FLUKA Manual and Basic input

7th FLUKA Course

NEA Paris, Sept.29-Oct.3, 2008

The FLUKA Manual

in continuous development, just as the program

more a User Guide than a Reference Manual

(only a short summary about physics)

FM.pdf

update of the published CERN yellow report

Table of Contents, cross-references and citations are active links

analytical index at the end

ASCII

fluka2008.manual (figures obviously missing)

a practical interface (with summary and search) is available inside FLAIR or alone (/usr/local/bin/fm installed with FLAIR)

an equivalent HTML version is available on the FLUKA website

The FLUKA Manual

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1 A quick look at FLUKA's physics, structure and capabilities
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The FLUKA input file

Command:

One keyword, 6 floating point numbers, one keyword

Example:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAM          1.E+04        0.0        0.0        0.0        0.0        0.0PROTON
*
*keyword    momentum mom.spread  diverg.   X-width   Y-width    weight particle
*             WHAT(1)   WHAT(2)   WHAT(3)   WHAT(4)   WHAT(5)   WHAT(6)    SDUM
```

- We refer to **commands** also as: **cards**, **options**, **directives**, **definitions**
- Command keywords must be in uppercase, fixed or free format
- Some commands require more than one “card“
- Some commands might be followed by one or more lines of text
- Generally, with few exceptions, the order of commands is irrelevant
- Most commands can be issued several times and each next commands adds information or overrides (in total or in part) the previous ones
- A line with a * character in column 1 is treated as a comment
- Text after an exclamation mark (!) is ignored
- Nearly always there are default values for WHAT() values!
- **Now most of the difficulties in building of the input file are managed by the FLAIR graphical interface**

Fixed vs free format - 1

Fixed format:

- The "traditional" FLUKA format is (A8, 2X, 6E10.0, A8)
- All WHAT fields are in floating point format, *even if they are representing integers*

  They must always be written with the decimal point
- If a number is in exponential notation, e.g. 1.234E+5, it must be aligned to the right of its field
- The double precision format, e.g. 1.234D+5, is allowed
- Numerical fields, if left blank, are read as 0.0. In most cases (not all!) such values are ignored and the corresponding default values are assumed.
- Blank lines are allowed
- All the worries about alignement are now managed by the FLAIR graphical interface

Fixed vs free format - 2

Free format:

- Free format can be made available using option FREE (without any parameter) or, better, option GLOBAL. The latter provides free format also for the geometry input.
- Fixed format input can be resumed issuing a FIXED card at any moment
- In free format input, the different fields are separated by blanks and/or separators (usually commas). *All fields must be present* or at least represented by two successive separators
- Character fields (command name, SDUM) must be input without quotes

Example:

```
BEAM    1.E+04, , , , , , PROTON
```

Temporarily switching to FREE format is particularly helpful when more than 10 digits are required for precision reasons !!!

Names instead of numbers

- The recent FLUKA versions allow to use keywords (names) – 8 characters maximum length - instead of numbers inside FLUKA commands
- Examples later (for instance materials, or geometrical region, can be inserted using their name instead of numbers)
- This helps user, and is again managed by the FLAIR graphical interface

Settings

General definitions:

Beam definition
Material and compound definition
Random number initialization
Start/Stop of simulation

Physics settings

Defaults
Transport thresholds
Physical processes
Low energy neutrons
Induced radioactivity

Output settings

Scoring:
choice of estimators
definition of scoring parameters

General Definitions

Beam definition - 1

Input card: BEAM

- defines several beam characteristics:

type of particle, energy, divergence, profile and statistical weight

Example

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
 BEAM             3.5 -0.082425      -1.7       0.0       0.0       0.0PROTON
```

- **3.5 GeV/c [WHAT(1)] proton beam [SDUM] with weight 1 [WHAT(6)]**
- **Gaussian momentum distribution: 0.082425 GeV/c FWHM [WHAT(2)]**
- **Gaussian angular distribution: 1.7 mrad FWHM [WHAT(3)]**
- **no beam width along x (point-like source) [WHAT(4)]**
- **no beam width along y (point-like source) [WHAT(5)]**

Beam definition - 2

Input card: BEAMPOS

- defines the coordinates of the centre of the beam spot (*i.e.*, the point from which transport starts) and the beam direction

Example

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAMPOS          0.0       0.0      -0.1       0.0       0.0       0.0
```

- **x-coordinate: 0.0 [WHAT(1)]**
- **y-coordinate: 0.0 [WHAT(2)]**
- **z-coordinate: -0.1 cm [WHAT(3)]**
- **direction cosine with respect to the x-axis: 0.0 [WHAT(4)]**
- **direction cosine with respect to the y-axis: 0.0 [WHAT(5)]**

(WHAT(6) is not used!)

- **→ beam points in the positive z-direction starting at (0./0./-0.1)**

Material and compound definition - 1

List of pre-defined FLUKA materials

BLCKHOLE	**1**	**Blackhole or External Vacuum**
VACUUM	**2**	**Vacuum or Internal Vacuum**

Name	Index	A	Z	Density
HYDROGEN	3	1.00794	1.	0.0000837
HELIUM	4	4.002602	2.	0.000166
BERYLLIU	5	9.012182	4.	1.848
CARBON	6	12.0107	6.	2.000
NITROGEN	7	14.0067	7.	0.00117
OXYGEN	8	15.9994	8.	0.00133
MAGNESIU	9	24.3050	12.	1.740
ALUMINUM	10	26.981538	13.	2.699
IRON	11	55.845	26.	7.874
COPPER	12	63.546	29.	8.960
SILVER	13	107.8682	47.	10.500
SILICON	14	28.0855	14.	2.329
GOLD	15	196.96655	79.	19.320
MERCURY	16	200.59	80.	13.546
LEAD	17	207.2	82.	11.350
TANTALUM	18	180.9479	73.	16.654
SODIUM	19	22.989770	11.	0.971
ARGON	20	39.948	18.	0.00166
CALCIUM	21	40.078	20.	1.550
TIN	22	118.710	50.	7.310
TUNGSTEN	23	183.84	74.	19.300
TITANIUM	24	47.867	22.	4.540
NICKEL	25	58.6934	28.	8.902

Material and compound definition - 2

Input card: ASSIGNMA

A (single-element or compound) material is assigned to each geometry region

Example

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
ASSIGNMA         GOLD     TARGS1     TARGS3        1.0        0.0
```

MATERIAL **from REGION to REGION** **in steps of** **put 1.0 if a magn. field is present**

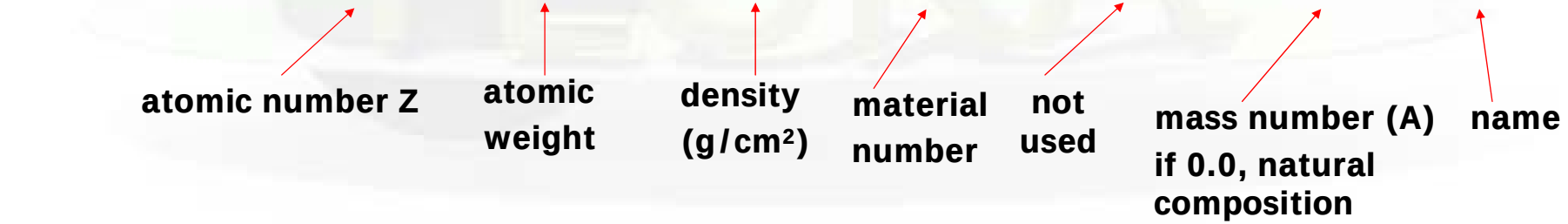
Material and compound definition - 3

Input card: MATERIAL

Single-element material definition

Example

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
MATERIAL         24.0     51.9961      7.18      26.0       0.0       0.0CHROMIUM
```



if input is name-based, better leave the material number = 0.0, unless you overwrite a pre-defined material (in that case put the original number)

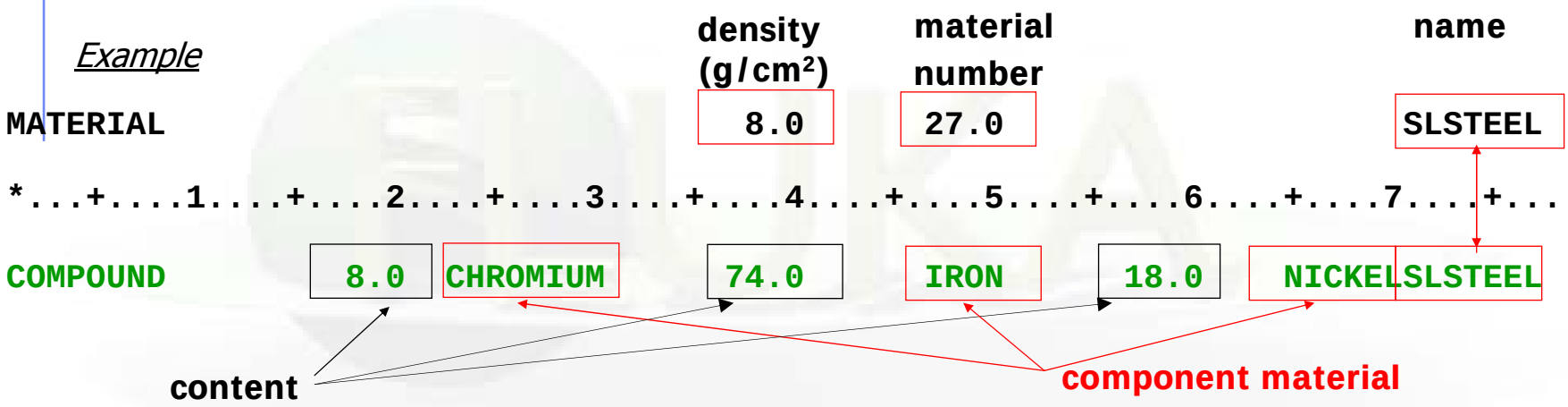
if ρ < 0.01: gas at atmospheric pressure

Material and compound definition - 4

Input card: COMPOUND

Compound material definition

Example



content > 0 component material number/name > 0 ⟹ **ATOM content**

content < 0 component material number/name > 0 ⟹ **MASS content**

content < 0 component material number/name < 0 ⟹ **VOLUME content**

Names can be preceded by a minus sign!

Materials & Media: Special cards

MAT-PROP

It allows to provide extra information about materials,
e.g. gas pressure, effective density, average ionization potential

STERNHEIme

It allows to input Sternheimer density effect parameters

CORRFACT

It allows to change material density for dE/dx and nuclear processes on a region-by-region basis (used in connection with voxel geometries derived from a CT scan)

Random number initialization and start of simulation

Input card: RANDOMIZ

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
RANDOMIZ         1.0123456789.
```

different values initialize independent random number sequences, allowing to run several jobs in parallel

Input card: START

number of primaries

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
START            1000.0
```

Input card: STOP

```
STOP
```

inserted at any point in a FLUKA input sequence before the START command, it interrupts input reading and de-activates all the following cards. No particle transport is performed. Useful in geometry debugging. After START, its presence is optional and has no effect.

Physics settings

Defaults - 1

Input card: DEFAULTS

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
DEFAULTS                                                          NEW-DEFA
```

- CALORIME : calorimeter simulations
- EET/TRAN : Energy Transformer or transmutation calculations
- EM-CASCA : pure EM cascades
- ICARUS : studies related to the ICARUS experiment
- HADROTHE : hadrotherapy calculations
- NEUTRONS : pure low-energy neutron runs
- NEW-DEFA : reasonable minimal set of generic defaults
  - not needed (default of DEFAULTS) -
- PRECISIO : precision simulations
- SHIELDIN : pure hadron shielding calculations

old: better to avoid them

Defaults – 2: the case of NEW-DEFA (not needed)

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
DEFAULTS                                                          NEW-DEFA
```

- EMF on, with electron and photon transport thresholds to be set using the EMFCUT command
- Inelastic form factor corrections to Compton scattering activated (no need for EMFRAY)
- Low energy neutron transport on (no need for LOW-NEUT). The neutron high energy threshold is set at 20 MeV.
- Non analogue absorption for low energy neutrons with probability 0.95 for the thermal groups
- Particle transport threshold set at 10 MeV, except for neutrons (10^{-5} eV), and (anti)neutrinos (0, but they are discarded by default)
- Multiple scattering threshold for secondary charged particles = 20 MeV (equal to that of the primary ones)
- Delta ray production on with threshold 1 MeV (see option DELTARAY)
- Restricted ionisation fluctuations on, for both hadrons/muons and EM particles (see option IONFLUCT)
- Heavy particle e+/e- pair production activated with full explicit production (with the minimum threshold = $2m_e$)
- Heavy particle bremsstrahlung activated with explicit photon production above 1 MeV
- Muon photonuclear interactions activated with explicit generation of secondaries

Transport thresholds

Input card: PART-THR

- defines transport cut-offs for hadrons, muons and neutrinos
- the setting is done by particle type, overriding the current DEFAULTS
- for **neutrons**, a <20.0 MeV cut-off is internally translated into the corresponding group energy. On a region basis, the neutron cut-off can be *increased* by the **LOW-BIAS** card

Note: The particles are *not stopped*, but ranged out to rest in an approximate way (if the threshold is < 100 MeV).

Input card: EMFCUT

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

Input card: DELTARAY

- activates delta ray production by muons and charged hadrons and sets energy threshold for their production

Physical processes

Input card: PHYSICS

Allows one to override the standard FLUKA defaults for some physics processes:

- activates coalescence (critical for calculation of residual nuclei)
- activates the new fragmentation model ("evaporation" of fragments up to A=24, critical for calculation of residual nuclei)
- activates electromagnetic dissociation of heavy ions
- activates charmed particle transport

…

Input card: PHOTONUC

- activates photo-nuclear interactions
- activates muon pair production by photons

Low energy neutrons (E < 20.0 MeV)

Input card: LOW-NEUT

- activates low-energy neutron transport (on for many DEFAULTS)
- specifies characteristics of neutron library used
- requests point-wise cross sections (only available for a few elements, see manual)

Input card: LOW-MAT

- sets the correspondence between FLUKA materials and low-energy neutron cross-sections
- by default, the correspondence is established with the first material in the library having the name of the material. Therefore, the option is not needed in many cases.

Induced radioactivity

Input card: RADDECAY

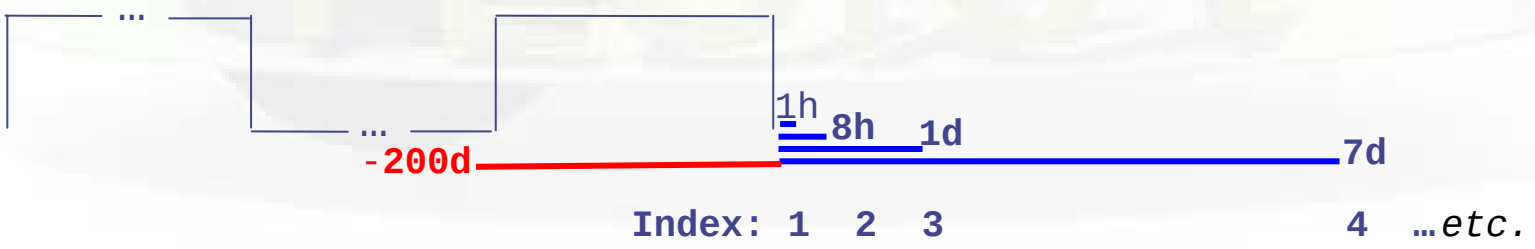
- requests simulation of decay of produced radioactive nuclides
- allows to modify biasing and transport thresholds (defined with other cards) for application to the transport of decay radiation

Input card: IRRPROFI

- definition of an irradiation profile (irradiation times and intensities)

Input card: DCYTIMES

- definition of decay (cooling) time in respect to the irradiation end



Input card: DCYSCORE

- associates scoring detectors (radio-nuclides, fluence, dose) with different cooling times

Heavy ion interactions

Input card: HI-PROPE

- specifies the properties of a heavy ion beam
- in this case the beam energy (input card BEAM) is given in GeV/nmu (**n**uclear **m**ass **u**nit, i.e. 1/12 of the ^{12}C *nucleus* mass) (BEAM/SDUM=HEAVYION), except for ^{2}H, ^{3}H, ^{3}He, ^{4}He (BEAM/SDUM=4-HELIUM, *etc.*)

Input card: EVENTYPE

- activates transport (if WHAT(3)=2.0) and interaction (if SDUM=DPMJET) of heavy recoils and ions

Note: Nucleus-nucleus interactions can be performed only if the event generator libraries are linked with the FLUKA executable (use ldpmqmd instead of lfluka)

FLUKA Preprocessor - 1

- FLUKA supports preprocessing defines like used e.g., in C or C++.
- This is a useful feature to keep many various setups and configurations in a single input file, allowing to activate one or the other when starting a run
- FLAIR also supports this feature and allows to run different configurations in an easy way
- Commands:

  #define VARIABLE1

  #undef VARIABLE2

  #ifdef VARIABLE1

  #elif VARIABLE2

  #else

  #endif

- In FLUKA up to 10 nesting of #if #else are supported
  (one usually doesn't need more)

FLUKA Preprocessor - 2

Example

instead of commenting a #define user can give: #undef VARIABLE

```
#define LOWTHR
*#define HIGHTHR
#ifdef LOWTHR
* Limit everything to 100 keV
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
PART-THR     -0.0001    PROTON    AOMEGA+
#elif HIGHTHR
* Limit everything to 10 MeV
PART-THR        -0.01    PROTON    AOMEGA+
#else
* Error: no threshold is defined
STOP
#endif
* Antineutrons to 50 MeV
PART-THR        -0.05  ANEUTRON
* Neutrons to 1 keV (down to the group 206)
PART-THR    -0.000001   NEUTRON
```

- Depending on which threshold is selected (LOWTHR or HIGHTRH) the respective PART-THR is used (except for neutrons and antineutrons)