FLUKA manuals and Basic Input

FLUKA Beginner's 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       0.0PROTON
*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, 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

- FLUKA also allows 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       0.0PROTON
```

- 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
```

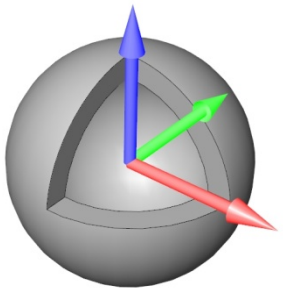
- x,y,z-coordinates: (0.0, 0.0, -0.1) cm [WHAT(1), WHAT(2), WHAT(3)]
- *direction cosine* with respect to the x-axis: 0.0 [WHAT(4)]
- *direction cosine* with respect to the y-axis: 0.0 [WHAT(5)]
- WHAT(6) is not used!

→ 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

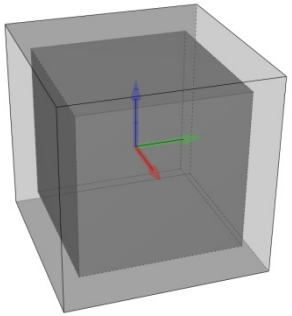
Special sources – *3D distributions*

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



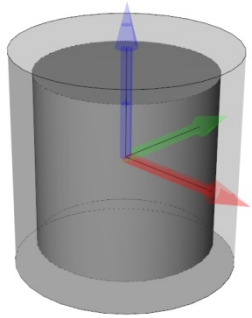
If **SDUM = SPHE-VOL**:

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**:

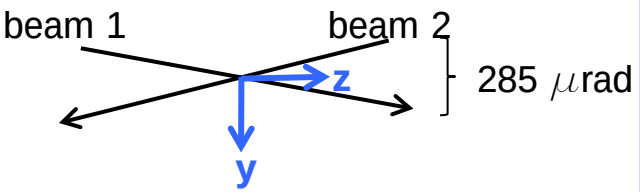
defines a spatially extended source in a cylindrical shell with the height parallel to the z-axis of the beam frame

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 μrad 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** = **CROSSSYM**: (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/cm³)	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	#	ρ: 2.2
Z: 15	Am: 30.973761	A:	dE/dx:

Notes:

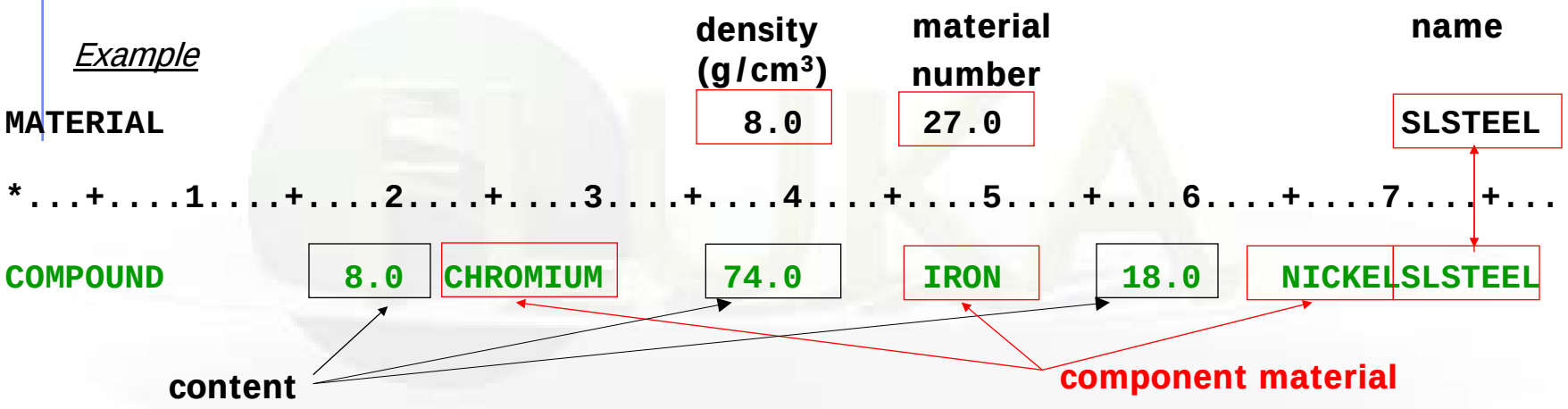
- if $\rho<0.01$: gas at atmospheric pressure
- Atomic Weight: it is **calculated by the code** using the internal database it's better to leave it empty
- Material number: use it **ONLY** if you want to **override** a predefined one
- Mass Number: to define specific **ISOTOPES**
  Do not confuse with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

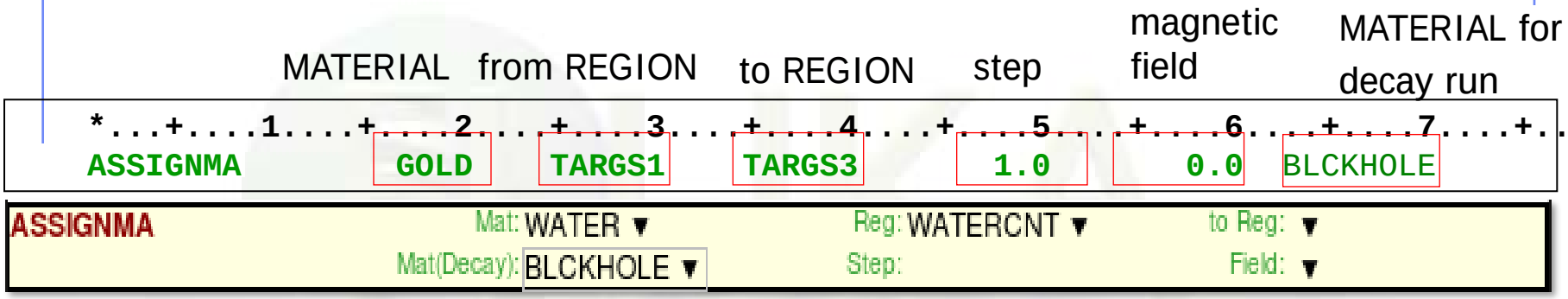
content < 0 component material number/name < 0 ⟹ **VOLUME content**

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



In the latest versions of FLUKA:

- WHAT(5) activates a magnetic field for the prompt and/or 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 for the moment.

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
- HADROTHE : hadrotherapy calculations
- NEW-DEFA : 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

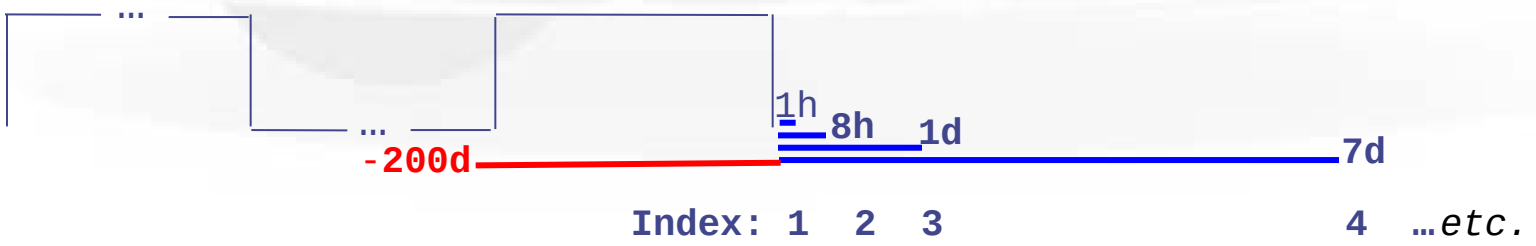
- requests simulation of decay of produced radioactive nuclides
- allows to modify biasing and transport thresholds (defined with other cards) for application to the transport of decay radiation

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 (**n**uclear **m**ass **u**nit, i.e. 1/12 of the ^{12}C *nucleus* mass), except for ^{2}H, ^{3}H, ^{3}He, ^{4}He;
- 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
```

- In the above example, depending on which threshold is selected (LOWTHR or HIGHTHR) the respective PART-THR is used (except for neutrons and antineutrons)