Monte Carlo Tutorial

Part 2 – Practical MC

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General recipe to setup a MC run
How to setup a MC run

First:
think very hard on what question you want to calculate, and what you need in order to achieve it.

Remember GIGO principle: Garbage in = Garbage out.
How to setup a MC run

GIGO applied on multiple levels:

- User input (specification of problem to be solved)
- Developer input (underlying models, transport engine, etc...)

Therefore:

- Do not trust MC simulation blindly
- Check your results:
  - experiments (ideally),
  - Hand / numerical calculations (or even estimates)
  - possibly supplemented by other MC codes.
How to setup a MC run

Then:

- Setup geometry
- Assign materials
- Setup beam
- Select physics to use
- Specify what to score
- **Hit the run button** (if there is one)

Then post-processing / analyzing your data follows.
Specify Geometry

- A particle needs to know where it is
- A particle needs to know where it is going
- Geometry often constructed from primitives using boolean logic
Geometric Primitives

Bodies in SHIELD-HIT12A and FLUKA

(figures from SHIELD-HIT manual)

SPH : A sphere defined by the center coordinates \((P_1, P_2, P_3)\) and the radius \(P_4\). The remaining arguments \(P_5\) and \(P_6\) are ignored.

BOX : A box spanned by 3 vectors. All vectors start in the point \((P_1, P_2, P_3)\) and point to the points \((P_4, P_5, P_6)\), \((P_7, P_8, P_9)\) and \((P_{10}, P_{11}, P_{12})\). They must be orthogonal on each other.

RCC : Right circular cylinder. One end of the cylinder is described by a circle with the center at \((P_1, P_2, P_3)\). The arguments \((P_4, P_5, P_6)\) hold a vector measured from the center to the opposite end of the cylinder. \(P_7\) marks the radius of the cylinder.

REC : Right elliptical cylinder. Similar to RCC, but instead of a radius, two additional vectors \((P_4, P_5, P_6)\) and \((P_{10}, P_{11}, P_{12})\) describe the minor and major axis. All three vectors must be orthogonal to each other.

ARB : Arbitrary convex polyhedron. This body is described by 8 points, i.e. 24 arguments. The points must be specified in the order as indicated by the figure to the left: Point 1 is \((P_1, P_2, P_3)\), point 2 \((P_4, P_5, P_6)\) ... point 8 \((P_{23}, P_{24}, P_{25})\).

RPP : Rectangular parallelepiped. \((P_1, P_2)\) marks minimum and maximum X coordinates. \((P_3, P_4)\) is min and max values for Y, and \((P_5, P_6)\) for Z.

TBC : A cone spanned by two circles. First circle is centered at point \((P_1, P_2, P_3)\) and has radius \(P_7\). The other end of the cone is described by the circle centered at the end of a vector \((P_4, P_5, P_6)\) starting from the center of the first circle. The second circle has a radius of \(P_8\). The radius in \(P_7\) must be larger then the radius in \(P_8\).

ELL : Ellipsoid. Centered at point \((P_1, P_2, P_3)\), three orthogonal vectors \((P_4, P_5, P_6)\), \((P_7, P_8, P_9)\) and \((P_{10}, P_{11}, P_{12})\) span the body. This body is differently defined than in FLUKA.
Combinational Geometry (CG)

Boolean logic applies:

Figure 8.1: Two bodies (marked as 1 and 2) describing 5 different zones.
Regions and Bodies

A region (lower case letters) is composed of bodies (upper case letters)

\[
\begin{align*}
    a &= A - B - C \\
    b &= B \\
    c &= C - D \\
    d &= D
\end{align*}
\]

Important: any point in the universe MUST be assigned to one and only one region.
Regions and Bodies

A region is composed of bodies

\[ a = A - B - C \]
\[ b = B \]
\[ c = C - D \]
\[ d = D \]

Next: assignment of regions to materials

\[ a \rightarrow \text{Vacuum} \]
\[ b \rightarrow \text{Polyethylene} \]
\[ c \rightarrow \text{Water} \]
\[ d \rightarrow \text{Silicon} \]
Specify a Beam

Such as: 25 MeV electrons, 15 x 15 cm², flat square.

Or more complex beams:
• Divergent beam, momentum spread, circular/annular shape
Or even more complex beams:
• Energy spectrum, particle spectrum, beam sampled from phase-space file, Isotropic distributions (space)
• Think if you can reduce beam to only irradiate areas you want to score -> saves time.
Setup Physics to Use

- A full simulation can be CPU intensive without adding any value to the result.
- If you can, limit physics to what is necessary to answer the question
  - Do we need electron transport down to 1 keV? Or is 100 keV sufficient?
  - Do we need neutron transport? What cutoff energy?
  - Do we need optical photons or fluorescence photons?
Physics

- A particle will undergo a range of steps,
  - what happens on its way?

(figure from Geant4 course)
Codes like Geant4 provide several different models → things get very complicated.

Assume you want to simulate 25 MeV electron beam

- Photon processes
  - Compton scattering (class name G4ComptonScattering)
  - Gamma conversion (also called pair production, class name G4GammaConversion)
  - Photo-electric effect (class name G4PhotoElectricEffect)
  - Muon pair production (class name G4GammaConversionToMuons)
- Electron/positron processes
  - Ionisation and delta ray production (class name G4eIonisation)
  - Multiple scattering (class name G4eMultipleScattering)
  - Positron annihilation into two gammas (class name G4eplusAnihilation)
- Muon processes
  - Bremsstrahlung (class name G4MuBremsstrahlung)
  - Ionisation and delta ray production (class name G4MuIonisation)
  - e+e- pair production (class name G4MuPairProduction)
- Hadron/ion processes
  - Bremsstrahlung (class name G4hBremsstrahlung)
  - Ionisation (class name G4hIonisation)
  - e+e- pair production (class name G4hPairProduction)

- Ionisation for ions (class name G4ionIonisation)
- Multiple scattering (class name G4hMultipleScattering)
- Ionisation for heavy exotic particles (class name G4hhIonisation)
- Ionisation for classical magnetic monopole (class name G4mplIonisation)
- Coulomb scattering processes
  - Alternative process for simulation of single Coulomb scattering of all charged particles (class name G4CoulombScattering)
  - Alternative process for simulation of single Coulomb scattering of ions (class name G4ScreenedNuclearRecoil)
- Processes for simulation of polarized electron and gamma beams
  - Compton scattering of circularly polarized gamma beam on polarized target (class name G4PolarizedCompton)
  - Pair production induced by circularly polarized gamma beam (class name G4PolarizedGammaConversion)
  - Photo-electric effect induced by circularly polarized gamma beam (class name G4PolarizedPhotoElectricEffect)
  - Bremsstrahlung of polarized electrons and positrons (class name G4ePolarizedBremsstrahlung)
  - Ionisation of polarized electron and positron beam (class name G4ePolarizedIonisation)
  - Annihilation of polarized positrons (class name G4eplusPolarizedAnnihilation)
- Processes for simulation of X-rays and optical protons production by charged particles
  - Synchrotron radiation (class name G4SynchrotronRadiation)
  - Transition radiation (class name G4TransitionRadiation)
  - Cerenkov radiation (class name G4Cerenkov)
  - Scintillations (class name G4Scintillation)
- The processes described above use physics model classes, which may be combined according to particle energy.
  - It is possible to change the energy range over which different models are valid, and to apply other models specific to particle type, energy range, and G4Region. The following alternative models are available:
    - Ionisation in thin absorbers (class name G4PAIModel)
And of course, remember to set the appropriate options and the scope of applicability of the physics models:

- SetLossFluctuations(G4bool)
- SetSubCutoff(G4bool, const G4Region* r=0)
- SetIntegral(G4bool)
- SetMinSubRange(G4double)
- SetMinEnergy(G4double)
- SetMaxEnergy(G4double)
- SetMaxEnergyForCSDARange(G4double)
- SetMaxEnergyForMuons(G4double)
- SetDEDXBinning(G4int)
- SetDEDXBinningForCSDARange(G4int)
- SetLambdaBinning(G4int)
- SetStepFunction(G4double, G4double)
- SetRandomStep(G4bool)
- SetApplyCuts(G4bool)
- SetSpline(G4bool)
- SetBuildCSDARange(G4bool)
- SetVerbose(G4int, const G4String name= "all")
- SetLambdaFactor(G4double)
- SetLinearLossLimit(G4double)
- ActivateDeexcitation(G4bool val, const G4Region* r = 0)
- SetMscStepLimitation(G4MscStepLimitType val)
- SetMscLateralDisplacement(G4bool val)
- SetSkin(G4double)
- SetMscRangeFactor(G4double)
- SetMscGeomFactor(G4double)
- SetLPMFlag(G4bool)
- SetBremsstrahlungTh(G4double)
- SetPolarAngleLimit(G4double)
- SetFactorForAngleLimit(G4double)
• But fortunately Geant4 offers some pre-configured physics packages, else you can copy from some of the examples.

• G4EmStandardPhysics
• G4Decay
• G4EmExtraPhysics
  – Eg: gamma-nuclear
• G4HadronElasticPhysics
• G4HadronInelasticPhysics
• G4StoppingPhysics
  – For particle at rest
• G4IonPhysics

• FLUKA is very different, tries to “take the best”, and has a set of default physics configurations.
Example for default physics configurations, FLUKA:

**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.

See also **GLOBAL**

- WHAT(1),..,WHAT(6): not used

- SDUM = CALORIME: defaults for calorimeter simulations
- EET/TRAN : defaults for Energy Transformer or transmutation calculations
- EM-CASCA : defaults for pure EM cascades
- ICARUS : defaults for studies related to the ICARUS experiment
- HADROTHE: defaults for hadrotherapy calculations
- NEUTRONS : defaults for pure low-energy neutron runs
- [NEW-DEFA : reasonable minimal set of new defaults - not needed]
- PRECISIO : defaults for precision simulations
- SHIELDIN : defaults for shielding calculations
Default configuration in FLUKA

In this course's exercises we will always use the HADRONTHE defaults.

HADROTHErapy

- EMF on
- Inelastic form factor corrections to Compton scattering and Compton profiles activated
- Low-energy neutron transport on down to thermal energies included, no need for option LOW-NEUT (high energy neutron threshold at 20 MeV)
- Fully analogue absorption for low-energy neutrons
- Particle transport threshold set at 100 keV, except for neutrons (1E-5 eV), and (anti)neutrinos (0, but they are discarded by default anyway)
- Multiple scattering threshold at minimum allowed energy, for both primary and secondary charged particles
- Delta ray production on with threshold 100 keV (see option DELTARAY)
- Restricted ionisation fluctuations on, for both hadrons/muons and EM particles (see option IONFLUCT)
- Tabulation ratio for hadron/muon dp/dx set at 1.03, fraction of the kinetic energy to be lost in a step set at 0.02 (see options DELTARAY, EMFFIX, FLUKAFIX)

(Says 0.05 elsewhere in Manual)
Scoring – Examples

- Dose deposition (1D, 2D, 3D maps)
- Fluence, or planar fluence of any particle, or particle group
- Energy deposited (in total, by any particle or particle group)
- Energy spectrum of any particle
- Fluence spectrum of any particle
- Generation or transmutation of particles
- Calculate material activation
- Record a phase-space file in a plane
Comparison with experiment
I.Gudowska and N.Sobolevsky

1D depth dose and fluence curve
SHIELD-HIT, Carbon ions on PMMA

FLUKA: Antiprotons on Water
(Bassler et al. 2007 :-)

12C 279 MeV/u, PMMA

1
0

Normalized Fluence

Depth /cm (water-equiv-depth)

0 5 10 15 20

Relative Dose

0 1 2 3 4 5 6

SHIELD-HIT

Exp. Matsufuji et al 2003

SH Z=6

SH Z=2

Exp. Z=6

Exp. Z=1

Exp. Z=2

Fluka 2006.3

Measurements

Relative dose [arbitrary units]

Water equivalent depth [mm]
SHIELD-HIT12A DDCs.

(David C. Hansen)
Scoring
Scoring - Dose and LET maps
2D dose maps of a
- antiproton,
- proton and
- carbon ion beam
• Compare MC codes with cars:

http://willworkforscience.blogspot.com/

→ “Monte Carlo Programs in Particle Therapy Research”
FLUKA
FLUKA

- In this course we will concentrate on FLUKA, since this is
  - easy to use
  - gives excellent results and
  - is very versatile.

- You can register at www.fluka.org and download it yourself
- Use online manual from webpage during exercises
- There is a Graphical User Interface “Flair”, which we will use in this course.
- Closed-source! But free to download object files, which can be linked to produce an executable.
FLUKA

- FLUKA is written in FORTAN 77, requires fortran compiler for linking the object files and generate executable.
- All configuration is handled by one monolithic input file
  - Fancy stuff which goes beyond, needs to be handled by user routines which can hook your own code into the FLUKA run-time.

- Input file is parsed by FLUKA. Old-schoolnik fortran 77 requires user adapts to computer language.
Any idea what this is?

It is a punch card, an USB stick of the 60ies, so to say...
This one has 80 columns of data, holding one line of code.
There is one card for each line.
Only [0-9] and [A-Z] + a few extra characters are used.
In “binary mode” each card holds two 36 bit words.
FLUKA – input file format

- Not only Fortran77 language reflects this, also input files.
- Because of the Punch card reminiscence, the input format to FLUKA is rather restricted. (There is also “FREE” mode.)
- These three lines thus corresponds to 3 punch cards:

```
BEAM  200.  0.2  1.5  1.2  0.7  1.0  PROTON

NO TABS ALLOWED! ONLY SPACES!
```

(sooner or later you will have a tab in your file and you will spend hours trying to find the mistake!)
THE TASK IS TO:

- Calculate charged pion fluence produced by monoenergetic proton beam with $p = 50 \text{ GeV/c}$, hitting a 5 cm Beryllium target.
- Target is $20 \times 20 \times 5 \text{ cm}^3$
- Surroundings are vacuum
FLUKA – Example input file (part 1)

*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8

TITLE
Charged pion fluence inside and around a proton-irradiated Be target
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
BEAM  
50.E+00          PROTON
BEAMPOS  
0.0       0.0       -50.0
*GEOBEGIN

A simple Be target inside vacuum
RPP blakhole  
-5000000.0       +5000000.0       -5000000.0       +5000000.0       -5000000.0       +5000000.0
RPP vacumbox  
-1000000.0       +1000000.0       -1000000.0       +1000000.0       -100.0       +1000000.0
RPP betarget  
-10.0       +10.0       -10.0       +10.0       0.0       +5.0
* plane to separate the upstream and downstream part of the target
XYP cutplane  
2.5
END
*
black hole
Blckhole  
5       +blakhole -vacumbox
*
vacuum around
Vacarund  
5       +vacumbox -betarget
*
Be target 1st half
UpstrBe  
5       +betarget +cutplane
*
Be target 2nd half
DwnstrBe  
5       +betarget -cutplane
END
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  
BERYLLIU       UpstrBe       DwnstrBe
*
External Black Hole
ASSIGNMAT  
BLCKHOLE       Blckhole
*
Vacuum
ASSIGNMAT  
VACUUM       Vacarund
*...+....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       BERYLLIU
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+)...8

AARHUS PARTICLE THERAPY GROUP
FLUKA – Example input file (part 2)

* e+e- and gamma production threshold set at 10 MeV
EMFCUT -0.010 0.010 1.0 BERYLLIU PROD-CUT
* score in each region energy deposition and stars produced by primaries
SCORE ENERGY BEAMPART
* Boundary crossing fluence in the middle of the target (log intervals, one-way)
USRBDX 99.0 PIONS+- -47.0 UpstrBe DwnstrBe 400. piFluenUD
USRBDX +50.0 +50.0 0.0 10.0 &
* Boundary crossing current in the middle of the target (log intervals, one-way)
USRBDX -1.0 PIONS+- -47.0 UpstrBe DwnstrBe 400. piCurrUD
USRBDX +50.00 +50.0 0.0 10.0 &
* Tracklength fluence inside the target, Upstream part and Downstream part
* Logarithmic energy intervals
USRTRACK -1.0 PIONS+- -48.0 UpstrBe 1000.0 20. piFluenU
USRTRACK 50.0 0.001 &
USRTRACK -1.0 PIONS+- -49.0 DwnstrBe 1000.0 20. piFluenD
USRTRACK 50.0 0.001 &
* Cartesian binning of the pion fluence inside and around the target
USRBIN 10.0 PIONS+- -50.0 50.0 50.0 50.0 50. piFluBin
USRBIN -50.0 -50.0 -10.0 100.0 100.0 60.0 &
* Cartesian binning of the deposited energy inside the target
USRBIN 10.0 ENERGY -51.0 10.0 10.0 10.0 5. Edeposit
USRBIN -10.0 -10.0 0.0 20.0 20.0 20.0 5.0 &
* RANDOMIZE 1.0
* START 1000000.0
STOP
FLUKA – Example 1: Specify Title

The title card for the example is as follows:

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

TITLE
Charged pion fluence inside and around a proton-irradiated Be target
```

Next: setup physics...

A “DEFAULT” card should follow, if anything else than the “NEW-DEFaults” are needed.
FLUKA – Example 1: Specify Physics

NEW-DEFAults (standard defaults active even if the DEFAULT card is not present)

- **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 down to thermal energies included,
- (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 last (thermal) groups
- Particle transport threshold set at 10 MeV, except for neutrons (1E-5 eV), and (anti)neutrinos (0, but they are discarded by default anyway)
- Multiple scattering threshold for secondary charged particles lowered to 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
FLUKA – Example 1: Specify Beam

The beam definition for our example can be the following (monochromatic, monodirectional proton beam of momentum 50 GeV/c):

```
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
BEAM      50.0E+00     PROTON
```

In our example, the beam starting point is given by:

```
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
BEAMPOS   0.0  0.0  -50.0
```

The BEAM card takes a lot of options, read the manual carefully...
FLUKA – Example 1: Specify Geometry

BLACKHOLE (region 1 “BH1”)

VACUUM (region 2 “VA2”)

Be target (region 3 and 4, separated by plane)

Proton Beam
FLUKA – Example 1: Specify Geometry

*...+...+...+...+...+...+...+...+...+...+...+...+...+...+...+...+...+...+...

GEObegin

A simple Be target inside vacuum

RPP 1-5000000.0+5000000.0-5000000.0+5000000.0-5000000.0+5000000.0
RPP 2-1000000.0+1000000.0-1000000.0+1000000.0 -100.0+1000000.0
RPP 3 -10.0 +10.0 -10.0 +10.0 0.0 0.0 +5.0

* plane to separate the upstream and downstream part of the target
XYP 4 2.5

END

* black hole
BH1 5 +1 -2

* vacuum around
VA2 5 +2 -3

* Be target 1st half
BE3 5 +3 +4

* Be target 2nd half
BE4 5 +3 -4

END

GEoend

BH1 = +1 - 2
VA2 = +2 - 3
BE3 = +3 +4
BE4 = +3 -4

RPP
**FLUKA – Example 1: Define Materials**

```plaintext
*...1...2...3...4...5...6...7...8
MATERIAL  4.0  9.0122  1.848  5.0  BERYLLIU
```

**WHAT(1)** - atomic number (meaningful only when NOT coupled to a COMPOUND card; otherwise set = 0.)

No default.

**WHAT(2)** - atomic weight in g/mole (meaningful only when NOT coupled to a COMPOUND card; otherwise set = 0.)

Default: computed according to the natural composition of an element with atomic number WHAT(1) if not coupled to a COMPOUND card, no default otherwise.

**WHAT(3)** - density in g/cm^3. Note that if the density is lower than 0.01, the material is considered to be a gas at atmospheric pressure unless set otherwise by MAT-PROP.

No default.

**WHAT(4)** - number (index) of the material

Default = NMAT + 1 (NMAT is the current number of defined materials. Its value is = 25 before any MATERIAL card is given, and doesn’t change if WHAT(4) overrides a number which has already been assigned)

**WHAT(5)** >= 2.0: alternate material number (or name, in name-based input) for ionisation processes (this material will be used instead of WHAT(1) for dE/dx etc.)

0 <= WHAT(5) <= 2: ignored
< 0.0: reset to default

Default: no alternate material

**WHAT(6)** - mass number of the material: set = 0 unless a specific individual isotope is desired. If not zero a nucleus of the given mass number is used by the EVAP generator for inelastic collisions, else the natural isotopic composition of the WHAT(1) element is used. For isotopic composition other than natural or single isotope, see COMPOUND

**SDUM** = name of the material

Default: COPPER, FLUKA material 12
FLUKA – Example 1: Define Materials

List of pre-defined FLUKA materials

<table>
<thead>
<tr>
<th>Fluka name</th>
<th>Fluka number</th>
<th>Common name</th>
<th>A</th>
<th>Z</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACKHOLE</td>
<td>1</td>
<td>Blackhole or External Vacuum</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VACUUM</td>
<td>2</td>
<td>Vacuum or Internal Vacuum</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HYDROGEN</td>
<td>3</td>
<td>Hydrogen</td>
<td>1.00794</td>
<td>1.0000000837</td>
<td></td>
</tr>
<tr>
<td>HELIUM</td>
<td>4</td>
<td>Helium</td>
<td>4.002602</td>
<td>2.0000000166</td>
<td></td>
</tr>
<tr>
<td>BERYLLIU</td>
<td>5</td>
<td>Beryllium</td>
<td>9.012182</td>
<td>4.0000001848</td>
<td></td>
</tr>
<tr>
<td>CARBON</td>
<td>6</td>
<td>Carbon</td>
<td>12.0107</td>
<td>6.0000000000002000</td>
<td></td>
</tr>
<tr>
<td>NITROGEN</td>
<td>7</td>
<td>Nitrogen</td>
<td>14.0067</td>
<td>7.00000000000017</td>
<td></td>
</tr>
<tr>
<td>OXYGEN</td>
<td>8</td>
<td>Oxygen</td>
<td>15.9994</td>
<td>8.000000000000133</td>
<td></td>
</tr>
<tr>
<td>MAGNESIU</td>
<td>9</td>
<td>Magnesium</td>
<td>24.3050</td>
<td>12.000000000000740</td>
<td></td>
</tr>
<tr>
<td>ALUMINUM</td>
<td>10</td>
<td>Aluminium</td>
<td>26.981538</td>
<td>13.0000000000002699</td>
<td></td>
</tr>
<tr>
<td>IRON</td>
<td>11</td>
<td>Iron</td>
<td>55.845</td>
<td>26.0000000000007874</td>
<td></td>
</tr>
<tr>
<td>COPPER</td>
<td>12</td>
<td>Copper</td>
<td>63.546</td>
<td>29.0000000000008960</td>
<td></td>
</tr>
<tr>
<td>SILVER</td>
<td>13</td>
<td>Silver</td>
<td>107.8882</td>
<td>47.0000000000001050</td>
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</tr>
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<td>SILICON</td>
<td>14</td>
<td>Silicon</td>
<td>28.0855</td>
<td>14.0000000000002329</td>
<td></td>
</tr>
<tr>
<td>GOLD</td>
<td>15</td>
<td>Gold</td>
<td>196.9655</td>
<td>79.00000000000019320</td>
<td></td>
</tr>
<tr>
<td>MERCURY</td>
<td>16</td>
<td>Mercury</td>
<td>200.59</td>
<td>80.00000000000013546</td>
<td></td>
</tr>
<tr>
<td>LEAD</td>
<td>17</td>
<td>Lead</td>
<td>207.2</td>
<td>82.00000000000011350</td>
<td></td>
</tr>
<tr>
<td>TANTALUM</td>
<td>18</td>
<td>Tantalum</td>
<td>180.9479</td>
<td>73.00000000000016654</td>
<td></td>
</tr>
<tr>
<td>SODIUM</td>
<td>19</td>
<td>Sodium</td>
<td>22.989770</td>
<td>11.0000000000000971</td>
<td></td>
</tr>
<tr>
<td>ARGON</td>
<td>20</td>
<td>Argon</td>
<td>39.948</td>
<td>18.000000000000000166</td>
<td></td>
</tr>
<tr>
<td>CALCIUM</td>
<td>21</td>
<td>Calcium</td>
<td>40.078</td>
<td>20.00000000000015500</td>
<td></td>
</tr>
<tr>
<td>TIN</td>
<td>22</td>
<td>Tin</td>
<td>118.710</td>
<td>50.00000000000073100</td>
<td></td>
</tr>
<tr>
<td>TUNGSTEN</td>
<td>23</td>
<td>Tungsten</td>
<td>183.84</td>
<td>74.00000000000019300</td>
<td></td>
</tr>
<tr>
<td>TITANIUM</td>
<td>24</td>
<td>Titanium</td>
<td>47.867</td>
<td>22.00000000000045400</td>
<td></td>
</tr>
<tr>
<td>NICKEL</td>
<td>25</td>
<td>Nickel</td>
<td>58.6934</td>
<td>28.00000000000089020</td>
<td></td>
</tr>
</tbody>
</table>
### FLUKA – Example 1: Assign Materials

For the present example the assignment could be:

<table>
<thead>
<tr>
<th></th>
<th>5.0</th>
<th>3.0</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASSIGNMAT</td>
<td>Be target, 1st and 2nd half</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASSIGNMAT</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>ASSIGNMAT</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>

* External Black Hole

* Vacuum
FLUKA – Example 1: Set cut-off values

The implicit NEW-DEFA default setting adopted in the example, sets, among other things, the production and transport threshold of heavy particles to 10 MeV. Production thresholds for e+e- and photons must be explicitly set using the EMFCUT command for all materials in the problem. Let us choose also in this case a 10 MeV threshold for the single material of the example (previously marked with material index 5 and name BERYLLIU). Following the instructions about the EMFCUT option, the card can be written as:

```plaintext
*...+...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
```

<table>
<thead>
<tr>
<th>WHAT(1)</th>
<th>= energy threshold for electron and positron production in GeV:</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.0</td>
<td>energy threshold for electron and positron production is</td>
</tr>
<tr>
<td></td>
<td>expressed as total energy (kinetic plus rest mass)</td>
</tr>
<tr>
<td>&lt; 0.0</td>
<td>energy threshold for electron and positron production is</td>
</tr>
<tr>
<td></td>
<td>expressed as kinetic energy</td>
</tr>
<tr>
<td>= 0.0</td>
<td>ignored</td>
</tr>
</tbody>
</table>
| Default: equal to the lowest electron transport cut-off in all regions made of this material (see Note 1 below)

WHAT(2) > 0.0 : energy threshold for photon production in GeV
WHAT(2) = 0.0 : ignored
Default: equal to the lowest photon transport cut-off in all regions made of this material (see Note 1 below)

WHAT(3) = FUDGE parameter. This parameter takes into account the contribution of atomic electrons to multiple scattering. For production and transport cut-offs larger than 100 keV it must be set = 1.0, while in the keV region it must be set = 0.0
Default: 0.0

WHAT(4) = lower bound (or corresponding name) of the FLUKA material number where electron/positron and photon production thresholds respectively equal to |WHAT(1)| and WHAT(2) apply. The material numbers or names are those pre-defined or assigned using a MATERIAL card.
("From material WHAT(4)...")
Default: 3.0
FLUKA – Example 1: Define Scorers

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
* Tracklength fluence inside the target, Upstream part and Downstream part
* Logarithmic energy intervals

| USRTRACK | -1.0 | 209.0 | -48.0 | 3.0  | 1000.0 | 20. piFluenU & & &
| USRTRACK | 50.0 | 0.001 | 50.0 | 0.001 |

First card:

WHAT(1) = 1.0 : linear binning in energy
   = -1.0 : logarithmic binning in energy
   Default = 1.0 (linear binning)

WHAT(2) = (generalised) particle type to be scored
   Default = 201.0 (all particles)

WHAT(3) = logical output unit:
   > 0.0 : formatted data are written on WHAT(3) unit
   < 0.0 : unformatted data are written on |WHAT(3)| unit
   Values of |WHAT(1)| < 21 should be avoided (with the exception of +11).
   Default = standard output unit

WHAT(4) = region defining the detector
   Default = 1.0

WHAT(5) = volume of the detector in cm**3
   Default = 1.0

WHAT(6) = number of energy bins
   Default = 10.0

SDUM = any character string (not containing '&') identifying the track-length detector. Max. 10 characters.

Don't forget

Continuation card:

WHAT(1) = maximum kinetic energy for scoring
   Default: Beam particle total energy as set by the BEAM
   option (if no BEAM card is given, the energy corresponding
to 200 GeV/c momentum will be used)

WHAT(2) = minimum kinetic energy for scoring
   (default: 0 if linear binning, 0.001 GeV otherwise)
   Note that the lowest energy limit of the last neutron group
   is 1.6E-14 GeV [1.6E-5 eV] for both the 253 and the 72 data set.

WHAT(3) .. WHAT(6) not used

SDUM = & in any position in column 71 to 78

209 = Charged pions
(see manual sec. 5.1 for particle codes!)
FLUKA – Example 1: Define Scorers

Here USRBIN asks for a 3D pion fluence map which goes into file “50”

Next a 3D energy deposit of the target is stored in file “51”.

USRBIN is probably the most important scorer.
It can be configured in many ways, read the manual entry carefully...
Finally, initialize the random number generator:

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

And tell how many primaries are to be simulated:

```
*R...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
START 100000.0
STOP
```

Save the file, and you are ready to run!
FLUKA – Example 1: running the example

$FLUPRO/flutil/rfluka -N0 -M5 example &

It will run 5 times, after run, it will produce a bunch of files for each scorer, and some general run-time information (errors, logs etc.)

The binary output from USRTRACK can be translated to ASCII with

ustsuw

The binary output from USRBIN can be translated to ASCII with

usbsuw

If you got 100 runs, you get tired of the interactive nature of these scripts. We have wrappers..
(live demonstration with flair)