



FLUKA Manual and Basic input

Beginners' FLUKA Course

The FLUKA Manual

in *continuous* development (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

`fluka2011.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

A summary description of FLUKA

Brief description about FLUKA and its capabilities, the implemented physics modules, installation, beginner's manual...

User's guide

- available particles and default materials;
 - detailed description of input options;
 - combinatorial geometry;
 - low-energy neutrons library;
 - how to write/compile/link user routines;
- ...and much more!

REMEMBER!

The very first ally when puzzled!

...and the very best friend of a beginner user!

The FLUKA input file

Command:

One keyword, 6 floating point numbers, one string

Example:

```
* . . . + . . . . 1 . . . . + . . . . 2 . . . . + . . . . 3 . . . . + . . . . 4 . . . . + . . . . 5 . . . . + . . . . 6 . . . . + . . . . 7 . . . . + . . . .
BEAM          1.E+04          0.0          0.0          0.0          0.0          0.0 PROTON
*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, numbers must have the decimal point
- Commands can be issued in 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, adding to or overriding (partially or totally) previous directives
- 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!
- Many difficulties in building the input file are managed by FLAIR

Fixed vs free format [1/2]

Fixed format:

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....
BEAM          1.E+04    0.0D+00          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
```

- The “traditional” FLUKA format is (A8, 2X, 6E10.0, A8)
 - Numbers: 10 digits at most can be used!
- All WHAT fields are in floating point format, even if they represent 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 used
- Blank lines are allowed, but **NOT** in the geometry declaration;
- All the worries about alignment are now managed by the FLAIR graphical interface

Fixed vs free format [2/2]

Free format:

- Free format can be made *locally* available issuing option **FREE** (without any parameter), until the option **FIXED** restores the fixed format; the opposite can be done either
- Option **GLOBAL** provides free format also for the geometry input
- 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

```
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
BEAM , 1.234567890E+04 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , PROTON
*
*keyword      momentum mom.spread  diverg.   X-width  Y-width  weight particle
*              WHAT (1)    WHAT (2)  WHAT (3)  WHAT (4)  WHAT (5)  WHAT (6)  SDUM
```

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* the user, improving the *readability* of the input FLUKA file, and is again managed by the FLAIR graphical interface

Structure of the input file

General definitions

Beam definition
Materials: definition and assignment
Random number initialization
Start/Stop of simulation

Physics settings

Defaults
Physical processes
Transport thresholds
Low energy neutrons
Induced radioactivity

Geometry (see dedicated lesson)

Output settings

Estimators / scoring cards (see dedicated lesson)



General Definitions

Beam definition [1/2]

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           0.0 PROTON
```

- 3.5 GeV/c [**WHAT(1)**] proton [**SDUM**] beam 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 [2/2]

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,y,z-coordinates: (0.0, 0.0, -0.1) cm [**WHAT(1)**, **WHAT(2)**, **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 to the positive z-direction starting at (0.,0.,-0.1)

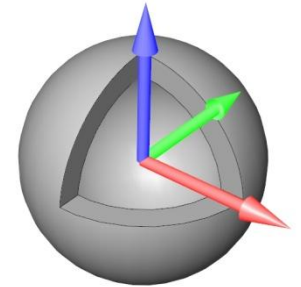
NB: if [**SDUM**] = **NEGATIVE** the beam points to the negative z-direction

Special sources – 3D distributions

FLUKA allows the user to define some 3D *spatial* distributions of source particles through the **BEAMPOS** card:

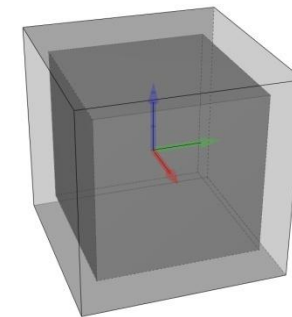
If **SDUM** = **SPHE-VOL**:

defines a spatially extended source in a **spherical shell**



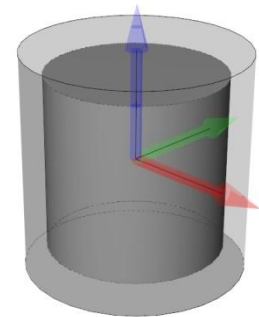
If **SDUM** = **CART-VOL**:

defines a spatially extended source in a **Cartesian shell** with the sides parallel to the beam frame axes



If **SDUM** = **CYLI-VOL**:

defines a spatially extended source in a **cylindrical shell** with the height parallel to the z-axis of the beam frame

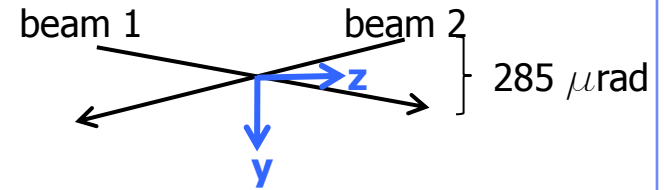


If **SDUM** = **FLOOD**:

defines a source distribution on a **spherical surface**, such as to produce a uniform and isotropic fluence within the sphere

Special sources – *pp collisions*

Input card: **SPECSOUR**



Example: LHC

7 TeV/c, full crossing angle of $285 \mu\text{rad}$ in yz-plane

Momentum vectors of colliding proton beams: *three possibilities*

1) If **SDUM** = **PPSOURCE**:

SPECSOUR	0.	0.9975	6999.9999	0.0	0.9975-6999.9999PPSOURCE
-----------------	-----------	---------------	------------------	------------	---------------------------------

- x, y, z-components of lab momentum for proton beam 1 [WHAT (1-3)]
- x, y, z-components of lab momentum for proton beam 2 [WHAT (4-6)]

2) If **SDUM** = **CROSSASY**: (pp collisions defined via lab momenta and polar angles)

3) If **SDUM** = **CROSSYM**: (pp collisions defined via lab momentum and crossing angle)

For all these special cases of source distributions, please refer to the FLUKA manual!

Materials in FLUKA

FLUKA can handle **elemental** materials (in either single isotopic composition or in natural composition) and **compounds** (chemical molecules, alloys, mixtures...)

Each material is uniquely identified by an index/name

FLUKA is provided with a set of **predefined** materials, and the user can use/modify them as well as define their own ones

Basically:

- MATERIAL** declaration of a material
- COMPOUND** definition of a compound (a **MATERIAL** card is nevertheless needed for the declaration of the compound)
- ASSIGNMA** material assignment to regions of geometry

Predefined materials

FLUKA is provided with a set of **25** predefined **natural elements** of most common use, e.g. Oxygen, Carbon, Iron... (check them out in the manual, Chap. 5)

The first two are of particular importance:

- **BLCKHOLE** (mat #1): material with infinite absorbance;
- **VACUUM** (mat #2): material with no absorbance;

12 compound materials with the composition suggested by **ICRU** are predefined as well.

All the predefined materials can be used **WITHOUT** the need of explicit **MATERIAL / COMPOUND** cards

NB for ICRU materials: if the user defines a **MATERIAL** card with the same name as the predefined ones **IT WILL OVERRIDE THE PREDEFINED.**

Material and compound definition [1/2]

Input card: **MATERIAL**

Single-element material definition

atomic number Z	atomic weight	density (g/cm ³)	material number	Alternate material to use for dE/dx	mass number (A)	name
* . . . + . . . 1 . . . + . . . 2 . . . + . . . 3 . . . + . . . 4 . . . + . . . 5 . . . + . . . 6 . . . + . . . 7 . . . + . . .						
MATERIAL	24.0	51.9961	7.18	26.0	0.0	0.0 CHROMIUM
MATERIAL	Name: PHOSPHO	#	p: 2.2			
Z: 15	Am: 30.973761	A:	dE/dx: ▼			

Notes:

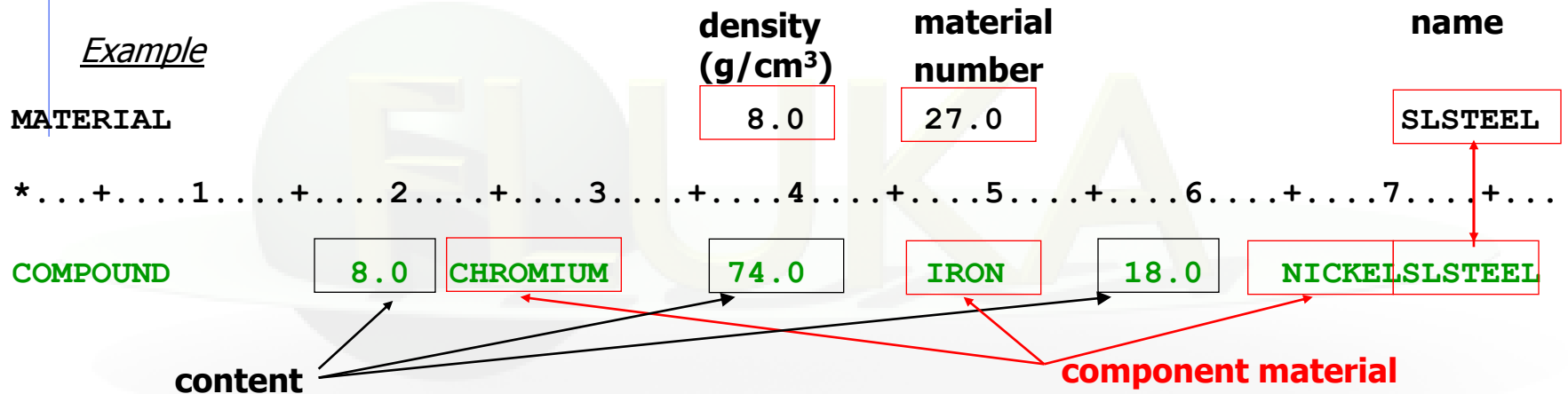
- if $\rho < 0.01$: gas at atmospheric pressure
- **Atomic Weight**: it is **calculated by the code** using the internal database it's better to leave it empty
- **Material number**: use it **ONLY** if you want to **override** a predefined one
- **Mass Number**: to define specific **ISOTOPES**
Do not confuse with the Atomic weight
- Choose a **name** corresponding to the **LOW-ENERGY neutron database** Section 10.4 in the manual

Material and compound definition [2/2]

Input cards: MATERIAL + 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!

Material assignment

Input card: **ASSIGNMA**

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

	MATERIAL	from REGION	to REGION	step	magnetic field	MATERIAL for decay run	
	* . . . + . . . 1 . . . + . . . 2 . . . + . . . 3 . . . + . . . 4 . . . + . . . 5 . . . + . . . 6 . . . + . . . 7 . . . + . . .						
	ASSIGNMA	GOLD	TARGS1	TARGS3	1.0	0.0	BLCKHOLE
ASSIGNMA		Mat: WATER ▼	Reg: WATERCNT ▼	to Reg: ▼			
		Mat(Decay): BLCKHOLE ▼	Step:		Field: ▼		

In the new version of FLUKA:

- **WHAT(5)** activates a magnetic field for the prompt and radioactive decay product transport (electric field not yet available)
- **WHAT(6)** permits to assign a different material for the radioactive decay product transport.
Only **VACUUM** and **BLCKHOLE** are allowed

Materials: special cards

MAT-PROP

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

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

Input card: **DEFAULTS**

Useful predefined transport settings for the most common problems: the user is not required to explicitly input the concerned cards (unless for overriding specific parameters)

* . . . + . . . 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
- HADROTHER : hadrotherapy calculations
- **NEW-DEFA** : **reasonable minimal set of generic defaults**
- not needed (default of DEFAULTS) -
- PRECISIO : precision simulations

Defaults: NEW-DEFA

Active settings, in case no DEFAULTS card is issued

```
* .....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 (see dedicated lesson about low-energy neutrons)
- 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**

- for electron, positron and photon, it sets:
 - energy thresholds for **production** in the selected **materials**;
 - **transport** cut-offs in the 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**

Nota:

The use of the **LAM-BIAS** card (see dedicated lesson on Biasing Techniques) coupled to the **PHOTONUC** card is recommended, in order to artificially *increase* the probability to have photonuclear reactions.

Low energy neutrons ($E < 20.0$ MeV)

FLUKA performs the transport of neutrons with energies lower than 20 MeV by means of a multi-group algorithm, currently based on 260 groups.

Input card: **LOW-NEUT**

- activates low-energy neutron transport (switched 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**

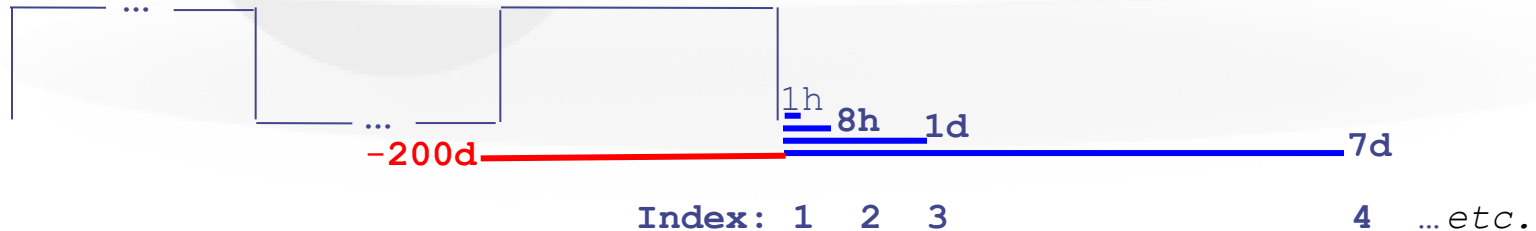
- requests simulation of decay of produced radioactive nuclides
- allows to modify biasing and transport thresholds (defined with other cards) for application to the transport of decay radiation

Input card: **IRRPROFI**

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

Input card: **DCYTIMES**

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



Input card: **DCYSCORE**

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

Heavy ions

Input card: **HI-PROPE**

- if **SDUM** of **BEAM** card is **HEAVYION**:
it specifies the properties of a heavy ion beam;
the beam energy (**WHAT(1)** of input card **BEAM**) is given in GeV/nmu (**nuclear mass unit**, i.e. 1/12 of the ^{12}C nucleus mass), except for ^2H , ^3H , ^3He , ^4He ;
- if **SDUM** of **BEAM** card is **ISOTOPE**:
it specifies the isotope of a radioactive source;
the beam energy and the beam momentum spread (**WHAT(1)** and **WHAT(2)** of input card **BEAM**) are meaningless;

Input card: **IONTRANS**

Determines the transport of ions (**WHAT(1)<0.0**), allowing to limit it to subsets of light ions ($A < 5$) and to choose between approximate and full transport (including nuclear interactions)

Note:

Nucleus-nucleus interactions above 100 MeV/n can be performed **only** if the event generators **DPMJET** and **RQMD** are linked to the FLUKA executable (use **ldpmqmd** instead of **lfluka**); for lower energies, the BME event generator is already linked in the standard executable;

FLUKA Preprocessor [1/2]

FLUKA supports preprocessing defines like those used 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

Conditional directives:

```
#define VARIABLE1  
#undef VARIABLE2  
#if VARIABLE1  
#elif VARIABLE2  
#else  
#endif
```

In FLUKA, up to **10 nested** levels of conditionals statements (`#if/#else/#endif`) are supported

Include directive:

```
#include /home/geometries/target2.geom
```

FLUKA Preprocessor [2/2]

Example

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

```
#define LOWTHR
*#define HIGHTHR
#if 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)