



FLUKA Manual and Basic input

Beginners' FLUKA Course

The FLUKA Manual

in continuous development, just as the program is
more of 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

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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          0.0 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, 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 alignment 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

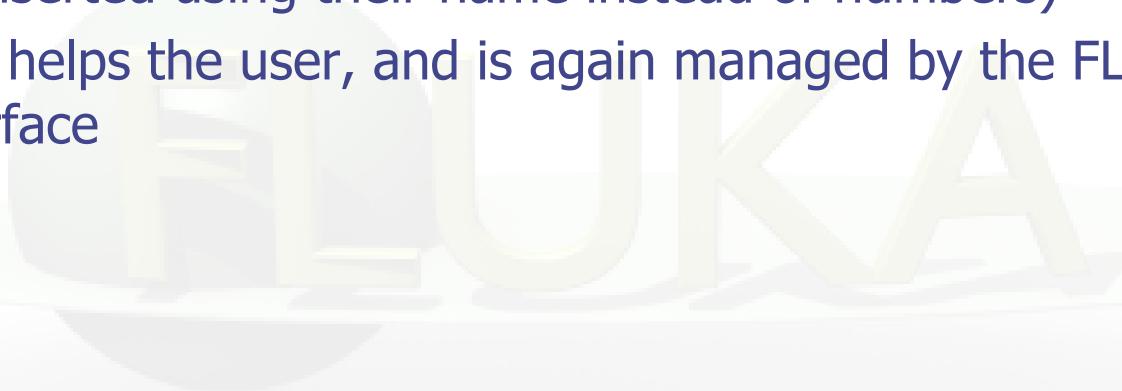
Example:

```
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 the 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          0.0 PROTON
```

- 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**

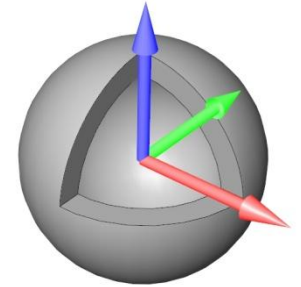
Example

```
*...+...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)

Extended sources – 1

Input card: **BEAMPOS**



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

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

Example

* . . . + . . . 1 . . . + . . . 2 . . . + . . . 3 . . . + . . . 4 . . . + . . . 5 . . . + . . . 6 . . . + . . . 7 . . . + . . .							
BEAMPOS		0.0	0.0	0.0	0.0	0.0	0.0
BEAMPOS		0.0	1.0	0.0	0.0	0.0	0.0 SPHE-VOL

- radius (in cm) of the inner sphere shell: 0.0 cm [WHAT(1)]
- radius (in cm) of the outer sphere shell: 1.0 cm [WHAT(2)]
- **WHAT(3) - WHAT(6)** are not used !

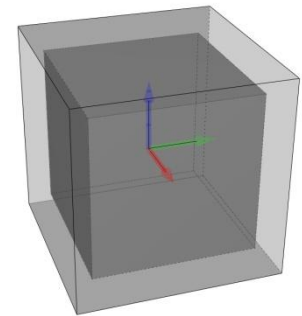
The shell is centred at the (x,y,z) point defined by another BEAMPOS card with SDUM = blank (or = NEGATIVE). The particle direction or angular distribution are those defined by BEAM, BEAMAXES and another BEAMPOS cards.

Extended sources – 2

Input card: **BEAMPOS**

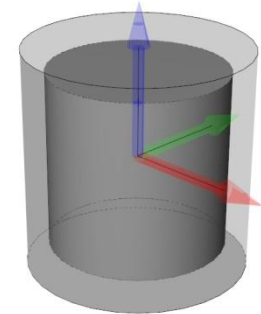
If **SDUM** = **CART-VOL**:

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

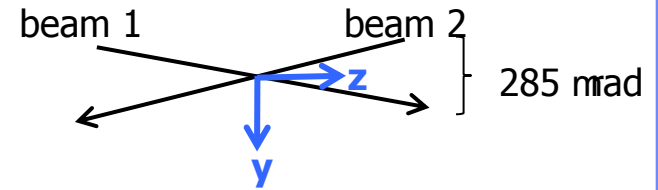


If **SDUM** = **FLOOD**:

defines a source distribution on a **spherical surface**

Special sources – *pp collisions*

Input card: **SPECSOUR**



Example: LHC

7 TeV/c, full crossing angle of 285 mrad 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, see Manual)

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

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

[g/cm³]

[g/cm³]

Material and compound definition - 2

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)** is controlling the magnetic & electric field for the prompt and radioactive decay product transport
- **WHAT(6)** is permitting to assign a different material for the radioactive decay product transport.

Only **VACUUM** and **BLCKHOLE** are allowed

Material and compound definition - 3

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	Z: 15	Name: PHOSPHO Am: 30.973761		# A:	p: 2.2 dE/dx: ▼		

Notes:

- if $\rho < 0.01$: gas at atmospheric pressure
- Atomic Weight is **calculated by the code** using the internal database is better to leave 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

Predefined ICRU materials

In the new version of FLUKA, the code contains several predefined materials with the composition suggested by ICRU

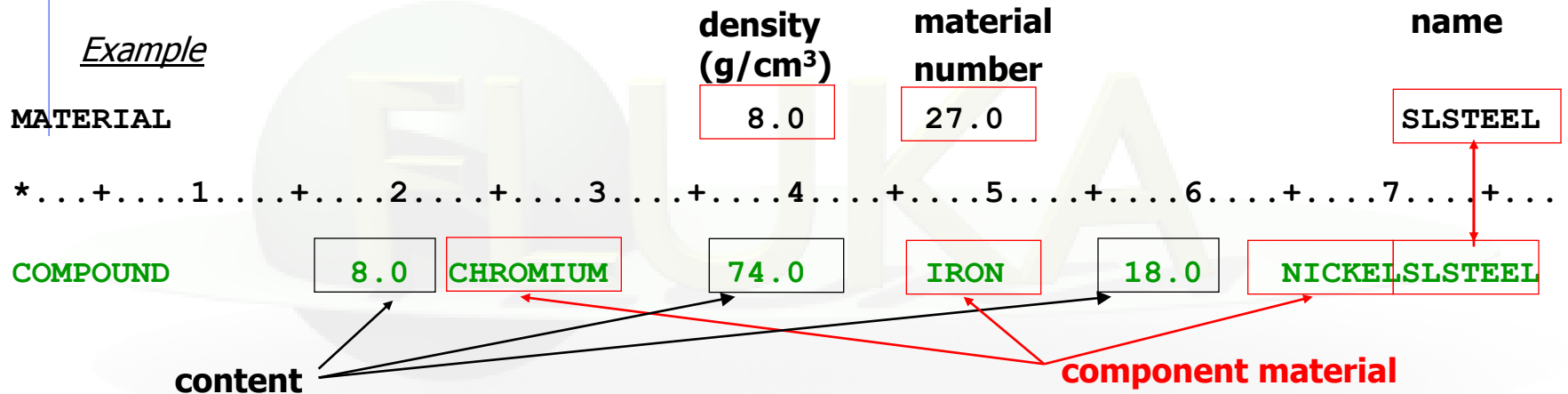
FLUKA	Material	ρ [g/cm ³]	FLUKA	Material	ρ [g/cm ³]
AIR	Dry air 20°C	0.00120479	BONECOMP	Compact bone	1.85
WATER	Water	1.0	BONECORT	Cortical bone	1.95
POLYSTYR	Polystyrene	1.06	MUSCLESK	Skeletal muscle	1.04
PMMA	Polymethyl methacrylate	1.19	MUSCLEST	Striated muscle	1.04
POLYETH Y	Polyethylene	0.94	ADTISSUE	Adipose tissue	0.92
PLASCINT	Plastic scintillator	1.032	KAPTON	Kapton	1.42

- The materials can be used WITHOUT the need of an explicit MATERIAL / COMPOUND cards
- If the user defines a MATERIAL card in the input with the same name as the predefined ones IT WILL OVERRIDE THE PREDEFINED.

Material and compound definition - 4

Input card: **COMPOUND**

Compound material definition



- 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

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

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**

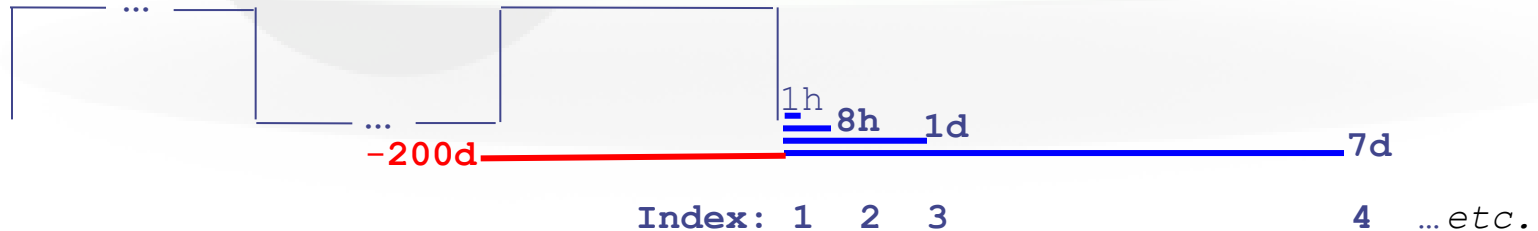
- requests simulation of decay of produced radioactive nuclides
- allows to modify biasing and transport thresholds (defined with other cards) for application to the transport of decay radiation

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 (**nuclear mass unit**, i.e. 1/12 of the ^{12}C *nucleus* mass) (**BEAM/SDUM=HEAVYION**), except for ^2H , ^3H , ^3He , ^4He (**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

Conditional directives:

```
#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)

Include directive:

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

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)