



User Programming in the FLUKA environment

FLUKA Advanced Course

Why user routines

- Fluka offers a rich choice of **built-in options** for scoring most quantities and for applying variance reduction techniques, without requiring the users to write a single line of code
- However there are special cases where “ad-hoc” routines are unavoidable, because the needed information cannot be obtained through standard options

What is available for the users

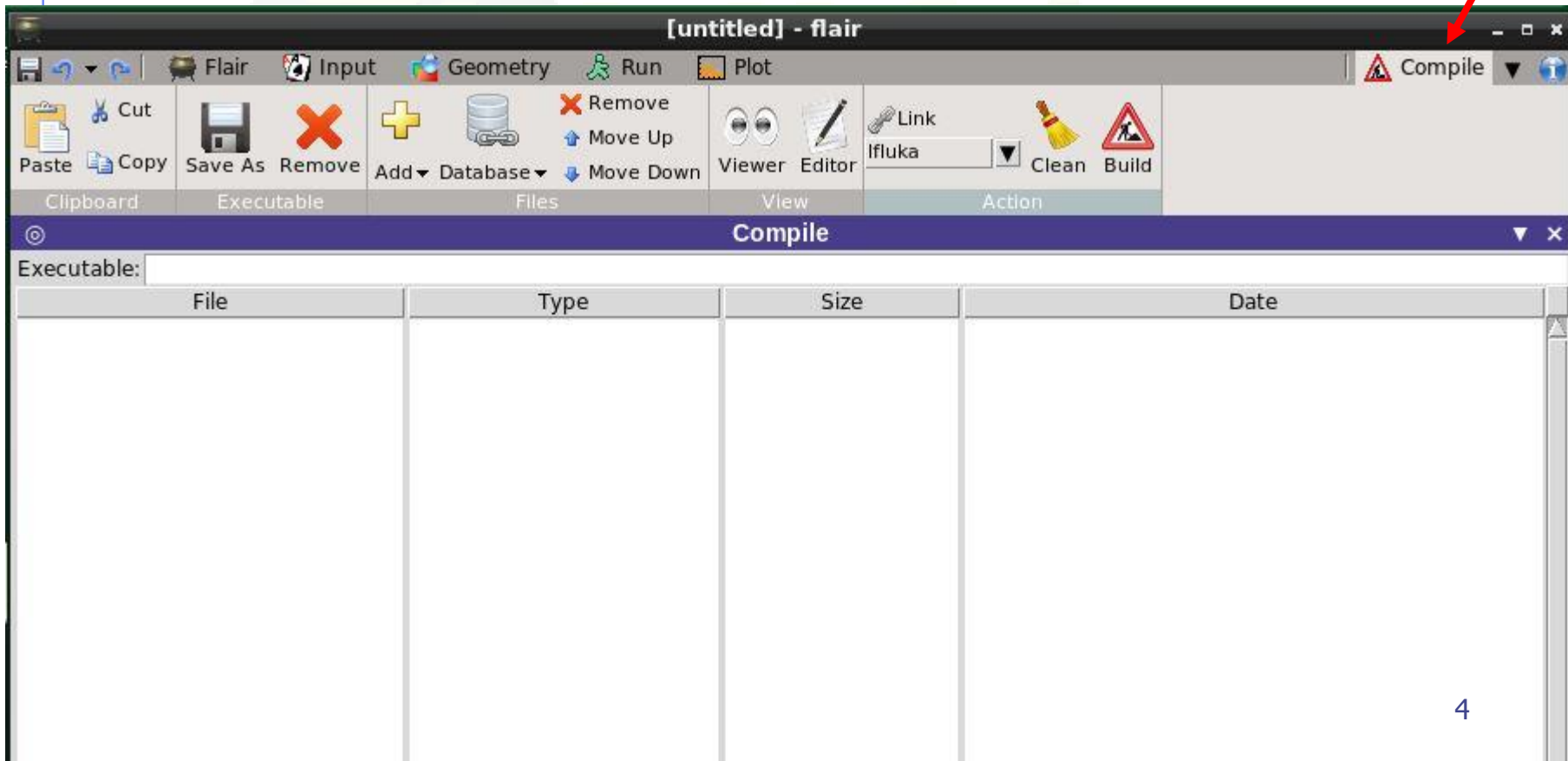
- A number of **user routine** templates are available in the `$FLUPRO/usermvax` directory and can be modified/activated by the user in order to fulfill non-standard tasks
- The **INCLUDE** files containing the COMMON blocks are in the `$FLUPRO/flukapro` directory
- An extended **mathematical library** can in principle be exploited by properly calling its members from inside an user routine
- The **compiling and linking scripts** are in the directory `$FLUPRO/flutil`
- Most user routines need to be **activated** by input directives

Flair can be used to edit, compile and link user routines in order to build a user-specific FLUKA executable

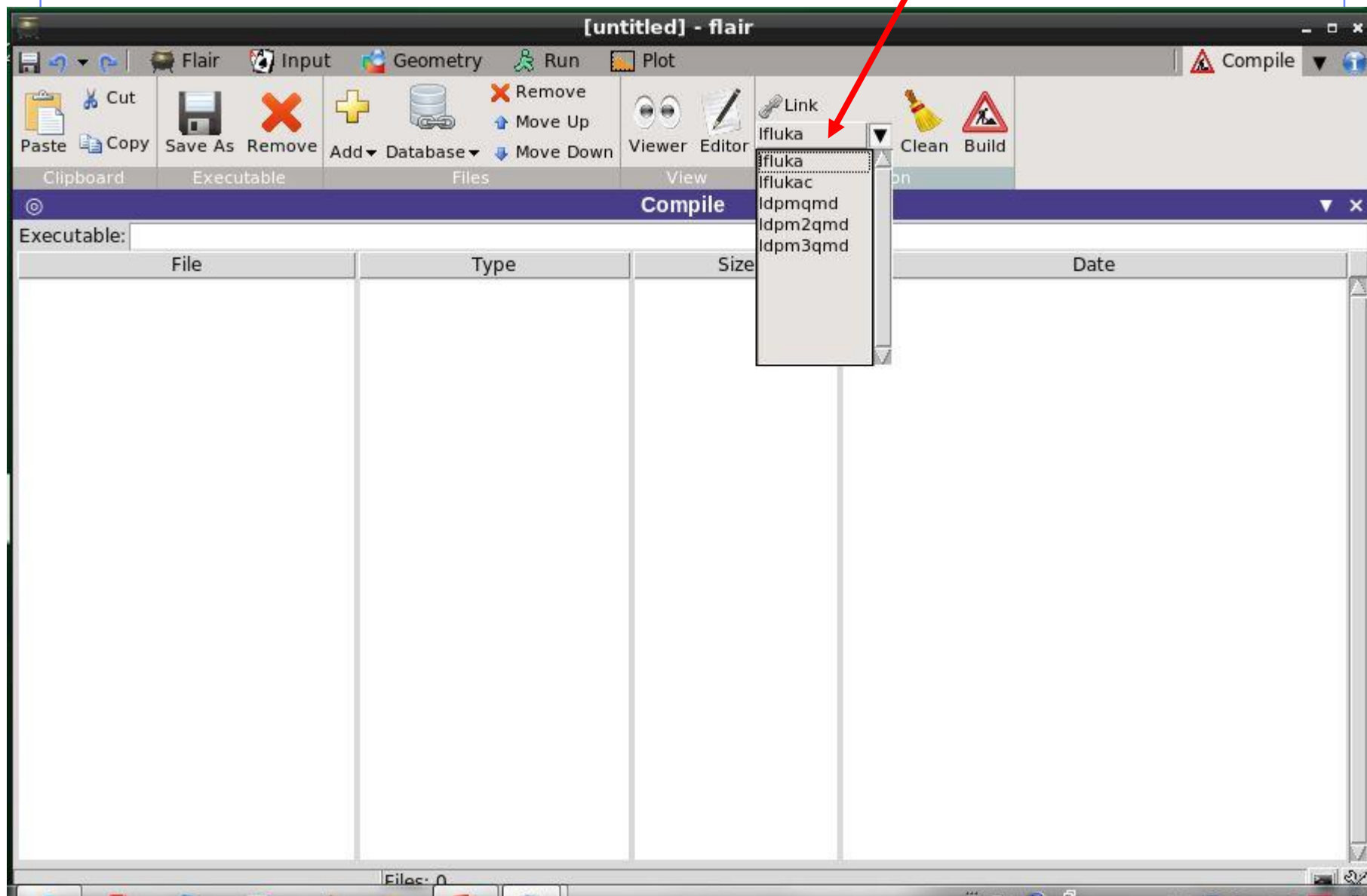
Flair interface (I)

Flair has a button in the Compile frame which scans the input file for possible cards that require an user routine

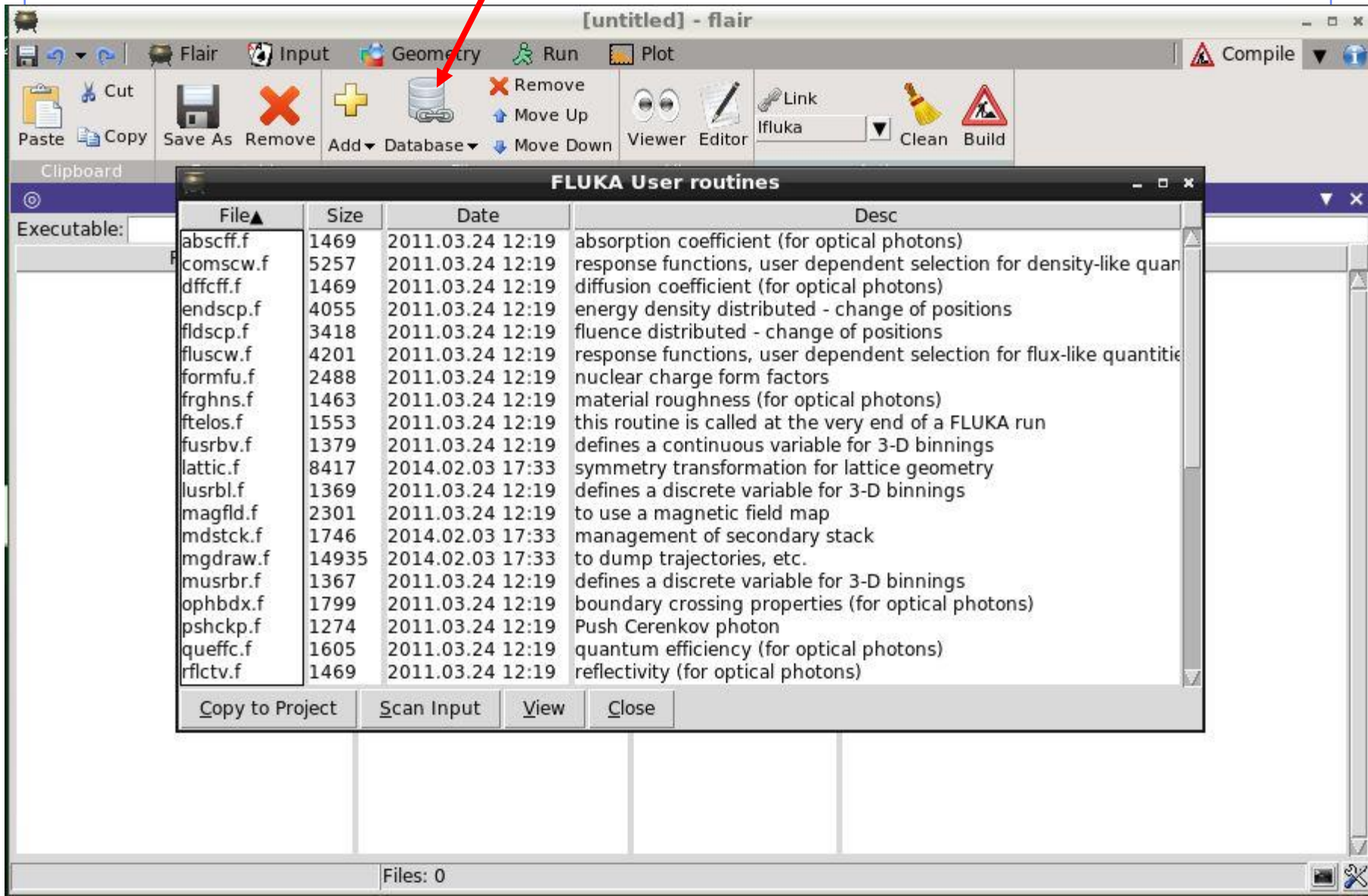
It allows to copy the template routine from `$FLUPRO/usermvax` to the project directory



Choosing the builder



Parsing content of \$FLUPRO/usermvax



The screenshot shows the Flair software interface with a toolbar at the top. A red arrow points to the Database icon in the toolbar. Below the toolbar, a dialog box titled "FLUKA User routines" is open, displaying a table of user routines. The table has columns for File, Size, Date, and Desc. The dialog box also has buttons for Copy to Project, Scan Input, View, and Close.

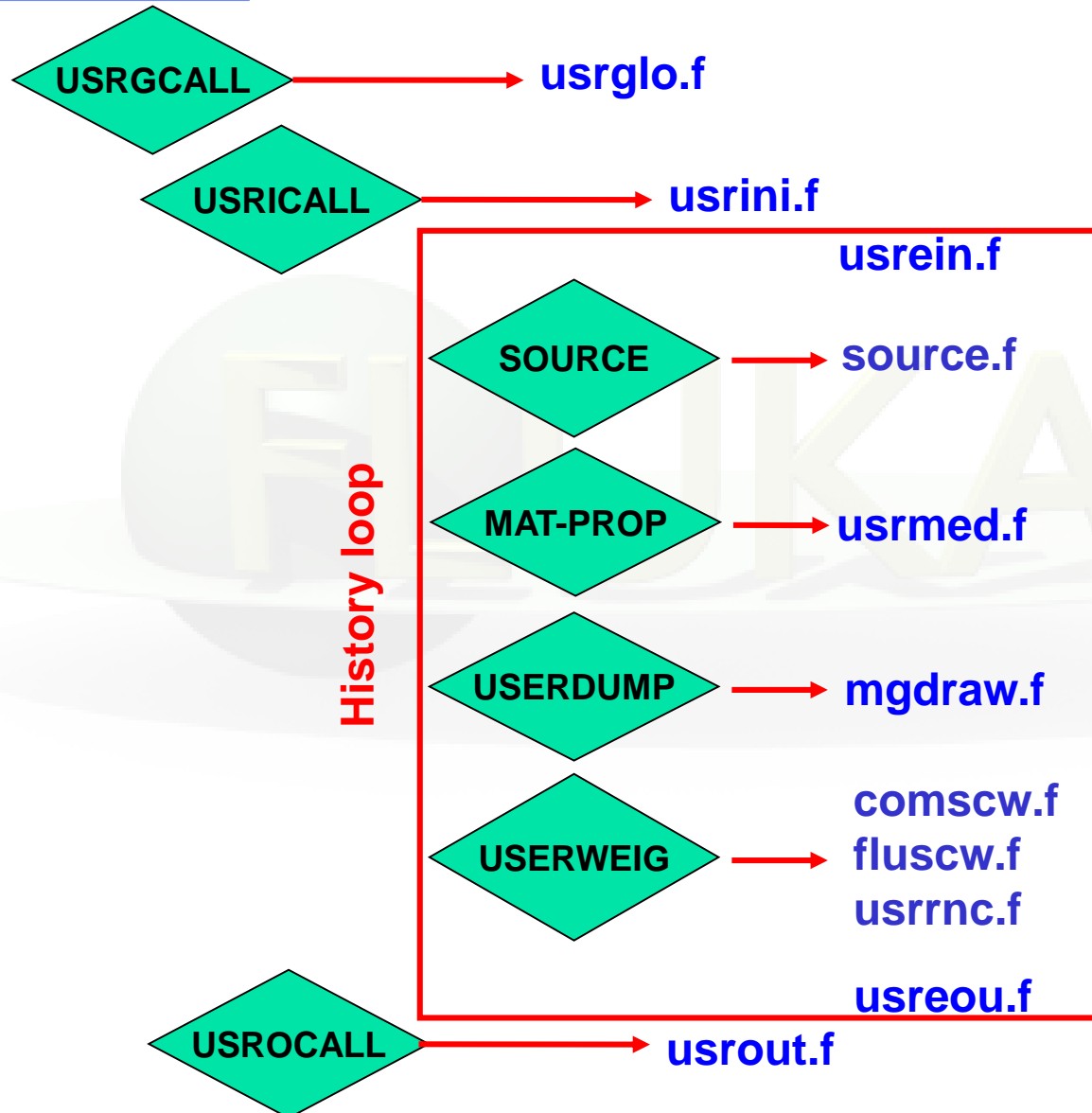
File	Size	Date	Desc
abscff.f	1469	2011.03.24 12:19	absorption coefficient (for optical photons)
comscw.f	5257	2011.03.24 12:19	response functions, user dependent selection for density-like quan
dfcfc.f	1469	2011.03.24 12:19	diffusion coefficient (for optical photons)
endscp.f	4055	2011.03.24 12:19	energy density distributed - change of positions
fldscp.f	3418	2011.03.24 12:19	fluence distributed - change of positions
fluscw.f	4201	2011.03.24 12:19	response functions, user dependent selection for flux-like quantitie
formfu.f	2488	2011.03.24 12:19	nuclear charge form factors
frghns.f	1463	2011.03.24 12:19	material roughness (for optical photons)
ftelos.f	1553	2011.03.24 12:19	this routine is called at the very end of a FLUKA run
fusrbv.f	1379	2011.03.24 12:19	defines a continuous variable for 3-D binnings
lattic.f	8417	2014.02.03 17:33	symmetry transformation for lattice geometry
lusrbl.f	1369	2011.03.24 12:19	defines a discrete variable for 3-D binnings
magfld.f	2301	2011.03.24 12:19	to use a magnetic field map
mdstck.f	1746	2014.02.03 17:33	management of secondary stack
mgdraw.f	14935	2014.02.03 17:33	to dump trajectories, etc.
musrbr.f	1367	2011.03.24 12:19	defines a discrete variable for 3-D binnings
ophbdx.f	1799	2011.03.24 12:19	boundary crossing properties (for optical photons)
pshckp.f	1274	2011.03.24 12:19	Push Cerenkov photon
queffc.f	1605	2011.03.24 12:19	quantum efficiency (for optical photons)
rflectv.f	1469	2011.03.24 12:19	reflectivity (for optical photons)

Adding routines from other directories

The screenshot shows the Flair software interface. The title bar reads "[untitled] - flair". The menu bar includes "Flair", "Input", "Geometry", "Run", and "Plot". The toolbar contains icons for "Paste", "Copy", "Save As", "Remove", "Add Database", "Remove", "Move Up", "Move Down", "Viewer", "Editor", "Link", "Clean", and "Build". The "Add Database" menu is open, showing options for "Fortran", "C/C++", "Object", and "Library". A red arrow points to the "Add Database" icon. Below the menu is a table with columns "File", "Type", "Size", and "Date". The status bar at the bottom indicates "Files: 0".

File	Type	Size	Date
------	------	------	------

Card – user routine correspondence



SOURCE card in the input

The screenshot displays the FLAIR software interface with the 'Input' window open. The 'SOURCE' card is highlighted in the main editor area. A red arrow points to the 'SOURCE' card in the left-hand tree view.

Input

Define the beam characteristics

BEAM Beam: Energy E : 1.0 Part: PROTON
 Δp : Flat $\Delta \phi$: Flat
Shape(X): Rectangular Δx : Shape(Y): Rectangular Δy :

Define the beam position

BEAMPOS x: y: z:
cosx: cosy: Type: POSITIVE

#if SECOND

#if ANALOGUE

OPEN Unit: 99 ASC Status: OLD
File: rdsorcePrecision_first_99

#else

OPEN Unit: 99 ASC Status: OLD
File: rdsorce_first_99

#endif

SOURCE #1: 99 #2: #3:
sdum: #4: #5: #6:

#endif

GEOBEGIN Log: Acc: Opt:
Inp: Out: Fmt: COMBNAME

Title:

Black body

SPH btkbody x: 0.0 y: 0.0 z: 0.0
R: 100000.0

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
*#define FIRST

Inp: rdsorce.inp Card:1 Total:69

Automatic recognition by FLAIR

The screenshot shows the 'rdsources.flair - flair' application window. The main toolbar includes icons for Flair, Input, Geometry, Run, Plot, and Compile. Below the toolbar is a secondary toolbar with icons for Cut, Copy, Paste, Save As, Remove, Add Database, Move Up, Move Down, Viewer, Editor, Link, Clean, and Build. A red arrow points from the top of the screen to the 'Add Database' icon in the secondary toolbar.

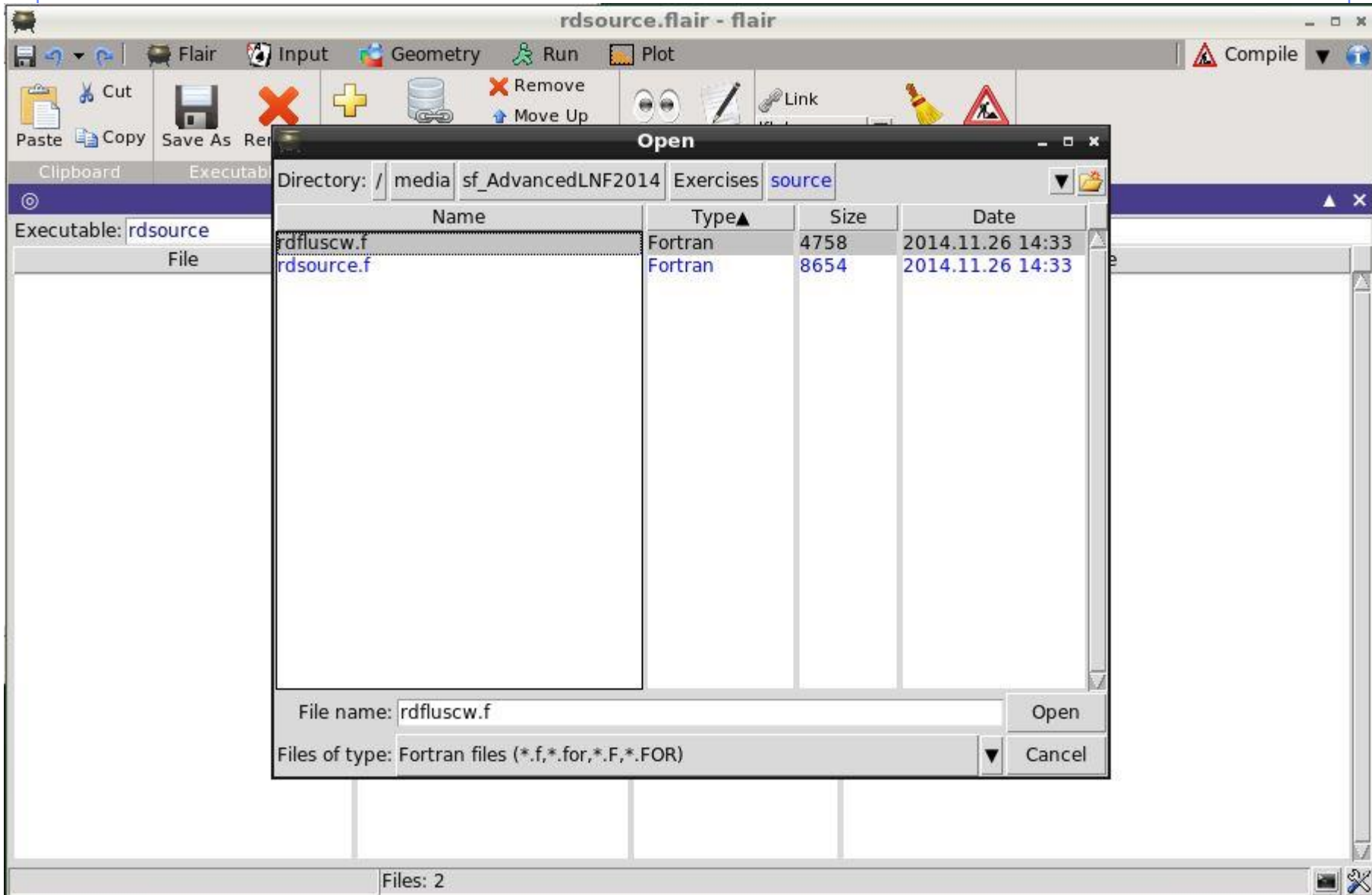
A dialog box titled 'FLUKA User routines' is open, displaying a table of routines. A red arrow points from the left side of the screen to the 'source.f' row in the table.

File	Size	Date	Desc
fldscp.f	3418	2011.03.24 12:19	fluence distributed - change of positions
fluscw.f	4201	2011.03.24 12:19	response functions, user dependent selection for flux-like quantities
formfu.f	2488	2011.03.24 12:19	nuclear charge form factors
frghns.f	1463	2011.03.24 12:19	material roughness (for optical photons)
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pshckp.f	1274	2011.03.24 12:19	Push Cerenkov photon
queffc.f	1605	2011.03.24 12:19	quantum efficiency (for optical photons)
rflectv.f	1469	2011.03.24 12:19	reflectivity (for optical photons)
rfrndx.f	1469	2011.03.24 12:19	refraction index (for optical photons)
soevsv.f	2672	2011.03.24 12:19	saving source events
source.f	7426	2011.03.24 12:19	to generate any distribution for source particles
stupre.f	4223	2011.03.24 12:19	set user variables (electrons and photons)

Buttons at the bottom of the dialog box: Copy to Project, Scan Input, View, Close.

Files: 2

Manual insertion from a user directory



User routine scope (I)

SCORING

- comscw.f
- fluscw.f
- endscp.f
- fldscp.f
- musrbr.f
- lusrbl.f
- fusrbv.f
- usrrnc.f

BIASING

- usbset.f
- usimbs.f
- udcdrl.f

LATTICE GEOMETRY

- lattic.f

SOURCE GENERATION

- source.f
- (soevsv.f)

MAGNETIC FIELD

- magfld.f

OPTICAL PHOTONS

- abscff.f
- dffcff.f
- frghns.f
- ophbdx.f
- queffc.f
- rflctv.f
- rfrndx.f

INITIALIZATION

- usrglo.f
- usrini.f
- usrein.f

OUTPUT

- usreou.f
- usrout.f

User routine scope (II)

accessing
particle stack

- mdstck.f
- stupre.f
- stuprf.f

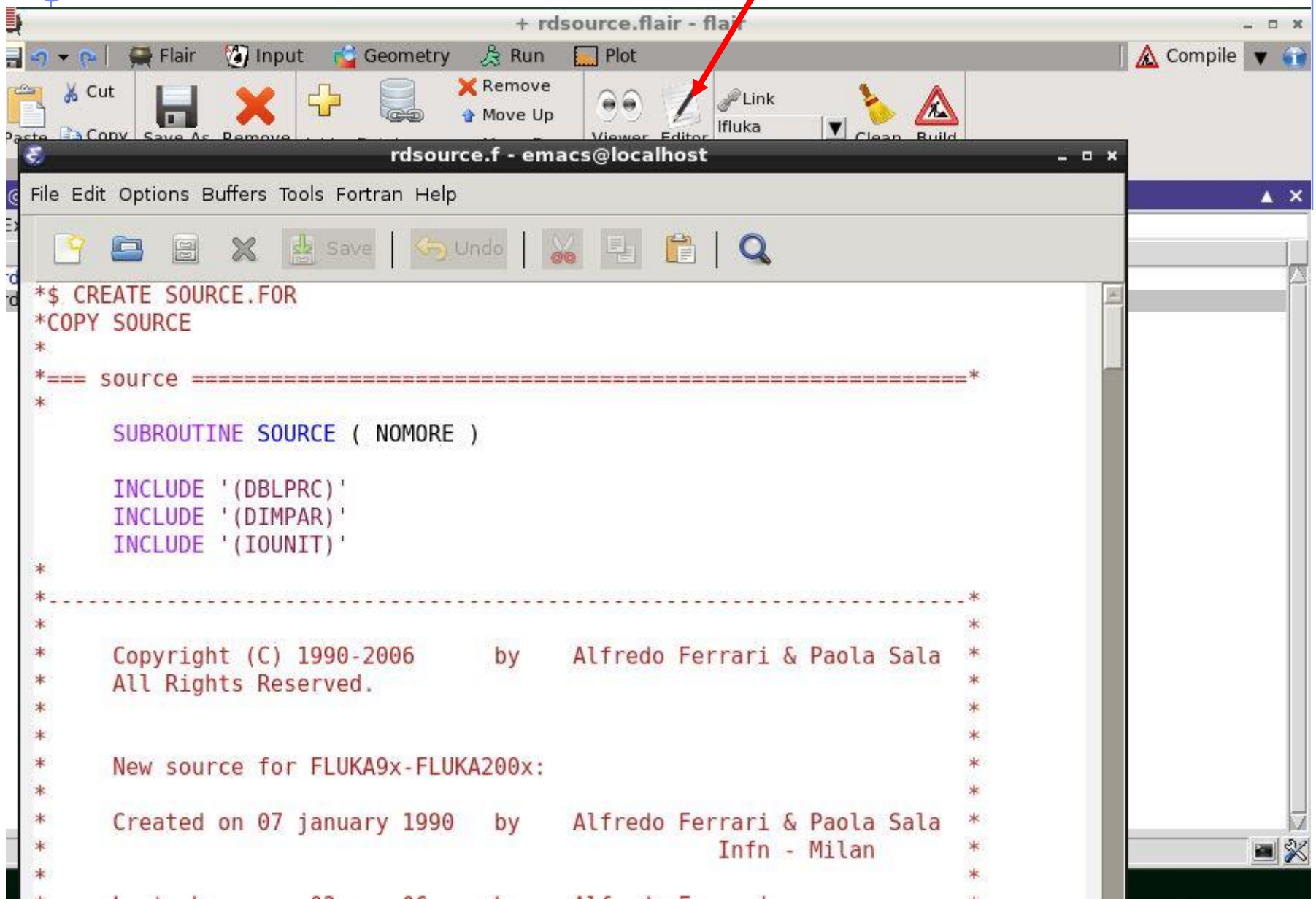
accessing
(almost) everything

- mgdraw.f

multipurpose

- usrmed.f

Editing routines



The image shows a software interface with a toolbar and an Emacs window. The toolbar includes icons for Cut, Copy, Save As, Remove, Move Up, Viewer, Editor, Link, Clean, and Build. A red arrow points to the 'Editor' icon. The Emacs window displays the following Fortran code:

```
File Edit Options Buffers Tools Fortran Help
* $ CREATE SOURCE.FOR
* COPY SOURCE
*
* === source =====*
*
* SUBROUTINE SOURCE ( NOMORE )
*
* INCLUDE '(DBLPRC)'
* INCLUDE '(DIMPAR)'
* INCLUDE '(IOUNIT)'
*
* -----*
*
* Copyright (C) 1990-2006      by      Alfredo Ferrari & Paola Sala
* All Rights Reserved.
*
*
* New source for FLUKA9x-FLUKA200x:
*
* Created on 07 january 1990   by      Alfredo Ferrari & Paola Sala
*                                     Infn - Milan
```


Compiling and linking

- A FLUKA executable with user routines is in general application specific. It must **be named and kept separately** from the standard FLUKA
- Everything is managed today by FLAIR, however it is important to know the following details (managed automatically inside FLAIR):
- **\$FLUPRO/flutil/fff** is the compiling script with the proper path to the INCLUDE subdirectory and the required compiler (g77 or gfortran) options

Example: **\$FLUPRO/flutil/fff usrini.f** generates **usrini.o**

then **\$FLUPRO/flutil/lfluka -m fluka -o flukamy usrini.o** will perform the proper linking generating the executable here called **flukamy**

- Tip: **\$FLUPRO/flutil/lfluka -m fluka -o flukamy usrini.f** will automatically call **\$FLUPRO/flutil/fff**

Compiling and linking (Build) by FLAIR

Clipboard Executable Files View Action

Compile

Executable: rdsorce

File	Type	Size	Date
rdfluscw.f	Fortran	4758	2014.11.26 14:33
rdsorce.f	Fortran	8654	2014.11.26 14:33

setting the name of new executable by the user specific for the problem under consideration

Successful building

The screenshot shows the 'Compile' window of the 'rdsourc.flair - flair' application. The window title is '+ rdsourc.flair - flair'. The toolbar includes icons for 'Flair', 'Input', 'Geometry', 'Run', and 'Plot'. The main toolbar contains 'Clipboard' (Paste, Copy), 'Executable' (Save As, Remove), 'Files' (Add, Database, Move Up, Move Down), 'View' (Viewer, Editor), and 'Action' (Link, Clean, Build). The 'Compile' window has a title bar 'Compile' and a subtitle 'Executable: rdsourc'. It contains a table with the following data:

File	Type	Size	Date
rdfluscw.f	Fortran	4758	2014.11.26 14:33
rdsourc.f	Fortran	8654	2014.11.26 14:33

A red arrow points to a green notification box in the bottom right corner of the window. The notification box contains the text 'Successful Build' and 'Executable rdsourc is successfully built'.

Files: 2

FLUKA programming rules

- Language is Fortran 77 (C routines can be linked)
- Double Precision everywhere, except for integer variables beginning with a letter in the range [i-n]
- Common blocks are in `$FLUPRO/flukapro` files and are loaded by the **INCLUDE** statement
- Each routine must start with the following includes/common blocks:

```
INCLUDE '(DBLPRC)'  
INCLUDE '(DIMPAR)'  
INCLUDE '(IOUNIT)'
```

Note the parentheses which are an integral part of the Fluka INCLUDE file names

- Users may add other FLUKA commons as well as their own commons which may reside in different places

Numerical precision

- Floating point representation

$$\pm d_0 d_1 d_2 \dots d_{p-1} \times \beta^e$$

where: β =base, $0.dddd$ =significant

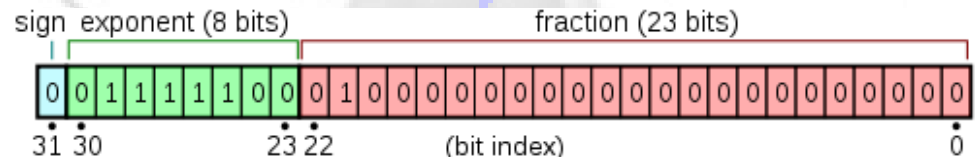
- Represents the number

$$\pm (d_0 + d_1 \beta^{-1} + \dots + d_{p-1} \beta^{-(p-1)}) \beta^e, \quad (0 \leq d_i < \beta)$$

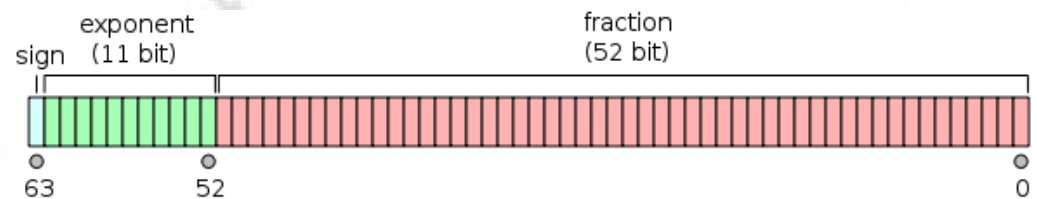
- Bits required: $\log_2(e_{max} - e_{min} + 1) + \log_2(\beta^p) + 1$
- Real numbers might not be exactly represented as a floating-point number. Example:
with $\beta=2$ the number 0.1 has an infinite representation and with $p=24$ will be represented as: 0.100000001490116119384765625

- IEEE representation:

- Single precision (32bit):



- Double precision (64bit):



Floating point: Accuracy

- **Cancellation:** subtraction of nearly equal operands may cause extreme loss of accuracy.
- **Conversions to integer are not intuitive:** converting $(63.0/9.0)$ to integer yields 7, but converting $(0.63/0.09)$ may yield 6. This is because conversions generally truncate rather than round.
- **Limited exponent range:** results might overflow yielding infinity, or underflow yielding a denormal value or zero. If a denormal number results, precision will be lost.
- **Testing for safe division is problematic:** Checking that the divisor is not zero does not guarantee that a division will not overflow and yield infinity.
- **Equality test is problematic:** Two computational sequences that are mathematically equal may well produce different floating-point values. Programmers often perform comparisons within some tolerance

Minimizing Accuracy Problems

- Use double precision whenever possible.
- Small errors in floating-point arithmetic can grow when mathematical algorithms perform operations an enormous number of times. e.g. matrix inversion, eigenvalues...
- Expectations from mathematics may not be realized in the field of floating-point computation. e.g. $\sin^2 \theta + \cos^2 \theta = 1$.
- Always replace the $x^2 - y^2 = (x+y)(x-y)$
- Equality test should be avoided: replace with "fuzzy" comparisons (if $\text{abs}(x-y) < \text{epsilon}$...)
- Adding a large number of numbers can lead to loss of significance, use Kahan algorithm instead
- For the quadratic formula use either

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{or} \quad \frac{2c}{-b \pm \sqrt{b^2 - 4ac}}$$

when $b^2 \gg 4ac$, then $\sqrt{(b^2 - 4ac)} \approx |b|$ therefore will introduce cancellation

Some COMMON blocks in short

BEAMCM:	beam particle properties (from BEAM and BEAMPOS)
SOURCM:	user variables and information for a user-written source
SOUEVT:	recording of the source event
CASLIM:	number of primary particles followed
FLKSTK:	main particle stack of FLUKA
EMFSTK:	particle stack for electrons and photons
GENSTK:	properties of secondaries created in a hadronic event
FHEAVY:	special stack for nuclear fragments
FLKMAT:	material properties
LTCLCM:	LaTtice CeLI CoMmon for lattice cell identification
TRACKR:	properties of the particle currently transported
PAPROP:	intrinsic particle properties (mass, charge, half live...)
SCOHLP:	variables concerning the current estimator type

(DBLPRC) (I)

DouBLE PReCision common

Included in all routines of Fluka, contains the declaration

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

and sets many mathematical and physical constants.

Users are strongly encouraged to adhere to "Fluka style" by

- using **systematically double precision** (except for very good reasons such as calling external single precision scoring packages)
- **and to use constants defined in this file for maximum accuracy.**

(DBLPRC) (II)

===== MATHEMATICALCONSTANTS =====

* ----- Numerical constants (double precision): -----*

* Zerzer = 0 *

PARAMETER (ZERZER = 0.D+00)

* Oneone = 1 *

PARAMETER (ONEONE = 1.D+00)

* Twotwo = 2 *

PARAMETER (TWOTWO = 2.D+00)

* Pipipi = Circumference / diameter *

PARAMETER (PIPIPI = 3.141592653589793238462643383279D+00)

* Twopip = 2 x Pipipi *

PARAMETER (TWOPIP = 6.283185307179586476925286766559D+00)

* Eneper = "e", base of natural logarithm *

PARAMETER (ENEPER = 2.718281828459045235360287471353D+00)

* Sqrtwo = square root of 2 *

PARAMETER (SQRTWO = 1.414213562373095048801688724210D+00)

(DBLPRC) (III)

===== P H Y S I C A L C O N S T A N T S =====

* ----- Primary constants: ----- *

* Clight = speed of light in cm s^{-1} *

PARAMETER (CLIGHT = 2.99792458 D+10)

* Boltzm = k Boltzmann constant (J K^{-1}) *

PARAMETER (BOLTZM = 1.380658 D-23)

* Amelgr = electron mass (g) *

PARAMETER (AMELGR = 9.1093897 D-28)

* Plckbr = reduced Planck constant (erg s) *

PARAMETER (PLCKBR = 1.05457266 D-27)

* ----- Derived constants: ----- *

* Alamb0 = Compton wavelength = $2 \pi r_0 / fsc$, being r_0 the classical electron radius *

* and fsc the fine structure constant *

PARAMETER (ALAMB0 = TWOTWO * PIPIPI * RCLSEL / ALPFSC)

* ----- Astronomical constants: ----- *

* Rearth = Earth equatorial radius (cm) *

PARAMETER (REARTH = 6.378140 D+08)

* ----- Conversion constants: ----- *

* GeVMeV = from GeV to MeV *

PARAMETER (GEVMEV = 1.0 D+03)

(IOUNIT)

Logical input and output unit numbers

The logical units up to 19 (included) are reserved for FLUKA

* lunin = *standard input* unit *
PARAMETER (LUNIN = 5)
* lunout = *standard output* unit *
PARAMETER (LUNOUT = 11)
* lunerr = *standard error* unit *
PARAMETER (LUNERR = 15)
...

Use the pre-defined output units when you need messages from your user routines:

```
WRITE ( LUNOUT, *) ' My initialization is active'  
WRITE (LUNERR, *) ' MySource : warning, energy is 0'
```

(CASLIM)

Keeps preset number of histories and current number of histories

- * /caslim/ is needed to decide when to stop the run
- * Trnlim = if $\text{cpu-time-left} < \text{tlim}$ the run will be ended
- * Tpmean = average time needed to follow one beam particle
- * Tprmax = i maximum time needed to follow one beam particle
- * Trntot = the cumulative time needed to follow the beam particles
- * **Ncases** = maximum number of beam particles to be followed
* modulo 1,000,000,000)
- * Mcases = maximum number of beam particles to be followed
* in excess of 1,000,000,000, divided by 1,000,000,000
- **Ncase** = current number of beam particles followed (modulo
• 1,000,000,000)
- * Mcase = current number of beam particles followed in excess
* of 1,000,000,000, divided by 1,000,000,000

Useful to be included whenever the current event number is needed

(FLKSTK)

At each interaction/decay... etc
new particles are feeding the stack

- * /Flkstk/ stack for the primaries
- * Wtflk = particle **statistical weight**
- * Pmoflk = particle (laboratory) **momentum** (GeV/c)
- * Tkeflk = particle (laboratory) **kinetic energy** (GeV)
- * Xflk = particle **position** x-coordinate
- * Yflk = particle position y-coordinate
- * Zflk = particle position z-coordinate
- * Txflk = particle **direction** x-coordinate
- * Tyflk = particle direction y-coordinate
- * Tzflk = particle direction z-coordinate
- * Txpol = x direction cosine of the particle **polarization**
- * Typol = y direction cosine of the particle polarization
- * Tzpol = z direction cosine of the particle polarization
- * Dfnear = distance to the nearest boundary
- * Agestk = **age** of the particle (seconds)
- * Cmpath = cumulative path travelled by the particle since it was produced (cm)
- * Iloflk = **particle identity** (Paprop numbering)
- * Igroup = energy group for low energy neutrons
- * Loflk = **particle generation**
- * Louse = user flag
- * Nrgflk = particle region number
- * Nlattc = particle lattice cell number

(TRACKR)

Transport of particles:
particles are taken from the Stack and
info for the particle during tracking are kept here

TRACK Recording

Ntrack = number of track segments

Mtrack = number of energy deposition events along the track

$0 < i < Ntrack$

Xtrack = end x-point of the ith track segment

Ytrack = end y-point of the ith track segment

Ztrack = end z-point of the ith track segment

$1 < i < Ntrack$

Ttrack = length of the ith track segment

$1 < j < Mtrack$

Dtrack = energy deposition of the jth deposition event

Dptrck = momentum loss of the jth deposition event

$Ntrack > 0, Mtrack > 0$: energy loss distributed along the track

$Ntrack > 0, Mtrack = 0$: no energy loss along the track

$Ntrack = 0, Mtrack = 0$: local energy deposition (the value and the point are not recorded in Trackr)

```
COMMON / TRACKR / XTRACK ( 0:MXTRCK ), YTRACK ( 0:MXTRCK ),  
& ZTRACK ( 0:MXTRCK ), TTRACK ( MXTRCK ),  
& DTRACK ( MXTRCK ), DPTRCK ( 3,MXTRCK ),
```

(TRACKR) : 2nd part

Jtrack = identity number of the particle: for recoils or kerma deposition it can be outside the allowed particle id range, assuming values like:

208: "heavy" recoil

211: EM below threshold

308: low energy neutron kerma

in those cases the id of the particle originating the interaction is saved inside J0trck (which otherwise is zero)

J0trck = see above

Etrack = total energy of the particle

Ptrack = momentum of the particle (not always defined, if < 0 must be obtained from Etrack)

Cx,y,ztrck = direction cosines of the current particle

Cx,y,ztrpl = polarization cosines of the current particle

Wtrack = weight of the particle

Wscrng = scoring weight: it can differ from Wtrack if some biasing techniques are used (for example inelastic interaction length biasing)

Ctrack = total curved path

Cmtrck = cumulative curved path since particle birth

(TRACKR) : 3rd part

Zfftrk = $\langle Z_{\text{eff}} \rangle$ of the particle

Zftrtk = actual Z_{eff} of the particle

Atrck = age of the particle

Wninou = neutron algebraic balance of interactions (both for "high" energy particles and "low" energy neutrons)

Wcinou = charge algebraic balance of interactions (for all interactions)

Spausr = user defined spare variables for the current particle

Ktrack = if > 0 neutron group of the particle (neutron)

Lt1trk = initial lattice cell of the current track
(or lattice cell for a point energy deposition)

Lt2trk = final lattice cell of the current track

Iprodc = flag for prompt(=1)/radioactive products(=2)

Ltrack = flag recording the generation number

Llouse = user defined flag for the current particle

Ispusr = user defined spare flags for the current particle

...

& SPAUSR(MKBMX1), STTRCK, SATRCK, TKNIEL, TKEDPA,
& WCINOU,

...

& IPRODC, ISPUSR(MKBMX2), LFSSSC, LPKILL

(FHEAVY)

- * npheav = number of heavy secondaries *
- * **kheavy(ip)** = type of the secondary ip *
- * (3 = deuteron, 4 = 3-H, 5 = 3-He, 6 = 4-He, *
- * 7-12 = "Heavy" fragment specified by Ibheav and Icheav) *
- * cxheav(ip) = direction cosine of the secondary ip with respect to x-axis *
- * cyheav(ip) = direction cosine of the secondary ip with respect to y-axis *
- * czheav(ip) = direction cosine of the secondary ip with respect to z-axis *
- * tkheav(ip) = kinetic energy of secondary ip *
- * pheavy(ip) = momentum of the secondary ip *
- * wheavy(ip) = weight of the secondary ip *
- * agheav(ip) = "age" of the secondary ip with respect to the interaction time *

- * amheav(kp) = atomic masses of the twelve types of evaporated *
- * or fragmented or fissioned particles *
- * amnhea(kp) = nuclear masses of the twelve types of evaporated *
- * or fragmented or fissioned particles *
- * anheav(kp) = name of the kp-type heavy particle *
- * **icheav(kp)** = charge of the kp-type heavy particle *
- * **ibheav(kp)** = mass number of the kp-type heavy particle *

Note that $kp = kheavy(ip)$!!!

(PAPROP)

intrinsic PArticle PROPERTIES

```
*      am   (i) = i_th particle mass (GeV)                *
*      ichrge(i) = electric charge of the i_th particle    *
*      ibarch(i) = baryonic charge of the i_th particle    *
*      ijdisc(i) = flag for discarding the i_th particle type *
*      tmnlf (i) = mean (not half!) life of the i_th particle (s) *
*      biasdc(i) = decay biasing factor for the i_th particle *
*      biasin(i) = inelastic interaction biasing factor for the i_th particle *
*      lhadro(i) = True if the i_th particle type is a hadron *
*      jspinp(i) = i_th particle spin (in units of 1/2)    *
*      iparty(i) = i_th particle parity (when meaningful)    *
```

(FLKMAT)

FLuKa MATerials

- * Amss(i) = Atomic weight (g/mole) of the i_th material *
- * Rho(i) = **Density** of the i_th material *
- * Ztar(i) = **Atomic number** of the i_th material *
- * Ainlg(i) = *Inelastic scattering length* of the i_th material *
- * for beam particles at the average beam energy in cm *
- * Aellng(i) = *Elastic scattering length* of the i_th material for *
- * beam particles at average beam energy in cm *
- * X0rad(i) = *Radiation length* of the i_th material in cm *
- * Dmgene(i) = Damage energy of the i_th material (GeV) *
- * Ainnth(i) = Inelastic scattering length of the i_th material *
- * for neutrons at threshold energy in cm *
- * Medium(k) = **Material number of the k_th region** *
- * Mssnum(i) = Mass number of the target nucleus for the i_th material *
- * if = < 0 it means that it is in the natural isotopic composition *
- * Libsnm(i) = flag whether inelastic interaction biasing must be done for this medium *
- * Matnam(i) = Alphabetical name of the i_th material number *
- * Aocmbm(i) = Atomic density of the i_th material in barn⁻¹ cm⁻¹ *
- * (Atoms Over Cm times Barn for Materials) *
- * Eocmbm(i) = Electron density of the i_th material in barn⁻¹cm⁻¹ *
- * (Atoms Over Cm times Barn for Materials) *

(EVTFLG)

Event FLags:

Flags indicating the event interaction type:

LELEVT = Elastic interaction
LINEVT = Inelastic interaction
LDECAY = Particle decay
LDLTRY = Delta ray production (Moller and Bhabha included)
LPAIRP = Pair production
LBRMSP = Bremsstrahlung
LANNRS = Annihilation at rest
LANNFL = Annihilation in flight
LPHOEL = Photoelectric effect
LCMPTN = Compton effect
LCOHSC = Rayleigh scattering
LLENSC = Low energy neutron scattering
LOPPSC = Optical photon scattering
LELDIS = Electromagnetic dissociation
LRDCAY = Radioactive decay

All **LOGICAL** variables!!!

comscw.f [1]

weighting energy deposition or star production

Argument list (all variables are input only)

IJ : particle type (1 = proton, 8 = neutron, etc.: see code in 5.1)
XA, YA, ZA : current particle position
MREG : current geometry region
RULL : amount to be deposited (unweighted)
LLO : particle generation
ICALL : internal code calling flag (not for general use)

Activated by option **USERWEIG** with **WHAT(6) > 0.0**. Energy and stars obtained via **SCORE**, **USRBIN & EVENTBIN** and production of residual nuclei obtained via **RESNUCLEi** are multiplied by the value returned by this **function**. If the logical flag **LSCZER** is set to **.TRUE.**, no amount will be scored.

comscw.f [2]

The user can implement any desired logic according to the argument list (*particle type, position, region, amount deposited, particle generation*) and information available in the included COMMONs.

COMMON SCOHLP provides the binning number **JSCRNG** [printed in the output file between the estimator type and the detector name] and the type **ISCRNG** of scored quantity:

ISCRNG = 1 → Energy density binning

ISCRNG = 3 → Residual nuclei scoring

ISCRNG = 5 → Activity density binning

ISCRNG = 2 → Star density binning

ISCRNG = 4 → Momentum transfer

ISCRNG = 6 → Net charge

Note that the same **JSCRNG** number can correspond to different detector types **ISCRNG** (use both to discriminate)

COMMON TRACKR gives current particle's properties and **COMMON SOUEVT** gives *current source particle's* ones

COMMON FLKMAT allows to access data concerning the current material, identified by the index **MEDFLK(MREG,IPODC)** (**IPODC=1** for prompt and **IPODC=2** for radioactive decay particles)

fluscw.f [1]

weighting fluence, current and yield

Argument list (all variables are input only)	
IJ	: particle type
PLA	: particle momentum (if > 0.0) or -PLA = kinetic energy (if < 0.0)
TXX, TYY, TZZ	: particle current direction cosines
WEE	: particle weight
XX, YY, ZZ	: particle position
NREG	: current region (after boundary crossing)
IOLREG	: previous region (before boundary crossing). Useful only with boundary crossing estimators (for other estimators it has no meaning)
LLO	: particle generation
NSURF	: internal code calling flag (not for general use)

Activated by option **USERWEIG** with **WHAT(3) > 0.0**. Yields obtained via **USRYIELD**, fluences calculated with **USRBDX**, **USRTRACK**, **USRCOLL**, **USRBIN**, and currents calculated with **USRBDX** are multiplied by the value returned by this **function**. If the logical flag **LSCZER** is set to **.TRUE.**, no amount will be scored.

fluscw.f [2]

ISCRNG = 1 → Boundary crossing estimator

ISCRNG = 2 → Track-length binning

ISCRNG = 3 → Track-length estimator

ISCRNG = 4 → Collision density estimator

ISCRNG = 5 → Yield estimator

To act for a given region, convert its name to the respective number as the routine is accessed the first time

CALL **GEON2R**('myregion', MYREG, IERR) Region Name to **Region #**

save it and compare it to NREG (MREG in case of comscw) runtime

mgdraw.f [1]

general event interface

Argument list (all variables are input only)

```
ICODE : FLUKA physical compartment originating the call
       = 1: call from subroutine KASKAD (hadrons and muons)
       = 2: call from subroutine EMFSCO (e-, e+ and photons)
       = 3: call from subroutine KASNEU (low-energy neutrons)
       = 4: call from subroutine KASHEA (heavy ions)
       = 5: call from subroutine KASOPH (optical photons)
MREG  : current region
```

Subroutine mgdraw is activated by option **USERDUMP** with **WHAT(1) ≥ 100.0**, usually writes a “collision tape”, i.e., a file where all or selected transport events are recorded. The default version (unmodified by the user) offers several possibilities, selected by **WHAT(3)**

mgdraw.f [2]

The different **ENTRY** points of mgdraw

MGDRAW called at each step, for trajectory drawing and recording dE/dx energy deposition events

BXDRAW called at boundary crossings (no record)

EEDRAW called at event end (no record)

ENDRAW for recording point energy deposition events

SODRAW for recording source particles

One can remove their default writing and/or customize them.

Additional flexibility is offered by the user entry **USDRAW**, interfaced with the most important physical events happening during particle transport.

mgdraw.f [3]

All six entries can be activated at the same time by setting `USERDUMP WHAT(3) = 0.0` and `WHAT(4) ≥ 1.0`.

They constitute a complete interface to the entire FLUKA transport. Therefore, mgdraw can be used not only to write a collision tape, but to do any kind of complex analysis (*e.g.*, event by event output as in HEP applications).

When mgdraw should better not be used

- When biasing is requested (non-analogue run)
- Whenever low-energy neutrons ($E < 20$ MeV) are involved, unless one has a deep knowledge of the peculiarities of their transport and quantities (*i.e.*, kerma, etc)

mgdraw.f: the MGDRAW entry

- MTRACK:** number of energy deposition events along the track
- JTRACK:** type of particle
- ETRACK:** total energy of the particle
- WTRACK:** weight of the particle
- NTRACK:** values of **XTRACK**, **YTRACK**, **ZTRACK**: end of each track segment
- MTRACK:** values of **DTRACK**: energy deposited at each deposition event
- CTRACK:** total length of the curved path

Other variables are available in **TRACKR** (but not written by **MGDRAW** unless the latter is modified by the user: particle momentum, direction cosines, cosines of the polarisation vector, age, generation, etc. see a full list in the comment in the **INCLUDE** file).

mgdraw.f: the BXDRAW entry

called at *boundary crossing*

Argument list (all variables are input only)

ICODE : physical compartment originating the call, as in the MGDRAW entry
MREG : region from which the particle is exiting
NEWREG : region the particle is entering
XSCO, YSCO, ZSCO : point where the boundary crossing occurs

mgdraw.f: the EEDRAW entry

called at the *event end*

Argument list (all variables are input only)

ICODE : physical compartment originating the call, as in the MGDRAW entry

mgdraw.f: the ENDRAW entry

called at point-like energy deposition
(for example: stopping particles, photoelectric effect, ...)

Argument list (all variables are input only)

```
ICODE : type of event originating energy deposition
ICODE = 1x: call from subroutine KASKAD (hadrons and muons);
        = 10: elastic interaction recoil
        = 11: inelastic interaction recoil
        = 12: stopping particle
        = 14: particle escaping (energy deposited in blackhole)
ICODE = 2x: call from subroutine EMFSCO (electrons, positrons and photons)
        = 20: local energy deposition (i.e. photoelectric)
        = 21 or 22: particle below threshold
        = 23: particle escaping (energy deposited in blackhole)
ICODE = 3x: call from subroutine KASNEU (low-energy neutrons)
        = 30: target recoil
        = 31: neutron below threshold
        = 32: neutron escaping (energy deposited in blackhole)
ICODE = 4x: call from subroutine KASHEA (heavy ions)
        = 40: ion escaping (energy deposited in blackhole)
ICODE = 5x: call from subroutine KASOPH (optical photons)
        = 50: optical photon absorption
        = 51: optical photon escaping (energy deposited in blackhole)
MREG  : current region
RULL  : energy amount deposited
XSCO, YSCO, ZSCO : point where energy is deposited
```

mgdraw.f: the SODRAW entry

Argument list

No arguments

It writes by default, for each source particle:

- NCASE:** number of primaries followed so far (with a minus sign to identify SODRAW output), from **COMMON CASLIM**
- NPFLKA:** stack pointer, in **COMMON FLKSTK**
- NSTMAX:** highest value of the stack pointer encountered so far, in **COMMON FLKSTK**
- TKESUM:** total kinetic energy of the primaries of a user written source, in **COMMON SOURCM**, if applicable. Otherwise = 0.0
- WEIPRI:** total weight of the primaries handled so far, in **COMMON SOURCM**

NPFLKA times:
(all variables in
COMMON FLKSTK)

ILOFLK:	type of source particle
TKEFLK + AM:	total particle energy (kinetic+mass)
WTFLK:	source particle weight
XFLK, YFLK, ZFLK:	source particle position
TXFLK, TYFLK, TZFLK:	source particle direction cosines

mgdraw.f: the USDRAW entry

called *after each particle interaction*
(requested by **USERDUMP** **WHAT(4) ≥ 1.0**)

```
Argument list (all variables are input only)
ICODE : type of event
ICODE = 10x: call from subroutine KASKAD (hadron and muon interactions);
        = 100: elastic interaction secondaries
        = 101: inelastic interaction secondaries
        = 102: particle decay secondaries
        = 103: delta ray generation secondaries
        = 104: pair production secondaries
        = 105: bremsstrahlung secondaries
ICODE = 20x: call from subroutine EMFSCO (electron, positron and photon interactions)
        = 208: bremsstrahlung secondaries
        = 210: Møller secondaries
        = 212: Bhabha secondaries
        = 214: in-flight annihilation secondaries
        = 215: annihilation at rest secondaries
        = 217: pair production secondaries
        = 219: Compton scattering secondaries
        = 221: photoelectric secondaries
        = 225: Rayleigh scattering secondaries
ICODE = 30x: call from subroutine KASNEU (low-energy neutron interactions)
        = 300: neutron interaction secondaries
ICODE = 40x: call from subroutine KASHEA (heavy ion interactions)
        = 400: delta ray generation secondaries
MREG  : current region
XSCO, YSCO, ZSCO : interaction point
```


stuprf.f and stupre.f (I)

SeT User PProperties for Fluka <Emf> particles

These two functions are used to **assign a value to one or more stack user variables** when the corresponding particle is loaded onto one of the stacks

(**FLKSTK** for hadrons/muons, and **EMFSTK** for electrons/positrons/photons).

In each of these stacks the user has access to one integer variable, one integer array and one double precision array.

Each of them is copied to a correspondent variable or array in **COMMON TRACKR** at the beginning of transport:

Correspondence	FLKSTK	EMFSTK		TRACKR
integer variable:	LOUSE	LOUEMF	→	LLOUSE
integer array:	ISPARK	IESPAK	→	ISPUSR
double precision array:	SPAREK	ESPAK	→	SPAUSR

In this way, user variables can be **PROPAGATED** and **KEPT** in memory across tracking and interactions !

stuprf.f and stupre.f (II)

The user can access and modify user variables in **TRACKR** via subroutine **MGDRAW** and its entries **ENDRAW**, **SODRAW** and especially **USDRAW**.

STUPRF and **STUPRE** can be used to copy **TRACKR** user variables to those of the relevant stack.

Note that a stack **OPPHST** exists also for optical photons, containing similar user variables and arrays **LOUOPP**, **ISPORK** and **SPAROK**. They can be used in user routines, but they are not handled by **STUPRE**.

STUPRF is called before loading into stack hadrons, muons, neutrinos and low-energy neutrons. The default version copies to stack the user flags of the parent.

STUPRE is called before loading into stack electrons, positrons and photons. The default version does nothing (the user variables of the parent particle are already set equal to the original projectile by the various electromagnetic interaction routines). Also the region/position etc. are already set inside the stack arrays.

By default, the last place of the **ISPARK** array keeps the **TRACK NUMBER** of the current particle

Typical use of **STUPRF/ STUPRE** is to keep in memory the "history" of a particle

Stuprf: the default

IJ = ID of interacting particle
MREG,XX,YY,ZZ : region and
position of the interaction

```
SUBROUTINE STUPRF ( IJ, MREG, XX, YY, ZZ, NPSECN, NPPRMR )
```

```
INCLUDE '(DBLPRC)'  
INCLUDE '(DIMPAR)'  
INCLUDE '(IOUNIT)'  
INCLUDE '(EVTFLG)'  
INCLUDE '(FLKSTK)'  
INCLUDE '(TRACKR)'
```

Suprf is called once for each particle in the stack of secondaries . NPSECN is the index of the current secondary , NPPRMR is the number of particles still flagged as "primary" (i.e. after elastic interaction)

```
LOUSE (NPFLKA) = LLOUSE  
DO 100 ISPR = 1, MKBMX1  
    SPAREK (ISPR,NPFLKA) = SPAUSR (ISPR)  
100 CONTINUE  
DO 200 ISPR = 1, MKBMX2  
    ISPARK (ISPR,NPFLKA) = ISPUSR (ISPR)  
200 CONTINUE
```

← This is the default: copy the TRACKR user variables to the stack.

```
* Increment the track number and put it into the last flag:  
IF ( NPSECN .GT. NPPRMR ) THEN  
    IF ( NTRCKS .EQ. 2000000000 ) NTRCKS = -2000000000  
    NTRCKS = NTRCKS + 1  
    ISPARK (MKBMX2,NPFLKA) = NTRCKS  
END IF  
RETURN
```

By default: if this Particle is **new**, consider it as a new track.

Stuprf: an example (I)

The user need: keep the history of neutrino production from a proton beam

The reaction scheme is :

Proton on thick target \rightarrow mesons \rightarrow decay into leptons and neutrinos.

reinteractions and multiple decay ($\pi \rightarrow \nu + \mu \rightarrow \nu + \nu + e$)

Want to know: which particle decayed, and where ,

where was produced the meson that decayed and its initial mom.

* if decay : store father identity, energy , r,z

```
IF ( LDECAY ) THEN
```

```
  SPAREK (1, NPFLKA) = ETRACK
```

```
  SPAREK (2, NPFLKA) = SQRT ( XX**2 + YY**2 )
```

```
  SPAREK (3, NPFLKA) = ZZ
```

```
  ISPARK (1, NPFLKA) = IJ
```

* If inelastic interaction

```
ELSE IF ( LINEVT ) THEN
```

```
  ISPARK (2, NPFLKA) = KPART ( NPSECN )
```

```
  ISPARK (3, NPFLKA) = MREG
```

```
  SPAREK (4, NPFLKA) = XX
```

```
  SPAREK (5, NPFLKA) = YY
```

```
  SPAREK (6, NPFLKA) = ZZ
```

```
  SPAREK (7, NPFLKA) = PLR ( NPSECN ) * CXR ( NPSECN )
```

```
  SPAREK (8, NPFLKA) = PLR ( NPSECN ) * CYR ( NPSECN )
```

```
  SPAREK (9, NPFLKA) = PLR ( NPSECN ) * CZR ( NPSECN )
```

```
END IF
```

LDECAY, LINEVT : from common
EVTFLG

Store in the first users
variables the energy and
identity of the decaying
particle , and the position

Use more variables to store
the id and momentum of each
particle from inelastic
interaction

Stuprf: an example (II)

In between interactions/decays, the user variables are copied WITHOUT CHANGES to the **trackr** common, and **back to the stack**. They are **propagated** to i.e. decay secondaries (neutrinos) by the default lines in the **stuprf.f** routine. They are accessible from the TRACKR common at every moment. The user can dump them on disk from , for instance, the mgdraw.f routine (see lecture on scoring for details)

```
* if I am in detector and it is a neutrino
IF ( NEWREG = MYDETREG) THEN
IF ( JTRACK .EQ. 5 .OR. JTRACK .EQ. 6 .
&      OR .JTRACK .EQ. 27 .OR. JTRACK .EQ. 28) THEN
  WRITE (MYDUMP , *) 'dump event ' , NCASE
&  JTRACK,  SNGL(ETRACK),
&  (ISPUSR(I),I=1,3),
&  (SNGL(SPAUSR(I)),I=1,9),
&  SNGL(WEE)
ENDIF
ENDIF
```

Particle indexes of neutrinos

Recover the infos in the TRACKR user arrays and dump them

Written : event number, neutrino ID, neutrino energy, ID of decaying particle, ID of ancestor from last inelastic int., Position of decay, position of last inel.int., momentum of the ancestor from the last inel. Int.

mdstck.f

MDSTCK is called after a nuclear interaction in which at least one secondary particle has been produced, before any biasing is applied, to decide which secondary will be loaded in the main stack for further transport.

The properties of the secondaries are stored in the secondary stack (**COMMON GENSTK**). With **MDSTCK**, users can analyse those secondaries, write them to a file, or even modify the content of **GENSTK** (for instance applying their own biasing).

In the latter case, however, it is their responsibility to make sure that energy is conserved, the various physical quantities are still consistent, etc.

usrmed.f (I)

USeR MEDium dependent directives

Argument list

IJ	:	particle type
EKSCO	:	particle kinetic energy (GeV)
PLA	:	particle momentum (GeV/c)
WEE	:	particle weight
MREG	:	previous region number
NEWREG	:	current region number
XX, YY, ZZ	:	particle position
TXX, TYY, TZZ	:	particle direction

Subroutine **USRMED** is activated by option **MAT-PROP** with **SDUM = USERDIRE**, for one or more materials indicated by the user. It is called every time a particle is going to be transported in one of the user-tagged materials.

usrmed.f (II)

Two cases are possible

1) **MREG = NEWREG**: the particle is going to move from a point inside the medium. The user is normally allowed to change only the particle weight.

→ simulating *attenuation* of optical photons in an absorbing medium by reducing the photon weight

2) **MREG ≠ NEWREG**: the particle is going to move from a point on a boundary between two regions. The user may change any of the following: particle weight, current region number, direction cosines.

→ simulating *refraction*, by changing the direction cosines so that the particle is still inside the new region. To do this, one generally needs the direction cosines of the normal to the surface: **TXNOR(NPFLKA), TYNOR(NPFLKA), TZNOR(NPFLKA)** (**COMMON FLKSTK** must be included)

→ simulating *reflection* (albedo) at a boundary. The direction cosines must be modified according to some reflection law or albedo angular distribution, and **NEWREG** must be set = **MREG**
In both cases the weight can also be reduced to account for surface reflectivity

But ... one can also kill the particle by putting **WEE=ZERZER**
(note that its energy will be lost and not deposited)

and particle **coordinates and energy** can be altered as well !!

a big power implies a big responsibility

Mathematical library

FLUKA contains many mathematical routines of general utility, so in general it should not be necessary to call external mathematical libraries (many taken from SLATEC):

flgaus:	Gaussian adaptive integration
erffun:	Error function
expin1:	E1 exponential function
besi0d:	Bessel function I0 (also I1, J0, J1, K0, K1)
dawsni:	Dawson function
gamfun:	Gamma function
radcub:	Real solutions of 3 rd order algebraic equation
flgndr:	Legendre polynomials
yinter, d..intp:	interpolation routines
rordin, rordde:	Sorting of vector values

.....

Also: expansion in Laguerre and Chebyshev polynomials, Bezier fit, and many others...

*For users who access the FLUKA source: they are in **mathmvax** directory*

At some time it will be possible to have a short-writeup for their use.

A few examples (I)

EXTERNAL FINTEG

DOUBLE PRECISION FUNCTION **FLGAUS** (FINTEG, XA, XB, EPSEPS, IOPT,
& NXEXP)

* Adaptive Gaussian quadrature routine

It gives the integral over the (XA,XB) interval of the product between X**NXEXP and the FINTEG function, to be coded by the user as a separate
DOUBLE PRECISION FUNCTION FINTEG (X)

SUBROUTINE **RADCUB** (AA0, AA1, AA2, AA3, X, X0, NRAD)

* Real solutions of 3rd order algebraic equation

It computes real solutions of the equation:

$$A0*X^3+A1*X^2+A2*X+A3=0$$

The solutions are put in the array X; if there is only one real solution it is put into X(1), while X(2) and X(3) are set to 1.d32. If A0=0 the routine computes standard solutions of a second or first degree equation. If it doesn't exist any real solution the whole array X is set to 1.d32. It is possible to compute solutions with a scale factor X0, to avoid loss of significancy with very large or very small numbers. The flag NRAD records the number of real solutions found.

A few examples (II)

DOUBLE PRECISION FUNCTION GAMFUN (X)

It calculates the double precision complete **Gamma function** for double precision argument X

SUBROUTINE RORDIN (RVECT, ICORR, LEN)

It rearranges a real array in increasing order

SUBROUTINE RORDDE (RVECT, ICORR, LEN)

It rearranges a real array in decreasing order

DOUBLE PRECISION FUNCTION FLGNDR (X, LMAX, PLGNDR)

* Function for **LeGeNDRe polynomials**

It computes $P_{l_{\max}}(x)$ and stores all values $P_i(x)$ for $i=0, l_{\max}$ into the PLGNDR array