

7.27

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....
EXPTRANS          1.       0.8       10.       18.        8.       0.
EXPTRANS         -1.        7.        8.        0.        0.       0.
*  Exponential transformation is requested for photons ,050particle no. 7,051
```

ed hadrons to a fixed fraction

tep (must not be > 0.2)
T4.938Td(is)-334(u)1(se)-1(d)-333(ith)]TJ/F508966T55.4590Td(SD

7.30 FREE

Activates free-format input

See also GLOBAL

7.31 GEOBEGIN

and debugging messages. Minor tracking problems, however, are reported on the error message file (logical unit 15, see Chap. 3 and Sec. 9.4), unless reporting has been de-activated by setting

7.32 GEOEND

4. It must be stressed too that the geometry debugger can be very time consuming, so don't ask for 100 μm

WHAT(5) : flag to request free format in the geometry input for bodies and regions. This format is described in 8.2.3.2 and 8.2.6.3, and requires the use of names (alphanumerical 8-character

7.35 IONFLUCT

Calculates ionisation energy losses of charged hadrons, muons, and electrons/positrons with ionisation fluctuations.

See also DELTARAY

WHAT(1) ≥ 1.0: switches on restricted energy loss fluctuations for hadrons and muons
≤ -1.0: switches o restricted energy loss fluctuations for hadrons and muons
= 0.0: ignored
Default : restricted energy loss fluctuations for hadrons and muons are activated if option DEFAULTS is missing or if it is used with

Note

1. The energy loss fluctuation algorithm is fully compatible with the DELTARAY option (p. 89

7.37 LAM–BIAS

|WHAT(2)| ≥ 1.0:

5. The biasing function for the decay direction is of the form $e^{-\frac{1-cos(\theta)}{\lambda}}$ where θ is the polar angle between

7.38 LOW–BIAS

Notes

1. The groups are numbered in

7.39 LOW–DOWN

7.40 LOW–MAT

7.41 LOW–NEUT

Notes

1. In Fluka, transport of neutrons with energies lower than a certain threshold is performed by a multigroup algorithm. For the neutron cross-section library currently used by Fluka, this threshold is 0.0196 GeV. The multi-group transport algorithm is described in Chap. 10.
2. Evaporation option (see EVENTYPE, p. 116) is mandatory if LOW–NEUT is requested. If low-energy neutrons are not transported (because of the chosen DEFAULTS, or because a DEFAULTS card is absent), the energy of neutrons beler threshold (default or set by PART–THR, p. 172) is deposited on the spot.
   This is true also for evaporation neutrons. If there is no interest in transporting low-energy neutrons, but this feature is not desired, it is suggested trequest LOW–NEUT, and to use LOW–BIAS (p. 135) with a group cut-o WHAT(1) = 1.0.
3. Gamma data are used only for capture gamma generation and not for transport (transport is done via the 85cm0g0G1006.9620Td[lect)1(ro)]TF628.966Tf22.5510Td[M)]TF498.966Tf10.0570Td[agneti)1(c)]TF628.966T

7.42 MATERIAL

7.43

For SDUM = LOWNTEMP:

WHAT(1) > 0.0: Temperature ratio (T_{actual}/T_{xsec}) with respect to the nominal one. The nominal temperature T_{xsec} (given by WHAT(3), see below) is the temperature for which the neutron cross-sections of the Fluka material(s) concerned have been prepared (see Tag(r)10.3, p. 295). See Notes 4, 5

Notes

7.45

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
```

7.46 MULSOPT

Sets the tracking conditions for multiple Coulomb scattering (MCS), for both hadrons/muons and e^+e^-. Can also be used to activate single scattering.

See also EMFFIX, FLUKAFIX, MCSTHRES, STEPSIZE

For SDUM = GLOBAL, GLOBEMF, GLOBHAD:

WHAT(1) : controls the step optimisation for multiple Coulomb scattering (see Note 1) and the number

: Fano correction for inelastic interactions of charged hadrons and muons on atomic electrons is switched o

: Fano correction for inelastic interactions of charged hadrons and muons on atomic electrons [48] is switched on

FANO–OFF

=

154

MULSOPT

FANO–ON

WHAT(6) = step length in assigning indices.
(“*. . . in steps of WHAT(6)* ”)
Default = 1.0

SDUM =

< 0.0: single scattering is not activated
= 0.0: ignored
Default : single scattering is not activated

WHAT(6) (meaningful only if single scattering is activated at boundaries and when step is too short: see WHAT(4) above)
> 0.0: number of single scatterings to be performed when crossing a boundary
= 0.0: ignored
< 0.0: resets the default
Default = 1.0

Notes

1.

7.47 MUPHOTON

7.48 MYRQMD

Not yet implemented. Prepared for new QMD generator

7.49 OPEN

Defines input/output files to be connected at run-time.

WHAT(1) > 0.0: logical unit number of a *formatted* file to be opened
< 0.0: logical unit number of an

7.50 OPT–PROD

Requests and controls production of Cherenkov, Transition and Scintillation Radiation in specified materials.

See also OPT–PROP, Chap. 13, and 13.2 examples in

SDUM = CERE–OFF: switches o Cherenkov production

For

WHAT(1) – WHAT(3): not used

WHAT(4) – WHAT(6): assignment to materials, see below

SDUM = CERE–OFF

SDUM = TRD–OFF

For

Notes

1. Optical photons such as those produced by Cherenkov e□ect are distinguished b b Fluka name (OPTIPHOT) and by t6eir Fluka id-nber (-1), as sho in 5.1.
2. To transport optical photons, it is necessary to define the optical properties of t28h6e relevan materials b of option OPT–PROP (p. 164). Users can also write t6eir own routines USRMED (p. 323), which is called at ever-64382(step64381(and)-382(at)-380(b)-29(oundar-64382(c)1(ros)-1(sings64381(whe)-1(n)-381(act)1(iv)57(ated64381(w)-1

7.51 OPTgPROP

SDUM = RESET

For SDUM = METAL: flag the material as metal

WHAT(1) = 1st optical property (not used at the moment)

WHAT(2) = 2nd optical property (not used at the moment)

WHAT(3) = 3rd optical property: (1 ÷ r), where r

WHAT(4) ÷ WHAT(6): assignment to materials, see below

Default = 0.0

2

For all previous SDUMs:

WHAT(4) = lower bound of the indices of materials to which the indicated optical properties refer
("*From material WHAT(4)...*")
Default = 3.0

WHAT(5) = upper bound of the indices of materials to which the indicated optical properties refer
("*...to material WHAT(5)...*")
Default = WHAT(4)

WHAT(6) = step length in assigning indices
("*...in steps of WHAT(6)*") 3.0

Example 1:

```
* Optical photon transport requested between 3.E15 and 7.E15 rad/s
* (4.77E5 and 1.11E6 GHz, or 314 to 628 nm) for materials 6,9,12,15 and 18
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
OPT-PROP       3.E15     6.E15     7.E15       6.0      18.0       3. OM-LIMIT
* User routine USRMED called when an optical photon is going to be transported
* in materials 6, 12 and 18
MAT-PROP         1.0       0.0       0.0       6.0      18.0       6. USERDIRE


Example 2:
* Material 11 has a reflectivity index = 0.32
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
OPT-PROP         0.0       0.0      0.32      11.0       0.0       0. METAL
```

Example 3:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
* Optical photon transport requested between 300 and 600 nm for water.
* (material 9). The optical properties are for the Na D line (589 nm)
```

7.52 PAIRBREM

Controls simulation of pair production and bremsstrahlung by high-energy

Notes

1. Initialisation of bremsstrahlung and pair production by heavy charged particles is very demanding in com-

7.53 PART–THRes

Sets di erent energy transport cut-o s for hadrons, muons and neutrinos.

See also EMFCUT, LOW–BIAS, THRESHOLd

The meaning of WHAT(1) depends also on the value of

Notes

1. When applied to neutrons, the cut-o energy defined by PART–THRes refers to the energy boundary between high-energy and low-energy neutrons, i.e., the upper limit of the first energy group in the multigroup transport

7.54 PHOTONUC

Activates gamma interactions with nuclei.

Example 1:

```
*GiantResonanceandQuasideuteronphotonuclearinteractionsarerequested
*inmaterial18.Thephotonhadronicinteractionlengthisartificially
*shortenedbyafactor0.02inordertoimprovestatistics
```

7.55 PHYSICS

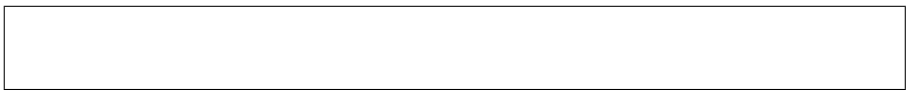
Allows to override the standard Fluka

```
For SDUM = EVAPORATion
```

7.56 PLOTGEOM

than one of the points P2 on the current line satisfies the quoted condition for a given P1, then only the nearest one to that P1 is taken.

7.57 POLARIZAti



|WHAT(1)| ≤ 1.0:

Defines the polarisation of a photon beam or source and activates transport

2. The program takes care of properly normalising the cosines unless they are badly unnormalised (in the latter case the code would reset to no polarisation). If WHAT(4) ≥ 1.0, the code makes sure that the two vectors are orthogonal within the minimum possible rounding errors.
3.

7.58 RADDECAY

requests simulation of radioactive decays and sets the corresponding biasing and transport conditions

See also DCYTIMES, DCYSCORE, IRRPROFIle, RESNUCLEi

WHAT(1) :

7.59 RANDOMIZe

7.60 RESNUw0]187

7.61 ROT–DEFIni

Defines rotations and translations to be applied to binnings.

See also EVENTBIN, ROTPRBIN, USRBIN

WHAT(1) : assigns a transformation index and the corresponding rotation axis
≤ 0.0

`j = 3:`

$$\begin{bmatrix} X_{new} \\ Y_{new} \\ Z_{new} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \end{bmatrix}$$

7.62 ROTPRBIN

7.64

4. The SCORE card defines the following scoring:
   (a) scoring by region the density of stars produced by the selected particles (if applicable, i.e., if the particles are hadrons — but not low-energy neutrons — photons or muons, or families of them). Stars produced by primary particles can be scored with id-number `210.0`, all stars with `201.0`.
   Results will be in stars/cm^3 p-enerer primary particle if region volumes have been input by setting `IVOPT = 3`

7.65 SOURCE

Invokes the use of a user-defined source routine SOURCE *to sample the primary particles.*

See also BEAM, BEAMPOS, POLARIZAti, USRICALL
us1knsd-3278koesened]TJ/F189.963Tf2161773lTd[(SOURCE)]TJ/F49.963Tf21.8380Td[(B.40278kT)83()40278k(

5. In old versions of Fluka, the call to SOURCE was requested by means of a flag in card START

7.66 START

Defines the termination conditions, gets a primary from a beam or from a source and starts the transport.

See also

7.67 STEPSIZE

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
ASSIGNMAT        2.0      15.0      30.0       5.0       1.0       0.0
* A magnetic field is present in vacuum r1gions 15, 20, 25 and 30.
MGNFIELD        20.0       0.2      0.10       0.0       0.0       0.0
STEPSIZE       -0.05       0.0      20.0      25.0       0.0       0.0
STEPSIZE         0.3       0.0      15.0       0.0       0.0       0.0
```

7.68 STERNHEIme

Allows to input Sternheimer density e ect parameters

7.69 STOP

Stops the execution of the program

See also START

WHAT(1) – WHAT(6) and SDUM: not used

Default (option STOP not given): no effect (the program stops at the end of the run when the conditions set in the START command (p. 199

7.70 TCQUENCH

Sets time cut-o s and/or quenching factors when scoring using the USRBIN or the EVENTBIN options.

See also TIME–CUT

WHAT(1) > 0.0: time cut-o for scoring (seconds)
< 0.0: resets any previously requested time cut-o to default (∞)
= 0.0: ignored

WHAT(2) > 0.0: first Birks law coe cient in g/(MeV·

7.71 THRESHOLd

7.72 TIME–CUT

7.73 TITLE

Notes

1. These weights are really extra, i.e., the results are multiplied by these weights at scoring time, but printed titles, headings and normalisations are not necessarily valid. It is the user's responsibility to interpret correctly the output. Actually, it is recommended to insert into standard output a user-written notice informing about the extra weighting
2. Setting the incident particle weight to a value di□erent from

7.76 USRBDX

6. When scoring neutron fluence or current, and the requested energy bin structure overlaps with that of the low-energy neutron groups, bin boundaries are forced to coincide with group boundaries and no bin can be smaller than the corresponding group.

```
 PARAMETER ( MXSCOR = MXENER*MXANGL )
 PARAMETER ( NMXGRP = 100 )       ! # of low-energy neutron groups

 LOGICAL LFUSBX, LWUSBX, LLNUSX
 CHARACTER RUNTIT*80,RUNTIM*32,TITUSX*10,FILNAM*80

 DIMENSION EBXLOW(MXUSBX), EBXHGH(MXUSBX), ABXLOW(MXUSBX),
&          ABXHGH(MXUSBX), DEBXBN(MXUSBX), DABXBN(MXUSBX),
&          AUSBDX(MXUSBX), NEBXBN(MXUSBX), NABXBN(MXUSBX),
&          NR1USX(MXUSBX), NR2USX(MXUSBX), ITUSBX(MXUSBX),
&          IDUSBX(MXUSBX), IGMUSX(MXUSBX), LFUSBX(MXUSBX),
&          LWUSBX(MXUSBX), LLNUSX(MXUSBX), TITUSX(MXUSBX),
&          ENGMAX (NMXGRP+1), SCORED(MXSCOR), ELIMIT(MXUSBX),
&          MX(MXUSBX), NHIGH(MXUSBX)

 DOUBLE PRECISION CUMUL, ANGINT, EN1, EN2, ELIMIT, DIFF

 WRITE(*,*)' Type the name of the input file:'
 READ (*,'(A)') FILNAM
 LQ = INDEX(FILNAM,' ') - 1
 OPEN (UNIT=1, FILE=FILNAM, STATUS='OLD', FORM='UNFORMATTED')
 OPEN (UNIT=2, FILE=FILNAM(1:LQ)//'.txt', STATUS='NEW')
```

```
END IF
```

```
=  8.0:
```

WHAT(4) = For Cartesian binning: X_{max}
For R–Z and R–Φ–Z binning: R_{max}

```
WHAT(5) =
```

7. When scoring energy deposition (generalised particles 208.0 and 211.0), it is recommended to set in the first USRBIN card WHAT(1) = 10.0, 11.0,...17.0 (rather than

7.78 USRCOLL

Defines a detector for a collision fluence estimator

See also USRBDX, USRBIN, USRTRACK

The full definition of the detector may require two successive cards. The second card, identified by the character " &

7.79 USRICALL

7.80 USROCALL

Calls user-dependent output.

See also

7.81 USRTRACK

Defines a detector for a track-length fluence estimator.

7.82 USRYIELD

For SDUM = BEAMDEF:

WHAT(1) = (projectile particle index)
Default = IJBEAM (beam particle)

WHAT(2) = target particle index (used by the code to define the c.m.s. frame)
Default = 1.0 (proton)

WHAT(3) = projectile momentum
Default = PBEAM (beam momentum)

WHAT(4,5,6) = projectile direction cosines
Default = UBEAM, VBEAM, WBEAM (beam direction cosines)

Default (option USRYIELD

```
*           Lorentz transformations, Feynman X etc.                    *
*  RUNTIM = date and time of the run (as printed on standard output)   *
*  RUNTIT = title of the run (as given by card TITLE)                  *
*  SCORED = result array                                               *
*  SGUSYL = aUopted cross section (if any)                             *
```

Example:

```
*...+....1....+.........+....3....+....4....+....5....+....6....+....7...+...8
USRYIELD      1399.0       13.      21.0       3.0       2.0       1.0TotPi+(E)
USRYIELD        50.0     0.001     100.03.14159265       0.0       3.0 &
* Score double differential yield of positive pions going from region 3 to
* region 2 with a polar angle between 0 and pi with respect to the beam
```

Default (if no WW–PROFIle

5. It can also be said that WW–FACTOr and BIASING

(option

7.85 WW–THRESh

Chapter 8

Combinatorial Geometry

8.1 Introduction

The Combinatorial Geometry (CG) used by Fluka is a modification of the package developed at ORNL for the neutron and gamma-ray transport program Morse [44] which was based on the original combinatorial

the GLOBAL command, p. 125). The remaining 60 characters can be used for any alphanumeric string at the user's choice.

8.2.3 Body data

8.2.4.3 Sphere. Code: SPH

A SPH (Fig. 8.3) is defined by 4 numbers: V_x, V_y, V_z

```
*  centred at point x=5, y=5, z=5, its axis making equal angles to
*  the three coordinate axes).
```

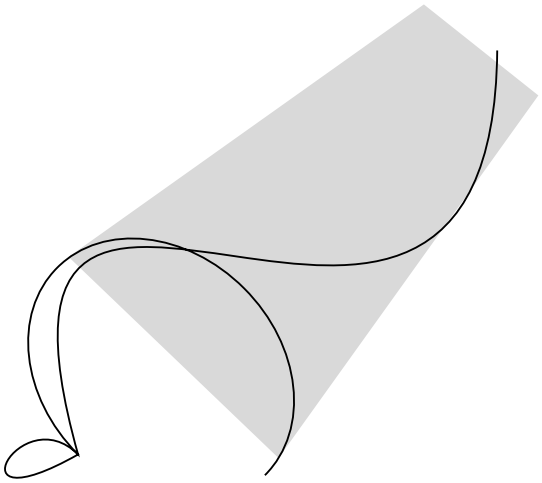


Fig. 8.6: Truncated Right Angle Cone (TRC)

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+.
  ELL  003               -400.0                  0.0                  0.0
                          400.0                  0.0                  0.0
                          1000.
```

The same example in free format:

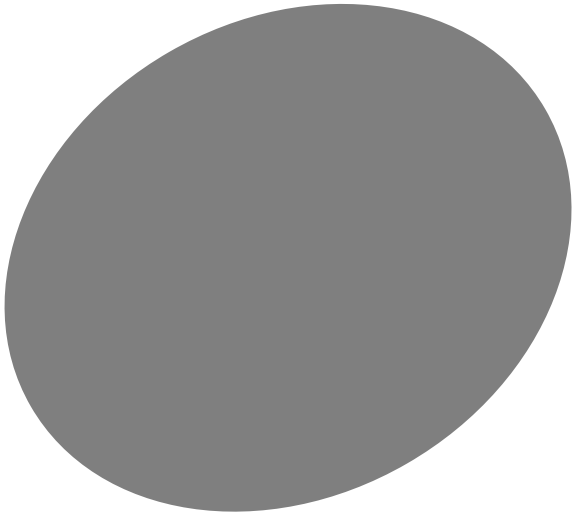


Fig. 8.7:

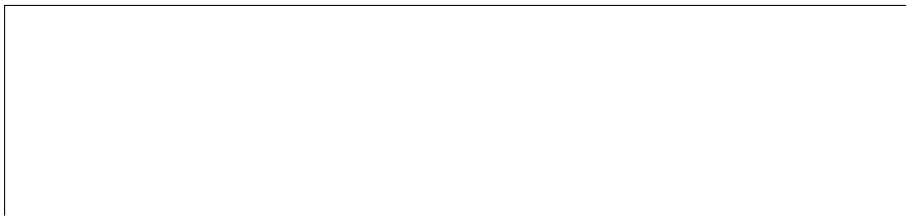
```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7..
  XCC  013    -480.0      25.0     300.0
* (an infinite cylinder of radius 300 cm, with axis defined by y=-480,
*  z=25)
```

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+.
  ZEC  101                 15.0                319.0                 33.0
                           80.0
```

The same body, described in free format:

```
ZEC  ChimneyA  15.0  319.0  33.0  80.0
```

NOTE



for this so-called “contiguity list”, and it is not essential that it be exact (if left blank, it is set to 5).

Default = 1.0

WHAT(4) =

```
      PARAMETER ( NX = 256 )
      PARAMETER ( NY = 256 )
      PARAMETER ( NZ = 220 )
      DIMENSION GOLEM(NX,NY,NZ)
      INTEGER*2 GOLEM
      CHARACTER TITLE*80
      DIMENSION IREG(1000), KREG(1000)
      INTEGER*2 IREG, KREG
*
      CALL CMSPPR
      DO IC = 1, 1000
         KREG(IC) = 0
      END DO
      OPEN(UNIT=30,FILE='ascii_segm_golem',STATUS='OLD')
      READ(30,*) GOLEM
      NO=0
      MO=0
      DO IZ=1,NZ
         DO IY=1,NY
            DO IX=1,NX1,NY
```

- The usual region list of NR regions, with the space occupied by body NB+1 (the "voxel volume") subtracted. In other words, the NR regions listed must cover the whole available space, except the space corresponding to the "voxel volume". This is easily obtained by subtracting body NB+1 in the relevant region definitions, even though this body is not explicitly input at the end of the body list. The code will automatically generate and add several regions:
  - a region NR+1

Chapter 9

Output

The output of Fluka consists of:

- a main (standard) output, written on logical output unit LUNOUT (predefined as 11 by default)
- a scratch file, of little interest to the user, written on output unit LUNGEO (16 by default). However, if the rfluka

to option LOW–NEUT, p. 141

bremsstrahlung by heavy particles (set with PAIRBREM, p. 170).

(k) Photonuclear reaction requests

– Energy deposited by hadron and muon dE/dx

RANDOMIZe (p. 186, is written in hexadecimal format.

9.4 Error messages

```
MAGNEW, TXYZ: ...[sum of the squares]... U,V,V: ...[3 cosines]...
```

A similar message may be issued by the tracking ro]TJΩ.GEOFAR:

```
GEOFAR, TXYZ: ...[sum of the squares]... U,V,V: ...[3 cosines]...
```

1.

```
Cartesian binning n.   1  "Cufront   " , generalised particle n.  208
   X coordinate: from -2.1100E-01 to  5.5910E+00 cm,    58 bins ( 1.0003E-01 cm wide)
   Y coordinate: from  0.0000E+00 to  5.4010E+00 cm,    53 bins ( 1.0191E-01 cm wide)
   Z coordinate: from  0.0000E+00 to -1.0000E-03 cm,     1 bins (-1.0000E-03 cm wide)
   Data follow in a matrix A(ix,iy,iz), format (1(5x,1p,10(1x,e11.4)))
```

```
*****  Test track-length/coll. reading program for the manual                    *****

          DATE: 10/25/ 4,  TIME: 10:32:59
```

9.7 RAY output

Tracking RAY pseudoparticles (Chap. 14, p. 336) produces only an unformatted file. No formatted output is available.

9.8-720.902cmBT/F830.580Td[(RA)1(YUs-1()]TJ/r-generted)-3-1()(out76tput)]TJ/F89.963Tf-53.5190Td

Chapter 10

Low-energy neutrons in FLUKA

10.1

The standard cross-section set has 72 neutron energy groups and 22 gamma groups, a structure which has been chosen for practical considerations. Gamma energy groups are used only for (n,γ) production, since transport of photons in Fluka is continuous in energy and angle and is performed through the EMF module.

Each material is identified by an alphanumeric name (a string not longer than 8 characters, all in upper case), and by three integer identifiers. Correspondence with Fluka

Table 10.1: Neutron energy group structure of the 72-group ENEA liroubrary

Neutron group n.	Lower limit (GeV)	Upper limit (GeV)
1	$1.7500 \cdot 10^{-2}$	$1.9600 \cdot 10^{-2}$
2	$1.4918 \cdot 10^{-2}$	$1.7500 \cdot 10^{-2}$
3	$1.3499 \cdot 10^{-2}$	$1.4918 \cdot 10^{-2}$
4	$1.2214 \cdot 10^{-2}$	$1.3499 \cdot 10^{-2}$
5	$1.1052 \cdot 10^{-2}$	$1.2214 \cdot 10^{-2}$
6	$1.0000 \cdot 10^{-2}$	$1.1052 \cdot 10^{-2}$
7	$9.0484 \cdot 10^{-3}$	$1.0000 \cdot 10^{-2}$
8	$8.1873 \cdot 10^{-3}$	$9.0484 \cdot 10^{-3}$
9	$7.4082 \cdot 10^{-3}$	$8.1873 \cdot 10^{-3}$
10	$6.7032 \cdot 10^{-3}$	$7.4082 \cdot 10^{-3}$
11	$6.0653 \cdot 10^{-3}$	$6.7032 \cdot 10^{-3}$
12	$5.4881 \cdot 10^{-3}$	$6.0653 \cdot 10^{-3}$
13	$4.9659 \cdot 10^{-3}$	$5.4881 \cdot 10^{-3}$
14	$4.4933 \cdot 10^{-3}$	$4.9659 \cdot 10^{-3}$
15	$4.0657 \cdot 10^{-3}$	$4.4933 \cdot 10^{-3}$
16	$3.6788 \cdot 10^{-3}$	$4.0657 \cdot 10^{-3}$
17	$3.3287 \cdot 10^{-3}$	$3.6788 \cdot 10^{-3}$
18	$3.0119 \cdot 10^{-3}$	$3.3287 \cdot 10^{-3}$
19	$2.7253 \cdot 10^{-3}$	$3.0119 \cdot 10^{-3}$
20	$2.4660 \cdot 10^{-3}$	$2.7253 \cdot 10^{-3}$
21	$2.2313 \cdot 10^{-3}$	$2.4660 \cdot 10^{-3}$
22	$2.0190 \cdot 10^{-3}$	$2.2313 \cdot 10^{-3}$
23	$1.8268 \cdot 10^{-3}$	$2.0190 \cdot 10^{-3}$
24	$1.6530 \cdot 10^{-3}$	$1.8268 \cdot 10^{-3}$
25	$1.4957 \cdot 10^{-3}$	$1.6530 \cdot 10^{-3}$
26	$1.3534 \cdot 10^{-3}$	$1.4957 \cdot 10^{-3}$
27	$1.2246 \cdot 10^{-3}$	$1.3534 \cdot 10^{-3}$
28	$1.1080 \cdot 10^{-3}$	$1.2246 \cdot 10^{-3}$
29	$1.0026 \cdot 10^{-3}$	$1.1080 \cdot 10^{-3}$
30	$9.0718 \cdot 10^{-4}$	$1.0026 \cdot 10^{-3}$
31	$8.2085 \cdot 10^{-4}$	$9.0718 \cdot 10^{-4}$
32	$7.4274 \cdot 10^{-4}$	$8.2085 \cdot 10^{-4}$
33	$6.0810 \cdot 10^{-4}$	$7.4274 \cdot 10^{-4}$
34	$4.9787 \cdot 10^{-4}$	$6.0810 \cdot 10^{-4}$
35	$4.0762 \cdot 10^{-4}$	$4.9787 \cdot 10^{-4}$
36	$3.3373 \cdot 10^{-4}$	$4.0762 \cdot 10^{-4}$

^{4} 4. $^{\cdot}$ 4

Table 10.2: Gamma energy group structure of the ENEA library

Gamma	Lower limia	Upper limia

. . . Continues. . .

. . . Continues. . .

Chapter 11

Collision tape

11.1 What is a collision tape and what is its purpose

A U134collision tape" is a U014le where quantities describing selected events are recorded in the course of a

3) data concerning local (point) energy deposition
4) any combination of the three above

Data are written on the collision tape in single precision and unformatted, but it is also possible for the user to modify the MGDRAW

= 10: elastic interaction recoil
= 11: inelastic interaction recoil
= 12: stopping particle
= 14: escape

ICODE = 2*x*: call from subroutine EMFSCO (electromagnetic part of Fluka);
= 20: local energy deposition (i.e. photoelectric)
= 21: below user-defined transport cut-o (but larger than EMF production cut-o)
= 22: below both user-defined transport cut-o and EMF production cut-o
= 23: escape

ICODE = 3*x*: call from subroutine KASNEU (low-energy neutron part of Fluka)
= 30: target recoil
= 31: neutron below threshold
= 32: escape

ICODE = 4*x*: call from subroutine KASHEA (heavy ion part of Fluka)
= 40: escape

ICODE = 5*x*: call from subroutine KASOPH (optical photon part of Fluka)
= 50: optical photon absorption
= 51: escape

In Case 3, the following variables are written:

First record:

```
2270.2673g0G1001-538.6308d[(2-270.2673g0179.63Tf-52.1308d[(2270.2673051)]TJ/F179.983Tf-22
```

Chapter 12

User routines

12.1.1 `INCLUDE` files

12.2 Description of available user routines

12.2.1 ABSCFF: user defined ABSorption CoeFFicient

Argument list (all variables are input only)		
WVLNGT	:	photon wavelength (in cm)
OMGPHO	:	angular frequency ($\omega = 2\pi\nu$) of the photon (in s^{-1})
MMAT	:	material index

Function ABSCFF

12.2.7

LUSRBL defines another discrete (integer) variable (by default: lattice number)

Argument list (all variables are input only)
IJ : particle type
PCONTR : particle momentum
XFLK, YFLK, ZFLK : particle position
MREG : current region
LATCLL : current lattice cell
ICALL : internal code calling flag (not for general use)

FUSRBV defines a continuous (double precision) variable (by default: pseudorapidioy with respect to the Z axis)

Argument list (all variables are input only)
IJ : particle type
PCONTR : particle momentum
XFLK, YFLK, ZFLK : particle position
MREG : current region
ICALL : internal code calling flag (not for general use)

The 3 functions are called at track-length events. What is scored is the particle track-length multiplied by the particle's weight, possibly modified by a user-written FLUSCW (1(c)12.6), as a function of the 3 variables defined by MUSRBR, LUSRBL and FUSRBV.

12.2.10 LATTIC: symmc transformation for lattice geometry

Subroutine LATTIC is activated by one or more LATTICE cards in the geometry input (1(c)12.9). It is expected to transform coordinates and direction cosines from any lattice cell (defined by card LATTICE) to

LATTIC returns the tracking point coore-43cnateSB(card).

When 1(g)-430284(l)1(attic430283(option)-282(is30283(activ)56(ated,)-293(1(g)-430283(trac)

The magnetic field spatial distribution is often read and interpolated from an external field map. Note that in any case the direction cosines *must* be properly normalised in double precision (e.g., `BTX = SQRT(ONEONE - BTY**2 - BTZ**2)`), even if `B = 0.0`.

Please read carefully the notes on option MGNFIELD (p. 151).

12.2.12

MTRACK : number of energy deposition events along the track
JTRACK : type of particle
ETRACK : total energy of the particle
WTRACK : weight of the particle
NTRACK values of XTRACK, YTRACK, ZTRACK: end of each track segment
MTRACK values of DTRACK: energy deposited at each deposition event
CTRACK :

ICODE : see argument list
JTRACK, ETRACK, WTRACK : see MGDRAW above

Information about the secondary particles produced is available in COMMON GENSTK

12.2.16 RFLCTV: user defined ReFLeCTiVity

Argument list (all variables are input o-ly)		
WVLNGT	:	photo- wavelength (i- cm)
OMGPHO	:	angular frequency ($\omega = 2\pi\nu$) of the photo- (i- s^{-1})
MMAT	:	material i-dex

Functio- RFLCTV returns a user-defined of the current material for an optical photo- of the give- wavelength or frequency..
It is activated by command OPT–PROP with SDUM = METAL and WHAT(3) < -99. See Sec. 7.51 a-d Chap. 13 for more informatio-.

12.2.17

12.2.19.4 Sampling from a generic distribution

One way to sample a value X

```
      INCLUDE '(SOURCM)'
      INCLUDE '(CHEPSR)'
```

These values can be used as parameters or switches for a multi-source routine capable to handle several cases, or to identify an external file to be read, etc., without having to compile and link again the routine.

In the SOURCE routine there are a number of mandatory statements, (clearly marked as such in accompanying comments) which must not be removed or modified. The following IF blo s27(k)-253(init)1(ialise)-1(s)-254(IF)1(()s255(k)e4
i.e., just after the call to SOURCE: see

12.2.24)

At the time SOURCE is called, the particle bank FLKSTK

```
         TZFLK (NPFLKA) = SQRT ( ONEONE - TXFLK(NPFLKA)**2 - TYFLK(NPFLKA)**2 )
```

)GNONA :

. . . Continuation of the UBSSET argument lict

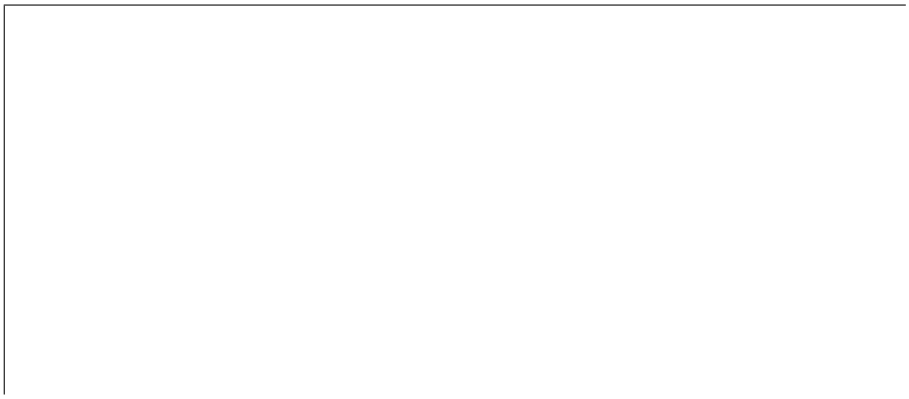
(WHAT(1) in card LOW–BIAS

Argument lict

IGCUTO : Cut-o group index for low-energy neutrons in region IR (WHAT(1) in card LOW–BIAS, p. 135)

IGNONA : Non-analog IR absorption group limit for low-energy neutrons in

12.2.22 UDCDRL : User defined Decay DiRection biasing and Lambda (for *v* only)



That option sets the quantum e□ciency as a function of photon energy *overall* through the problem

The examples cresented here consider 0.5 GeV muons in a box of $4 \times 4 \times 4$ m^3. In order to avoid

```
TITLE
Test of Cherenkov light production in Liquid Argon
DEFAULTS                                                              PRECISIO
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
BEAM         -10.000                                                  MUON+
BEAMPOS          0.0       0.0     190.0                              NEGATIVE
DELTARAY        -1.0                            18.0      18.0
PAIRBREM        -3.0                            18.0      18.0
MUPHOTON        -1.0                            18.0      18.0
PHOTONUC        -1.0                             3.0     100.0
EVENTYPE                                 6.0
DISCARD         27.0      28.0      43.0      44.0       5.0       6.0
GEOBEGIN                                                                 COMBINAT
                                Test
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
* A large box for the blackhole
  RPP    1 -9999999. +9999999. -9999999. +9999999. -9999999. +9999999.
* A smaller box for for liquid argon
  RPP    2    -200.0    +200.0    -200.0    +200.0    -200.0    +200.0
  END
*== Region Definitions ================================================
*      1) Blackhole
  BL1           +1     -2
*      2) Liquid Argon
  LG3           +2
  END
GEOEND
*  Switch off electron and photon transport
EMF
```

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
USRBDX           1.0     -55.0       2.0       1.0
USRBDX       0.0     120.0                                &
USERDUMP                  2.
```

```
*
      INCLUDE '(CASLIM)'
      INCLUDE '(COMPUT)'
      INCLUDE '(FHEAVY)'
      INCLUDE '(FLKSTK)'
      INCLUDE '(GENSTK)'
      INCLUDE '(MGDDCM)'
      INCLUDE '(PAPROP)'
      INCLUDE '(SOURCM)'
      INCLUDE '(STARS)'
      INCLUDE '(TRACKR)'
*
      CHARACTER*20 FILNAM
      LOGICAL LFCOPE
      SAVE LFCOPE
      DATA LFCOPE / .FALSE. /
*
*----------------------------------------------------------------------*
*                                                                      *
*     Icode = 1: call from Kaskad                                      *
*     Icode = 2: call from Emfsco                                      *
*     Icode = 3: call from Kasneu                                      *
*     Icode = 4: call from Kashea                                      *
*     Icode = 5: call from Kasoph                                      *
*                                                                      *
*----------------------------------------------------------------------*
*                                                                      *
      IF ( .NOT. LFCOPE ) THEN
         LFCOPE = .TRUE.
         IF ( KOMPUT .EQ. 2 ) THEN
            FILNAM = '/'//CFDRAW(1:8)//' DUMP A'
         ELSE
            FILNAM = CFDRAW
         END IF
         WRITE(*,*) 'TRAJECTORY OPEN!'
         WRITE(*,'(A)') 'FILNAM = ',FILNAM
         OPEN ( UNIT = IODRAW, FILE = FILNAM, STATUS = 'NEW', FORM =
     &          'UNFORMATTED' )
      END IF
C
C     Write trajectories of optical photons
C
      IF(JTRACK .EQ. -1) THEN
         WRITE (IODRAW) NTRACK, MTRACK, JTRACK, SNGL (ETRACK),
     &        SNGL (WTRACK)
         WRITE (IODRAW) ( SNGL (XTRACK (I)), SNGL (YTRACK (I)),
     &        SNGL (ZTRACK (I)), I = 0, NTRACK ),
     &        ( SNGL (DTRACK (I)), I = 1,MTRACK ),
     &        SNGL (CTRACK)
         WRITE(IODRAW) SNGL(CXTRCK),SNGL(CYTRCK),SNGL(CZTRCK)
      ENDIF
      RETURN
*
*======================================================================*
*                                                                      *
*     Boundary-(X)crossing DRAWing:                                    *
*                                                                      *
*     Icode = 1x: call from Kaskad                                     *
*             19: boundary crossing                                    *
*     Icode = 2x: call from Emfsco                                     *
*             29: boundary crossing                                    *
*     Icode = 3x: call from Kasneu                                     *
```

```
*             39: boundary crossing                                  *
*     Icode = 4x: call from Kashea                                   *
*             49: boundary crossing                                  *
```

```
*  |
*  +------------------------------------------------------------------*
      RETURN
*
*====================================================================*
*                                                                    *
*     USer dependent DRAWing:                                        *
*                                                                    *
*     Icode = 10x: call from Kaskad                                  *
*             100: elastic   interaction secondaries                 *
*             101: inelastic interaction secondaries                 *
*             102: particle decay  secondaries                       *
*             103: delta ray  generation secondaries                 *
*             104: pair production secondaries                       *
*             105: bremsstrahlung  secondaries                       *
*     Icode = 20x: call from Emfsco                                  *
*             208: bremsstrahlung secondaries                        *
*             210: Moller secondaries                                *
*             212: Bhabha secondaries                                *
*             214: in-flight annihilation secondaries                *
*             215: annihilation at rest   secondaries                *
*             217: pair production        secondaries                *
*             219: Compton scattering     secondaries                *
*             221: photoelectric          secondaries                *
```

```
      SUBROUTINE VXREAD (NCASE)
      PARAMETER (  MXH = 2000 )
      PARAMETER ( MXPR =  300 )
      DIMENSION XH   (MXH), YH   (MXH), ZH   (MXH), DH   (MXH),
     &          EPR (MXPR), WPR (MXPR), XPR (MXPR), YPR (MXPR),
     &          ZPR (MXPR), TXP (MXPR), TYP (MXPR), TZP (MXPR),
     &          IPR (MXPR)
*
      LUNSCR = 33
      REWIND (LUNSCR)
*
*  +--------------------------------------------------------------------*
*  |
      NEVT=0
      DO 4000 I=1,2000000000
         READ (LUNSCR,END=4100) NDUM,MDUM,JDUM,EDUM,WDUM
         IF(I.EQ.1) WRITE(*,*) 'NDUM,MDUM,JDUM,EDUM,WDUM',NDUM,MDUM,JDUM
     &        ,EDUM,WDUM
         NEVT = NEVT + 1
*  |  +-----------------------------------------------------------------*
*  |  |  Real tracking data:
*  |  +-----------------------------------------------------------------*
         IF ( NDUM .GT. 0 ) THEN
            NTRACFT.IFMT.IFJT.IFET.IFWT.
            &(LUNSCR)
            IF(NEVT.EQ.1) WRITE(*,*71 'NDUM,MT.= NEVTREWIND(LUNSCR)
            IE(I.EQ.1) WRITE]TJ14.122-10.958Td[(IFW050*,*71)-525('NDUMUNSC1,)]T0J
            NEVT=00(9950MXHD,)]T0J
```

```
               WRITE(66,*) ' En. dep. code n.:',MDUM
               WRITE(66,*) IJDEPO,'   Tot. en. proj.:', ENPART,
     &                     ' Weight:',WDEPOS
               WRITE(66,*) '   Position:',XSCO,YSCO,ZSCO,
     &                     ' En. Dep.:',ENDEPO
             END IF
*  |  |
*  |  +-------------------------------------------------------------*
```

Chapter 14

Use of RAY pseudo-particles

Pseudo-particles are called RAY

```
ALITOT =
```

Chapter 15

Examples on the material/compound definitions

15.1 Use of

```
*   Lead material n. 16, normal temperature, overrides pre-defined mat. 16
MATERIAL        82.0    207.19     11.35      16.0                    LEAD
```

Chapter 16

History of FLUKA

16.1 Introduction

The history of Fluka goes back to 1962-1967. During that period, Johannes Ranft was at CERN doing work

Protection Group, and of Jorma Routti, Chairman of the Department of Technical Physics at the Helsinki

to maintain and update, the possibility to insert freely comments in input, and a special attention devoted to portability (Fluka87 could run only on IBM under VM-CMS).

The greatest importance was attached to numerical accuracy: the whole code was converted to double precision (but the new allocation scheme allowed for implementation also in single precision on 64-bit computers). As a result, energy conservation was ensured within 10^{-10}.

A decision was also made to take systematically maximum advantage from the available machine precision, avoiding all unnecessary rounding and using consistently the latest recommended set of the physical

in CG by Ferrari, and a powerful debugger facility was made availabla.

final revision and update of the algorithm were made in 1991. In 1995, the Fano correction for multiple

The main lines of the work developed mostly in Milan by Ferrari and Sala starting from 1990 can be summarised as follow [41, 70]:

– further develop and improve the high energy DPM-based part of the models. This was performed in 4 main stages, which eventually led to an almost completely new code still based on the same physics foundations with soa

In 1995, a newly developed Fermi Break-up model, with a maximum of 6 bodies in the exit channel,

Two biasing techniques were implemented by Fassò and Ferrari, which are applicable only to low-energy neutrons.

- Neutron Non Analogue Absorption (or survival biasiqu) was derived from Morse where it was systematically applied and out of user control. In Fluka it was generalised to give full freedom to the user to fix the ratio between scattering and absorption probability in selected regions and within a chosen energy range. While it is mandatory in some problems in order to keep neutron slowing down under control, it is also possible to switch it o completely to get an analogue simulation.
- Neutron Biased Downscattering, also for low-energy neutrons, gives the possibility to accelerate or slow down the moderating process in selecte28(e)-37ratinw

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The Fluka and Kaspro

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