Sources

Advanced FLUKA Course
Overview

1. Built-in sources
   - Beam definition
   - Extended sources
   - Colliding beams
   - Synchrotron radiation (SPEC SOUR)

2. User-defined sources
   - User routine SOURCE
   - Useful auxiliary routines
   - Sampling techniques
   - Two-step methods
Built-in sources
Beam definition – 1

Input card: BEAM

defines several beam characteristics:
type of particle, energy, divergence, profile

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

If SDUM = blank:
defines the coordinates of the centre of the beam spot 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       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)
Beam definition - 3

Input card: BEAMAXES

defines the beam reference frame which all parameters defined with BEAM and BEAMPOS refer to (angular divergence, transverse profile, polarization, extended sources)

Example

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+
BEAMAXES       1.0       0.0       0.0       0.0 0.7071068 0.7071068
```

- cosine of angle between x-axis of beam and x-axis of geometry frame \[\text{WHAT}(1)\]
- cosine of angle between x-axis of beam and y-axis of geometry frame \[\text{WHAT}(2)\]
- cosine of angle between x-axis of beam and z-axis of geometry frame \[\text{WHAT}(3)\]
  
  \[(1,0,0) \rightarrow \text{x-axes of beam and geometry frames are parallel}\]

- cosine of angle between z-axis of beam and x-axis of geometry frame \[\text{WHAT}(4)\]
- cosine of angle between z-axis of beam and y-axis of geometry frame \[\text{WHAT}(5)\]
- cosine of angle between z-axis of beam and z-axis of geometry frame \[\text{WHAT}(6)\]
  
  \[(0,0.7071068,0.7071068) \rightarrow \text{z-axis of beam frame is at 45deg to both y- and z-axes of geometry frame}\]
Extended sources - Spherical shell source

Input card: BEAMPOS

If \texttt{SDUM = SPHE-VOL}: defines a spatially extended source in a spherical shell

\textbf{Example}

\begin{verbatim}
*...1...2...3...4...5...6...7...
BEAMPOS  0.0  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  0.0SPHE-VOL
\end{verbatim}

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

The shell is centred at the \((x,y,z)\) point defined by another BEAMPOS card with \texttt{SDUM} = blank (or = NEGATIVE). The particle direction or angular distribution are those defined by \texttt{BEAM}, \texttt{BEAMAXES} and another BEAMPOS cards.
Extended sources - **Cylindrical shell source**

Input card: BEAMPOS

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

**Example**

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

- radius (in cm) of the inner cylinder defining the shell: 0.0 cm [**WHAT (1)**]
- radius (in cm) of the outer cylinder defining the shell: 1.0 cm [**WHAT (2)**]
- height (in cm) of the inner cylinder defining the shell: 0.0 cm [**WHAT (3)**]
- height (in cm) of the outer cylinder defining the shell: 1.0 cm [**WHAT (4)**]
- **WHAT (5) - 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 - Cartesian shell source

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

Example

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

- length (in cm) of the x-side of the inner parallelepiped defining the shell: 0.0 cm [WHAT (1)]
- length (in cm) of the x-side of the outer parallelepiped defining the shell: 1.0 cm [WHAT (2)]
- length (in cm) of the y-side of the inner parallelepiped defining the shell: 0.0 cm [WHAT (3)]
- length (in cm) of the y-side of the outer parallelepiped defining the shell: 1.0 cm [WHAT (4)]
- length (in cm) of the z-side of the inner parallelepiped defining the shell: 0.0 cm [WHAT (5)]
- length (in cm) of the z-side of the outer parallelepiped defining the shell: 1.0 cm [WHAT (6)]

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 - *Spherical surface source*

**Input card:** BEAMPOS

If **SDUM** = **FLOOD**: 
defines a source distribution on a *spherical surface*

**Example**

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BEAMPOS</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>BEAMPOS</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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

The surface is centred at the (x,y,z) point defined by another BEAMPOS card with **SDUM** = blank (or = **NEGATIVE**). The particle direction is sampled according to a diffusive distribution so as to generate a uniform fluence equal to \(1/(\pi R^2)\) inside the sphere (in absence of materials)
Extended sources - Example

Radioactive source of $^{60}$Co (two main $\gamma$-emissions: 1332.5 keV and 1173.2 keV)

cylindrical shape, 2cm diameter, 2mm height along z, centre of cylinder base at origin

\[
\begin{align*}
&+1+2+3+4+5+6+7+
\end{align*}
\]

BEAM 0.0
HI-PROPE 27.0 60.0
BEAMPOS 0.0 0.0 0.1 0.0 0.0 0.0 0.0
BEAMPOS 0.0 1.0 0.0 0.2 0.0 0.0 0.0

or

\[
\begin{align*}
&+1+2+3+4+5+6+7+
\end{align*}
\]

BEAM 1252.8E-6 10000.0
BEAMPOS 0.0 0.0 0.1 0.0 0.0 0.0 0.0
BEAMPOS 0.0 1.0 0.0 0.2 0.0 0.0 0.0

If height along x (instead of z) add

\[
\begin{align*}
&+1+2+3+4+5+6+7+
\end{align*}
\]

BEAMAXES 0.0 0.0 -1.0 1.0 0.0 0.0 0.0
Special sources - hadron-nucleus collision

Input card: SPECSOUR

Example: LHC
7 TeV/c, full crossing angle of 285 µrad in yz-plane

Momentum vectors of colliding beams: three possibilities

1) If SDUM = PPSOURCE:

| SPECSOUR | 0.0000 | 0.9975 | 6999.9999 | 0.0000 | 0.9975-6999.9999PPSOURCE |

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

2) If SDUM = CROSSASY:

| SPECSOUR | 7000.0000 | 142.5E-6 | 90.0000 | 7000.0000 | 142.5E-6 | 0.0000CROSSASY |

- lab momentum for beam 1 particle [WHAT (1)]
- polar angle (rad) between beam 1 particle momentum and positive z-direction [WHAT (2)]
- azimuth angle (deg!) defining crossing plane [WHAT (3)]
- lab momentum for beam 2 particle [WHAT (4)]
- polar angle (rad) between beam 2 particle momentum and negative z-direction [WHAT (5)]
Special sources – hadron-nucleus collision

3) If $SDUM = CROSSSYM$:

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

| SPEC SOUR | 7000. | 142.5E-6 | 90.0 | 0.0 | 0.0 | 0.0 | 0.0CROSSSYM |

- lab momentum for beam 1 and 2 particle [WHAT(1)]
- half crossing angle (rad) [WHAT(2)]
- azimuth angle (deg!) defining crossing plane [WHAT(3)]
- WHAT(4) – WHAT(6) are not used!

Interaction point of colliding beams (continuation card):

| SPEC SOUR | 7000. | 142.5E-6 | 90.0 | 0.0 | 0.0 | 0.0 | 0.0CROSSSYM |
| SPEC SOUR | 12.E-4 | 12.E-4 | 5.0 | & |

- sigma_x in cm for Gaussian sampling around XBEAM: 12 um [WHAT(7)]
- sigma_y in cm for Gaussian sampling around YBEAM: 12 um [WHAT(8)]
- sigma_z in cm for Gaussian sampling around ZBEAM: 5 cm [WHAT(9)]

(XBEAM,YBEAM,ZBEAM) defined with BEAMPOS card

- sampling limit, in sigma, applying along x, y, and z [WHAT(10)]
  $\leq 0$ no limit
Special sources - hadron-nucleus collision

<table>
<thead>
<tr>
<th>BEAM</th>
<th>3000.0</th>
<th>HEAVYION</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI-PROPE</td>
<td>82.0</td>
<td>208.0</td>
</tr>
<tr>
<td>SPECSOUR</td>
<td>574000.0</td>
<td>142.5E-6</td>
</tr>
<tr>
<td>SPECSOUR</td>
<td>12.E-4</td>
<td>12.E-4</td>
</tr>
<tr>
<td>SPECSOUR</td>
<td>82.0</td>
<td></td>
</tr>
</tbody>
</table>

- ID of beam 1 particle (default: the one of BEAM) [WHAT(11)]
- mass number of beam 2 particle (default: proton) [WHAT(12)]
- charge of beam 2 particle [WHAT(13)]

| SPECSOUR   | 7000.0 | 0.000335 | 180.0 | 0.0 | 0.0 | 0.0 | 0.0CROSSSYM |
| SPECSOUR   | 0.0    | 0.0      | 5.34  | 0.0 |     |     | 0.0& |
| SPECSOUR   | 1.0    | 1.057E-5 | 1.057E-5 | 1.057E-5 | 1.057E-5 | 0.0&& |

- sigma_th_C (rad) for the Gaussian sampling of the beam 1 particle angle wrt the ideal momentum in the Crossing plane [WHAT(14)]
- sigma_th_O (rad) for the Gaussian sampling of the beam 1 particle angle wrt the ideal momentum in the Orthogonal plane [WHAT(15)]
- the same as WHAT(14) for beam 2 particle [WHAT(16)]
- the same as WHAT(15) for beam 2 particle [WHAT(17)]
Special sources - hadron-nucleus collision

Three interaction types are available:

- \( i_0 + i_1 \times 10 + i_2 \times 100 \)  
  - \( i_0 \) = flag for nuclear nonelastic interactions
  - \( i_1 \) = flag for nuclear elastic interactions
  - \( i_2 \) = flag for electromagnetic dissociation (EMD) interactions
  - default: nuclear nonelastic + EMD if selected with the `PHYSICS(SDUM = EM-DISSO)` card

For collisions in the DPMJET energy range, don't forget (to link it as well as to input) the following card:

| *...+....1...+....2...+....3...+....4...+....5...+....6...+....7...+....* |
| PHYSICS          | 8000.0 | LIMITS |

\( \text{WHAT} (1) \) [GeV/c] must be larger than the maximum nucleon centre-of-mass momentum
Special sources - Synchrotron radiation

- Sophisticated low energy photon transport including polarization effects for Compton, photoelectric and coherent scattering, and full account for bound electron effects: already available in FLUKA since several years

- FLUKA can model the emission of Synchrotron Radiation:
  - by any charged particle, with arbitrary orientation vs magnetic field and traversing up to 2 circular arcs or helical paths, accounting for the emitted photon polarization, as a function of the emitted photon energy, and sampling SR photon energy and SR photon angle

The emitting charged particle is NOT transported:
SR photons are sampled directly.

Readily usable for bending magnets and wigglers (two steps so far).
Special sources – Synchrotron radiation

\[ E_c = \frac{3}{2} \frac{\hbar c \gamma^3}{\rho} \]

\[ E_c [\text{MeV}] = 2.21 \cdot 10^{-6} \frac{E^3 [\text{GeV}]}{\rho [\text{km}]} \]

\[ E_{irr} = \frac{8}{9} \pi \alpha \gamma E_c \]

\[ E_{irr} [\text{GeV/turn}] = 3.98 \cdot 10^{-2} E [\text{GeV}] E_c [\text{MeV}] \]
Special sources – synchrotron radiation

- $\Delta E = 8.5 \text{ GeV/turn}$ (dE/ds = 1.375 keV/cm in the dipoles)
- $P = 8.5 \times I[\text{mA}] \text{ MW} = 8.5 \times 10\text{mA} = 85 \text{ MW}$ in the whole accelerator
  (dP/ds = 1.375 x I[mA] W/cm in the dipoles)
Special sources - synchrotron radiation

FREE
SPECSOUR , ELECTRON, 175.0, 979948.86, 0.0000001, 0.0, -1.0, SYNC-RAD
SPECSOUR , 1050.0, -0.59467382951, 0., 1134.9997568, -1.0714843289E-02, 0.0, &
FIXED

- particle emitting the radiation [WHAT (1)]
- emitting particle momentum [GeV/c if >0] or kinetic energy [GeV if <0] [WHAT (2)]
- curvature radius [cm if >0] or magnetic field [T if <0] [WHAT (3)]
- photon spectrum lower limit [GeV] [WHAT (4)]
- x/y-components of the magnetic field versor [WHAT (5/6)]

The z-component sign is positive for SYNC-RAD and negative for SYNC-RDN

- length [cm] of the emission arc [WHAT (7)]
- coordinates (x/y/z [cm]) of the starting point of a possible second arc of same length [WHAT (8/9/10)]
- x/y-components of the emitting particle direction versor at the beginning of the second arc [WHAT (11/12)]

The starting point of the first arc as well the initial direction of the emitting particle are defined in the BEAMPOS card
Synchrotron radiation: 2-arc example
A comment about the units

All simulation results for the synchrotron radiation SPECSOUR are quoted per simulated synchrotron radiation photon.

From the output file (previous ex.):

```
<<< Synchrotron radiation source n. 1 >>>

Emitting particle: ELECTRON P: 3.00000 GeV/c
  Initial position : 0.0000000 0.50000000 -1400.00000 cm
  Initial direction: 0.0000000 0.10000000 0.99498744

Magnetic field: 2.0000000 0.0000000 0.0000000 T
Nominal curvature radius: 500.34614 cm
Nominal arc: 150.00000 cm
Arc angle: 0.29979246 rad
Actual curvature radius: 500.34614 cm
Actual arc: 150.00000 cm
Transverse p T: 3.00000 GeV/c and gamma: 5870.85237

Critical energy: 0.0000119705 GeV

Photon emission threshold : 1.00000000E-07 GeV
Photons >1 eV/nominal unit length: 0.11693748 cm^-1
Photons/unit length 1 eV - thres.: 2.36704527E-02 cm^-1
Photons/unit length above thres.: 9.30610323E-02 cm^-1

Total energy/nominal unit length: 4.55537630E-07 GeV/cm
Energy/unit length below thresh.: 7.54228751E-10 GeV/cm
Energy/unit length above thresh.: 4.54783401E-07 GeV cm
```

in this specific case we have to scale results by 150*.093061 to obtain results per primary emitting particle.
BEAM Visualization
USRBIN

- Create a **USRBIN** covering the beam position (preferentially Cartesian X-Y-Z) with BEAMPART as scoring particle
- Set all materials to VACUUM (to speed up calculation)
- Make one run of 1 cycle
- Visualize the results:
  - in flair as USRBIN plot
  - in the geometry editor as a custom USRBIN layer (don’t forget to set properly the colorband)
With USERDUMP

- Add a **USERDUMP** card selecting ONLY Source particles
- Make one run of 1 cycle
- Create a USERDUMP plot in flair:
  - Select the “Source” tab
  - You have the ability to make
    - 1D histogram plots of any of the source quantities
    - 2D scattered plots for any of the source quantities with even the possibility to overlay on a geometry image
User-defined sources
• Allows the **definition of primary particle properties** (in space, energy, time, direction, or mixture of particles) which cannot be described with built-in sources.

• Activated with **input card SOURCE**. The parameter list of that card (two continuation cards possible!) allows the user to pass on up to 18 numerical values **WHASOU(1-18)** and one 8-character string **SDUSOU** via **COMMON /SOURCM/**.

• At each call, one (or more) particle(s) must be loaded onto **COMMON /FLKSTK/** (particle bank) before returning control. The relevant variable values can be read from a file, generated by some sampling algorithm, or just assigned.

• **Argument list:** if **NOMORE=1** (output variable) the run will be terminated after exhausting the primary particles loaded onto the stack in the present call. The history number limit set with card START will be overridden.
Source routine - 2

... LOGICAL LFIRST
*
SAVE LFIRST
DATA LFIRST / .TRUE. /
...

NOMORE = 0
*
| First call initializations:
IF ( LFIRST ) THEN
* | *** The following 3 cards are mandatory ***
   LFIRST = .FALSE.
   TKESUM = ZERZER
   LUSSRC = .TRUE.
* | *** User initialization ***

Any first-time initialization can be inserted here, for example
- setting up parameters passed on via SOURCE card
- reading spectra from data files

END IF
...


NPFLKA = NPFLKA + 1
* Wt is the weight of the particle
WTFLK (NPFLKA) = ONEONE
WEIPRI = WEIPRI + WTFLK (NPFLKA)
* Particle type (1=proton.....). Ijbeam is the type set by the BEAM
* card
* +-------------------------------------------------------------------*
* | (Radioactive) isotope:
  IF ( IJBEAM .EQ. 2 ) THEN
    IARES = IPROA
    IZRES = IPROZ
    IISRES = IPROM
    CALL STISBM ( IARES, IZRES, IISRES )
    IJHION = IPROZ * 1000 + IPROA
    IJHION = IJHION * 100 + KKHEAV
    IONID = IJHION
    CALL DCDION ( IONID )
    CALL SETION ( IONID )
* |
* +-------------------------------------------------------------------*
* | Heavy ion:
  ELSE IF ( IJBEAM .EQ. 2 ) THEN
    IJHION = IPROZ * 1000 + IPROA
    IJHION = IJHION * 100 + KKHEAV
    IONID = IJHION
    CALL DCDION ( IONID )
    CALL SETION ( IONID )
    ILOFLK (NPFLKA) = IJHION
* | Flag this is prompt radiation
    LRADDC (NPFLKA) = .FALSE.
* | Group number for "low" energy neutrons, set to 0 anyway
    IGROUP (NPFLKA) = 0
* |
* +-------------------------------------------------------------------*
* | Normal hadron:
  ELSE
    IONID = IJBEAM
    ILOFLK (NPFLKA) = IJBEAM
* | Flag this is prompt radiation
    LRADDC (NPFLKA) = .FALSE.
* | Group number for "low" energy neutrons, set to 0 anyway
    IGROUP (NPFLKA) = 0
  END IF
* |
* +-------------------------------------------------------------------*
Source routine - 4

... * Particle age (s)
  AGESTK (NPFLKA) = +ZERZER
  AKNSHR (NPFLKA) = -TWOTWO
* Kinetic energy of the particle (GeV)
  TKEFLK (NPFLKA) = SQRT ( PBEAM**2 + AM (IONID)**2 ) - AM (IONID)
* Particle momentum
  PMOFLK (NPFLKA) = PBEAM
* Cosines (tx,ty,tz)
  TXFLK (NPFLKA) = UBEAM
  TYFLK (NPFLKA) = VBEAM
  TZFLK (NPFLKA) = WBEAM
  &
  &
  &
* Polarization cosines:
  TXPOL (NPFLKA) = -TWOTWO
  TYPOL (NPFLKA) = +ZERZER
  TZPOL (NPFLKA) = +ZERZER
* Particle coordinates
  XFLK (NPFLKA) = XBEAM
  YFLK (NPFLKA) = YBEAM
  ZFLK (NPFLKA) = ZBEAM
...

momentum and energy
- by default taken from BEAM card
  (PBEAM in COMMON /BEAMCM/)
- the user can set (consistently!) any momentum or energy here (either from file or sampled)
- **NOTE**: BEAM card is always mandatory for initialization purposes. Momentum/energy set here must not exceed the respective BEAM card value.

direction cosines and coordinates
- by default taken from
  BEAMPOS card
  (COMMON /BEAMCM/)
- ensure proper normalization of cosines!

polarization
- **TXPOL = -2** flag for “no polarization”
* User dependent flag:
  LOUSE (NPFLKA) = 0

...*

* User dependent spare variables:
  DO 100 ISPR = 1, MKBMX1
    SPAREK (ISPR,NPFLKA) = ZERZER
  100 CONTINUE

* User dependent spare flags:
  DO 200 ISPR = 1, MKBMX2
    ISPARK (ISPR,NPFLKA) = 0
  200 CONTINUE

Variables that allow to store additional information in COMMON /FLKSTK/, such as information on ancestors of a certain particle.
Auxiliary routines - Random numbers

... = FLRNDM (XDUMMY)
returns a 64-bit random number [0-1]

NOTE: Fundamental for SOURCE! No other external random generators must be used, otherwise the history reproducibility will be lost.

CALL FLNRRN (RGAUSS)
returns a normally distributed random number RGAUSS

CALL FLNRR2 (RGAUS1, RGAUS2)
returns an uncorrelated pair of normally distributed random numbers RGAUS1 and RGAUS2

CALL SFECFE (SINT, COST)
returns SINT and COST, sine and cosine of a random azimuthal angle
SINT**2 + COST**2 = 1.D+00

CALL RACO (TXX, TYY, TZZ)
returns a random 3D direction (TXX, TYY, TZZ)
TXX**2 + TYY**2 + TZZ**2 = 1.D+00
Auxiliary routines - Name <-> number conv.

Conversion of region name to number

CALL GEON2R ( REGNAM, NREG, IERR )

Input variable:
REGNAM = region name (CHARACTER*8)

Output variables:
NREG = region number
IERR = error code (0 on success, 1 on failure)

Conversion of region number to name

CALL GEOR2N ( NREG, REGNAM, IERR )

Input variable:
NREG = region number

Output variables:
REGNAM = region name (CHARACTER*8)
IERR = error code (0 on success, 1 on failure)
CALL OAUXFI (‘file’, LUN, ‘CHOPT’, IERR)

to open an auxiliary file (to read data or parameters) looking automatically for the file in some default locations (temporary directory, working directory)

CALL FLABRT (‘routine_name’, ‘message’)

this allows to force a FLUKA abort on user request: it might be useful to perform a debugging (using gdb for instance)

CALL SFLOOD ( XXX, YYY, ZZZ, UXXX, VYYY, WZZZ )

returns a random position XXX, YYY, ZZZ on the surface of a sphere of radius 1 and centre 0 (multiply XXX, YYY, ZZZ by the actual radius and add the centre coordinates) and a random direction UXXX, VYYY, WZZZ (cosines) so as to generate a uniform fluence inside the sphere, equal to $1/(\pi R^2)$, being R the actual sphere radius.
Sampling from a distribution - Discrete

1) From the cumulative distribution

- Suppose to have a **discrete** random variable \( x \), that can assume values \( x_1, x_2, \ldots, x_n, \ldots \) with probability \( p_1, p_2, \ldots, p_n, \ldots \)
- Assume \( \sum p_i = 1 \), or normalize it
- Divide the interval \([0,1)\) in \( n \) subintervals, with limits
  \[ y_0 = 0, \; y_1 = p_1, \; y_2 = p_1 + p_2, \; \ldots \]
- Generate a uniform pseudo-random number \( \xi \)
- Find the \( i^{th} \) y-interval such that
  \[ y_{i-1} \leq \xi < y_i \]
- Select \( X = x_i \) as the sampled value

Since \( \xi \) is uniformly random:

\[
P(x_i) = P(y_{i-1} \leq \xi < y_i) = y_i - y_{i-1} = p_i
\]
2) By adjusting weights

- Suppose to have a fluence energy spectrum $\Phi$ given in $N$ discrete energy bins between $E_0$ and $E_N$: $\Phi_1, ..., \Phi_N$
- Generate a uniform pseudo-random number $\xi$
- Find the $i^{th}$ energy bin such that
  $$E_{i-1} \leq \xi (E_N - E_0) < E_i$$
- Generate another uniform pseudo-random number $\xi \in [0,1)$ and sample an energy uniformly within the $i^{th}$ energy bin
- Assign a weight $\Phi_i$ to that primary particle

*Note:* This method is often used for spectra steeply decreasing with energy (e.g., $\Phi \sim 1/E$), where the result depends significantly on the particle cascades initiated by high energy primaries, as it ensures faster convergence to the true value.
Example Sampling from a histogram - 1

PARAMETER (NMAX=1000)
DIMENSION ERG(NMAX), CUM(NMAX)
CHARACTER*250 LINE
SAVE  N, ERG, CUM

IF ( LFIRST ) THEN
  ...
  LUNRD = NINT(WHASOU(1))
  N = 0
  SUM   = ZERZER
  EPREV = ZERZER
10 CONTINUE
  READ (LUNRD, '(A)', ERR=9999, END=20 ) LINE
  READ (LINE, *, ERR=10) E, H
  N = N + 1
  IF (N .GT. NMAX)
    &            CALL FLABRT('SOURCE','Please increase NMAX')
  IF (N .EQ. 1 .AND. ABS(H).GT.AZRZRZ)
    &            CALL FLABRT('SOURCE','ZERO was expected as first value')
  *** Create cumulative sum of dE*V
    SUM = SUM + H*(E-EPREV)
    EPREV = E
    ERG(N) = E
    CUM(N) = SUM
  GO TO 10
20 CONTINUE
  CLOSE (LUNRD)
END IF
9999 CALL FLABRT('SOURCE', 'Error reading source file')

Logical unit from input file as WHAT(1) of the SOURCE card. Use OPEN card to open the file which contains pairs Energy-Value. First value is supposed to be 0 in order to set the lower energy limit.

Example: hsource.f
Example Sampling from a histogram - 2

* From this point ..... 

*** Select a random energy interval 
   C = CUM(N) * FLRNDM(C)
*** Find interval (CUM(1)=0)
   DO I=2,N
       IF (CUM(I) .GT. C) THEN
           *** Found interval I, select a random energy inside
           E = ERG(I-1) + (ERG(I)-ERG(I-1))*FLRNDM(C)
           GO TO 90
       END IF
   END DO
Sampling from a distribution - Continuous

1) By integration

- Integrate the distribution function $f(x)$, analytically or numerically, and normalize to 1 to obtain the normalized cumulative distribution

$$F(x) = \frac{\int_{x_{\text{min}}}^{x} f(t)dt}{\int_{x_{\text{min}}}^{x_{\text{max}}} f(t)dt}$$

- Generate a uniform pseudo-random number $\xi \in [0,1)$
- Get the desired result by finding the inverse value $x = F^{-1}(\xi)$, analytically or most often numerically, i.e. by interpolation (table look-up)

Since $\xi$ is uniformly random:

$$P(a < x < b) = P(F(a) \leq \xi < F(b)) = F(b) - F(a) = \int_{a}^{b} f(x)dx$$
**Sampling from a distribution - Continuous**

**Example**

Take \( f(x) = e^{-\frac{x}{\lambda}}, \ x \in [0, \infty) \)

Cumulative distribution:

\[
F(t) = \int_0^t e^{-\frac{x}{\lambda}} \, dx = \lambda \left(1 - e^{-\frac{t}{\lambda}}\right)
\]

Normalized:

\[
F'(t) = \int_0^t e^{-\frac{t}{\lambda}} \, dx = 1 - e^{-\frac{t}{\lambda}}
\]

Generate a uniform pseudo-random number \( \xi \in [0,1) \)

\[
1 - e^{-\frac{t}{\lambda}} = \xi
\]

Sample \( t \) by inverting

\[
t = -\lambda \ln(1 - \xi)
\]

Repeat N times
Sampling from a distribution - Continuous

2) By rejection

- Let be $f'(x)$, a normalized distribution function, which cannot be sampled by integration and inversion
- Let be $g'(x)$, a normalized distribution function, which can be sampled, and such that $Cg'(x) \geq f'(x)$, $\forall x \in [x_{\text{min}}, x_{\text{max}}]$.
- Sample $X$ from $g'(x)$, and generate a uniform pseudo-random number $\xi \in [0, 1)$.
- Accept $X$ if $\xi < f'(X)/Cg'(X)$, if not repeat the previous step.

The overall efficiency (accepted/sampled) is given by:

$$ R = \int \frac{f'(x)}{Cg'(x)} g'(x) \, dx = \frac{1}{C} $$

and the probability that $X$ is accepted is unbiased:

$$ P(X) \, dX = \frac{1}{R} g'(X) \, dX \times \frac{f'(X)}{Cg'(X)} = f'(X) \, dX $$
Sampling from a distribution - Continuous

**Example**

- Let be \( f'(x) = \frac{1 + 3x^2}{4} \), \( x \in [-1,1] \),
- Take \( g'(x) = 1/2 \), \( C=2 \)
- Generate two uniform pseudo-random numbers \( \xi_1, \xi_2 \in [0,1) \)
- Accept \( X = 2\xi_1 - 1 \) if \( \xi_2 < \frac{1 + 3X^2}{4} \), if not repeat
3) By adjusting weights

- Suppose to have a fluence energy spectrum $\Phi(E)$ given in between $E_0$ and $E_1$
- Generate a uniform pseudo-random number $\xi \in [0,1)$ and calculate the sampled energy $E = E_0 + \xi (E_1 - E_0)$
- Assign a weight $\Phi(E)$ to that primary particle
**Two-step methods**

**Goal:** predict radiation fields and observables in remote locations in a huge geometry

Ex.1: LHCb experiment

**Problem:**
direct calculation in one step can be highly inefficient due to the small affected phase-space

Ex.2: MYRRHA ADS
Two-step methods

Solution: split simulation into two steps.

Two different approaches are possible:

✓ (1) Calculation of radiation fields in a suitable location:
   for each particle type, calculate fluence distributions, double-differential in energy and angle

(2) Sample from the calculated distributions in a user-defined source, and score the interested quantities at the location of interest

Obs: - it must be clear that in this way the correlations within one full event are lost. All quantities are calculated as average quantities
- pay attention to calculate the radiation fields in step (1) covering all the phase space relevant for step (2)

✓ (1) Dumping particles at the location of interest:
   write all information on particles entering it (type, energy, position, direction) into an external file

(2) Read the information from the external with a user-defined source
First approach: an example

In this example, a source term built calculating the neutrons backward emitted at the location (A) was important to calculate the average neutron and photon fluence on detectors very far from the neutron production point.