Radioactive Sources

1. Define a Radioactive Source

BEAM, **BEAMPOS** & **HI-PROPE** cards

How to Define an Isotope Point Source

- To define a radioactive isotope as a point source you will need the following cards:

  - **BEAM**
  - **HI-PROPE**
  - **BEAMPOS** (one card)

Minimal Set !!!!

The **BEAM** card: particle type = ISOTOPE

BEAM		Beam:	Momentum ▾	p:		Part:	ISOTOPE ▾
Δp:	Flat ▾	Δp:		Δφ:	Flat ▾	Δφ:	
Shape(X):	Rectangular ▾	Δx:		Shape(Y):	Rectangular ▾	Δy:	

Select particle type from the dropdown menu

(Default particle: **PROTON)**

ISOTOPE: Radioactive isotope sources

The HI-PROPE card

- Specifies the properties of a heavy ion primary, or a radioactive isotope primary.

HI-PROPE	Z: 27.	A: 60.	Isom:

Isotope selection:

Atomic and mass numbers of the Isotope

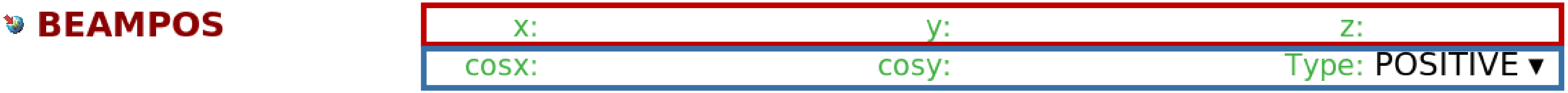
Default: Z=6, A=12

Isomeric state:

Isomeric state of the heavy ion if < 0.

Default: ground state

The BEAMPOS card: beam position (and direction)



Position:

The beam position is defined with its **x**, **y** and **z** coordinates [cm]

Default: Origin of the coordinate system

Direction:

The direction is over written. The source will be isotropic.

If interested in “non-isotropic/directional decay”, you would need to manipulate the geometry, i.e. back hole.

How to Define a Volumetric Source

- Volumetric sources can be defined with a 2nd **BEAMPOS** card:
- Volumetric sources are centred around the position defined in the 1st **BEAMPOS** card
- The location inside the volume is sampled uniformly
- **Warning:** The spatial distributions specified in the **BEAM** card will be disregarded

The 2nd BEAMPOS card: source shape

BEAMPOS Rin: Rout: Type: SPHE-VOL ▾

- Select type from the drop-down menu
- Available types of volumetric sources:
  - Spherical shell (**SPHE-VOL**)
  - Cylindrical shell (**CYLI-VOL**)
  - Cartesian shell (**CART-VOL**)
  - Spherical surface (**FLOOD**) : Not relevant for Radioactive Sources

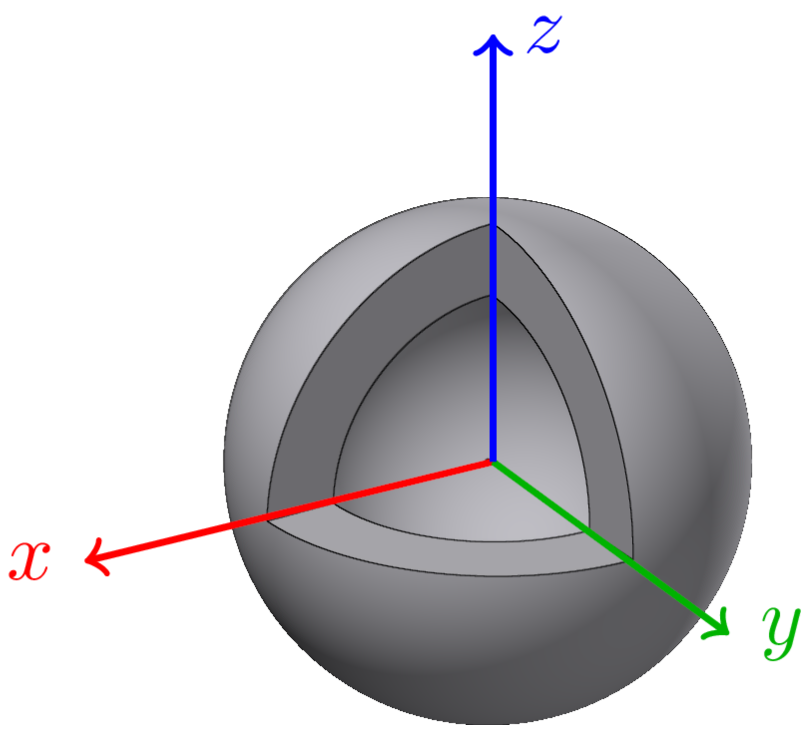
Volumetric sources – *Spherical shell*

BEAMPOS Rin: Rout: Type: SPHE-VOL ▾

Specifies a spherical shell shaped source

Input fields:

- **Rin**: Inner radius [cm]
- **Rout**: Outer radius [cm]



Note: The reference coordinate system can be changed with the **BEAMAXES** card

Volumetric sources – *Cylindrical shell*

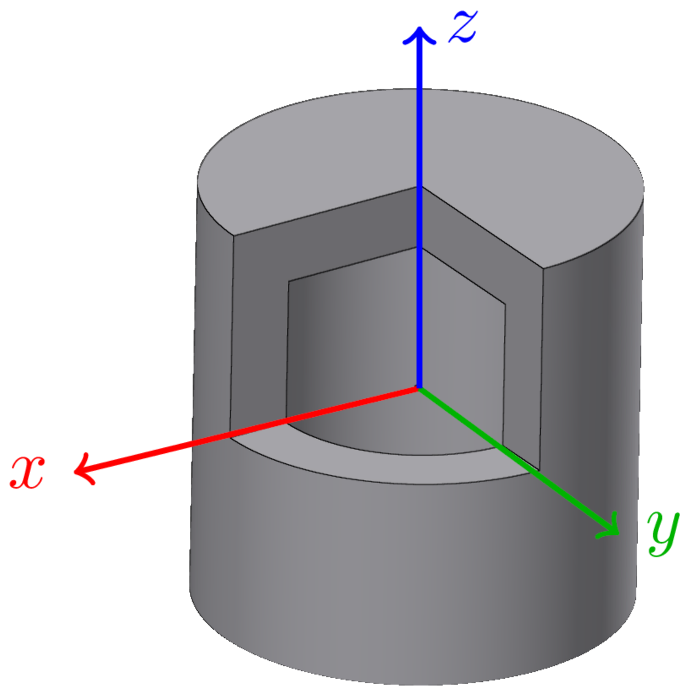
BEAMPOS Rin: Rout: Type: CYLI-VOL ▾
Hin: Hout:

Specifies a cylindrical shell shaped source around the **z** axis of the geometry

Input fields:

- **Rin**: Inner radius [cm]
- **Rout**: Outer radius [cm]
- **Hin**: Inner height [cm]
- **Hout**: Outer height [cm]

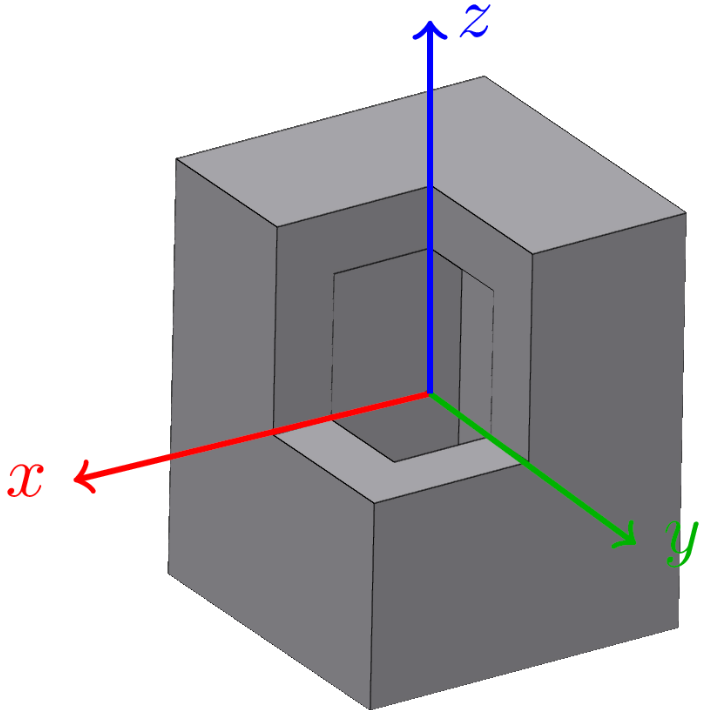
Note: The reference coordinate system can be changed with the **BEAMAXES** card



Volumetric sources – *Cartesian shell*

BEAMPOS Xin: Xout: Type: CART-VOL ▾
Yin: Yout:
Zin: Zout:

Specifies a Cartesian shell shaped source along the axes of the geometry



Input fields:

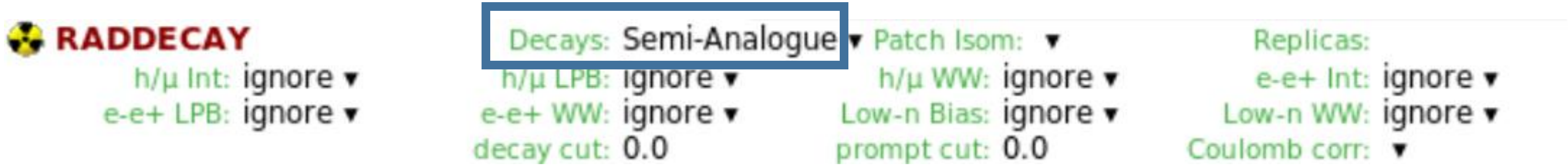
- **Xin & Xout**: Inner & outer length of the **`x`**-sides
- **Yin & Yout**: Inner & outer length of the **`y`**-sides
- **Zin & Zout**: Inner & outer length of the **`z`**-sides

Note: The reference coordinate system can be changed with the **`BEAMAXES`** card

2. Scoring with Radioactive Source

RADDECAY & DYSCORE card

The `RADDECAY` card



Requests simulation of radioactive decays

Input field:

- **Decays**: radioactive decay flag

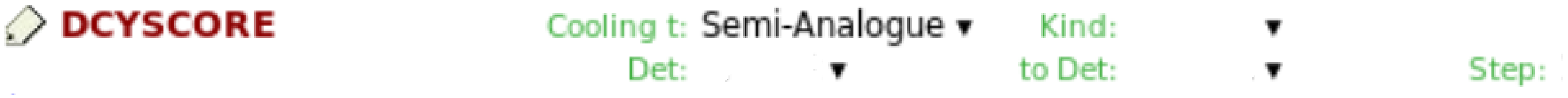
Select mode from the dropdown menu

Semi-analogue mode: Switching on of radioactive decays

The `RADDECAY` card

- In the semi-analogue mode,
  - each single radioactive nucleus is treated in a Monte Carlo way like all other unstable particles: a random decay time, random daughters, random radiation are selected and tracked.
  - allows for an analogue event-by-event analysis, with the time structure recorded in the particles age variable.
  - it is called semi-analogue because radiation spectra are inclusive: e.g., no correlated gamma cascade is reproduced.

The DCYSCORE card



Associates the scoring detectors to semi-analogue decay mode.
You can use multiple DCYSCORE cards.

Input fields: Select mode from the dropdown menu

- **Cooling t:** Semi-analogue
- **Kind:** USRBIN, USRTRACK, etc.
- **Det - to Det**: Select detector (range) .
- **STEP:** .Steps of the detector range (*Default*: 1)

The `DCYSCORE` card

- Scorings associated with the semi-analogue mode will use only the decay particles information (no prompt).

- If `DCYSCORE` is not present, then no scoring at all can take place

  → EMPTY PLOTS!

- Quantities are normalized per decay (of the mother)
  - You need to know the activity of your source to get rates
  - Examples for DOSE-EQ scoring…

$$\text{Dose}\left[\frac{pSv}{decay}\right] * Activity[Bq] \rightarrow Dose\ rate[\frac{pSv}{s}]$$

2. Examples of Radioactive Source

Simple Example

Example:

Radioactive source of ^{60}Co (two main γ-emissions: 1332.5 keV and 1173.2 keV)
cylindrical shape, 2cm diameter, 2mm height along z, centre of cylinder at origin

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BEAM		Beam:	Momentum ▾	p:		Part:	ISOTOPE ▾
Δp:	Flat ▾	Δp:		Δφ:	Flat ▾	Δφ:	
Shape(X):	Rectangular ▾	Δx:		Shape(Y):	Rectangular ▾	Δy:	
HI-PROPE		Z:	27.	A:	60.	Isom:	

Simple Example

Example:

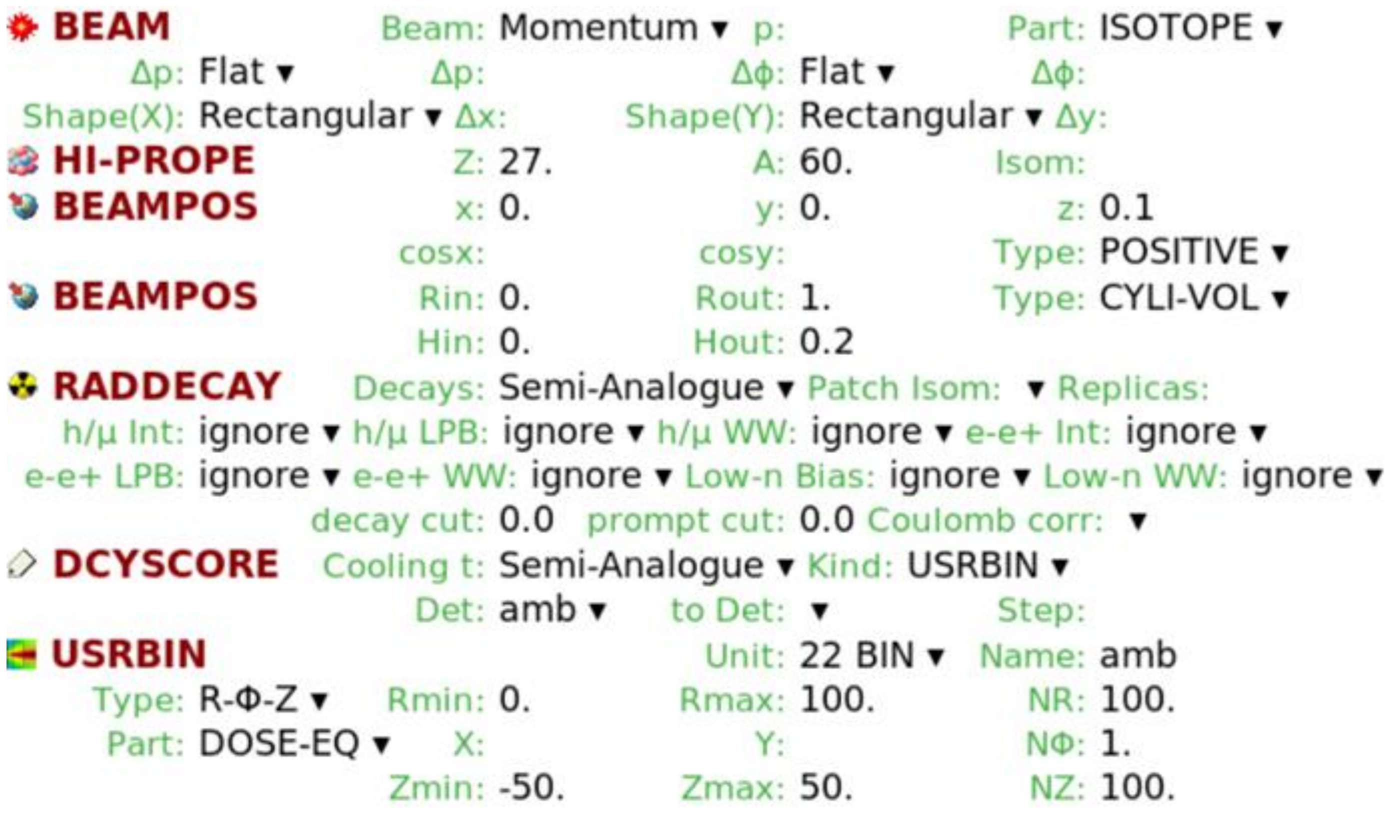
Radioactive source of ^{60}Co (two main γ-emissions: 1332.5 keV and 1173.2 keV)
cylindrical shape, 2cm diameter, 2mm height along z, centre of cylinder at origin

BEAM	Beam: Momentum ▾	p:		Part: ISOTOPE ▾
	Δp: Flat ▾	Δp:	Δϕ: Flat ▾	Δϕ:
	Shape(X): Rectangular ▾	Δx:	Shape(Y): Rectangular ▾	Δy:
HI-PROPE		Z: 27.	A: 60.	Isom:
BEAMPOS		x: 0.	y: 0.	z: 0.1
		cosx:	cosy:	Type: POSITIVE ▾
BEAMPOS		Rin: 0.	Rout: 1.	Type: CYLI-VOL ▾
		Hin: 0.	Hout: 0.2	

Simple Example

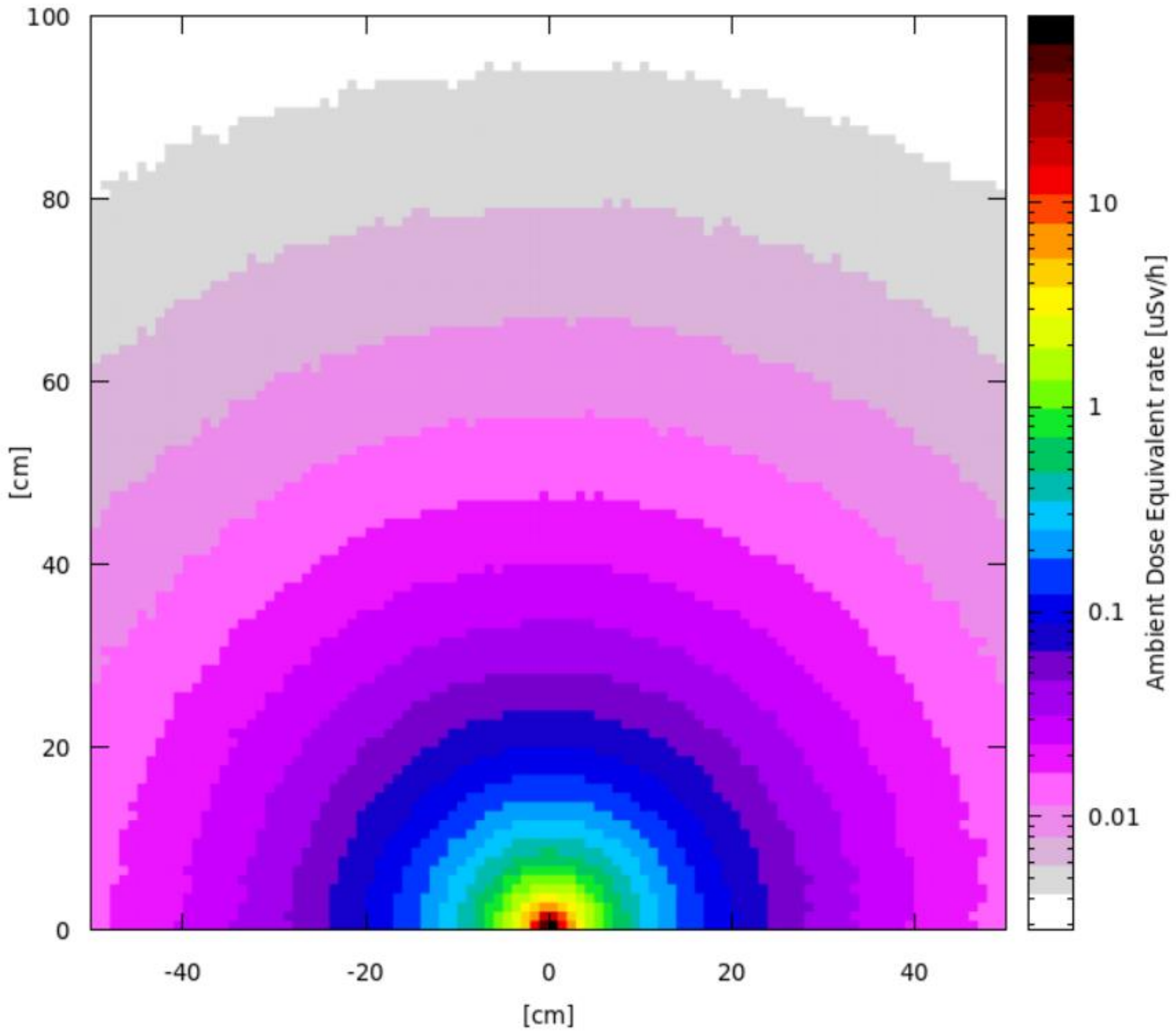
Example:

Radioactive source of ^{60}Co (two main γ-emissions: 1332.5 keV and 1173.2 keV)
cylindrical shape, 2cm diameter, 2mm height along z, centre of cylinder at origin



Simple Example

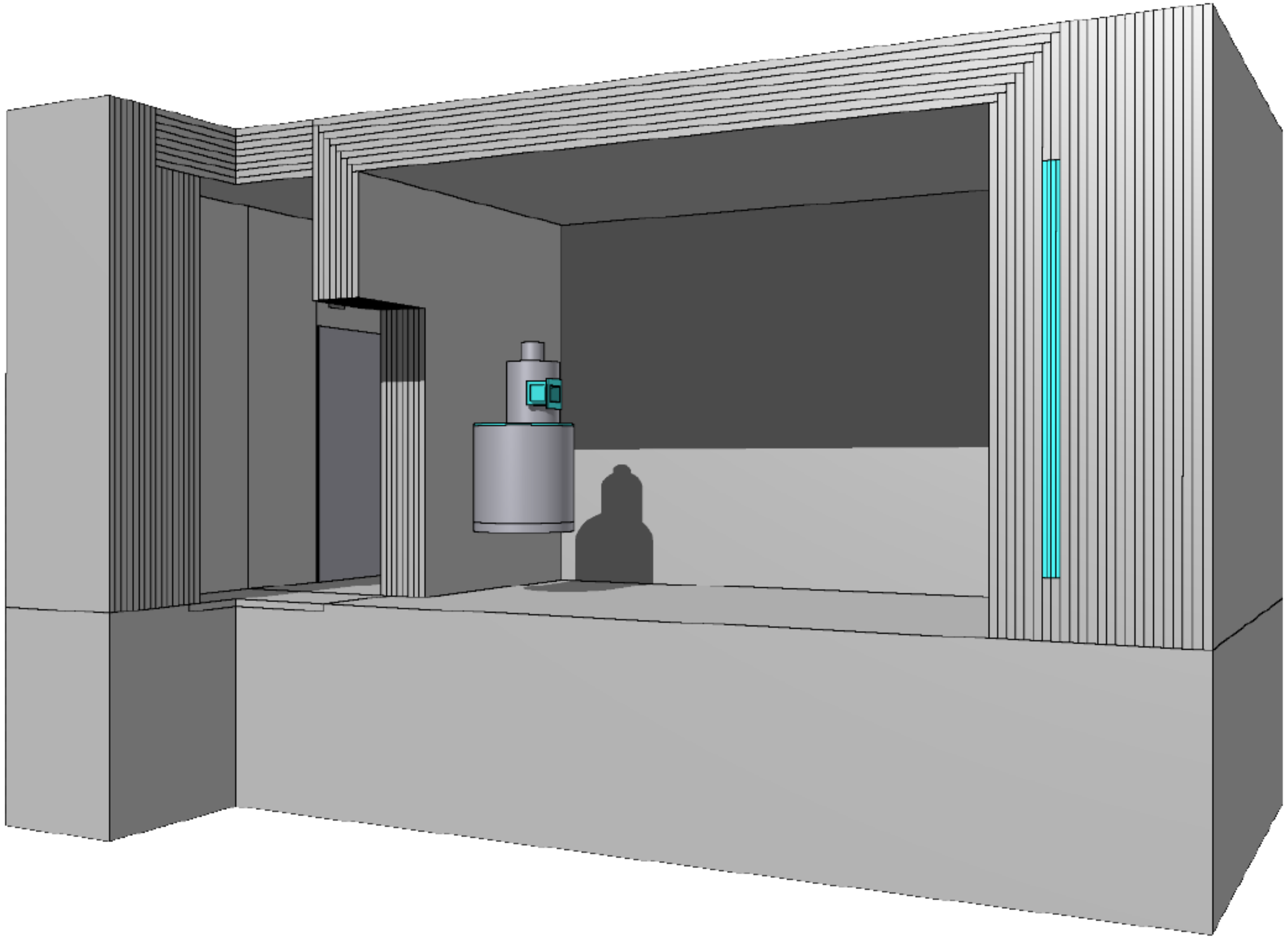
- Assuming 10 kBq of activity
  - Careful with the normalization!



A More Complicated Example

Example:

A realistic irradiation facility: an irradiator in a concrete cave

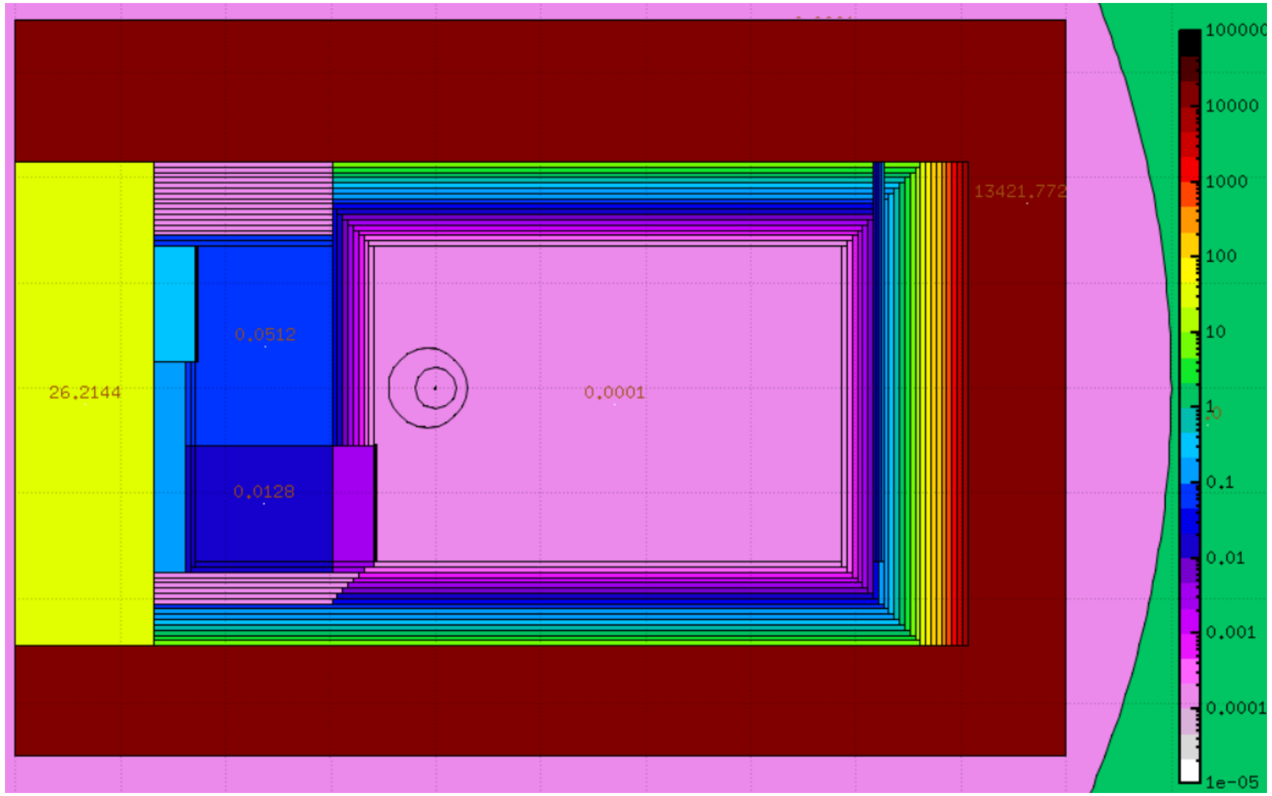


A More Complicated Example: Source

BEAM	Beam: Momentum ▾	p:	Part: ISOTOPE ▾
Δp: Flat ▾	Δp:	Δφ: Isotropic ▾	
Shape(X): Rectangular ▾	Δx:	Shape(Y): Rectangular ▾	Δy:
HI-PROPE	Z: 27.	A: 60.	Isom:
BEAMPOS	x: 0.0	y: -0.175	z: 0.0
	cosx:	cosy:	Type: NEGATIVE ▾
BEAMAXES	cosBxx: 1.	cosBxy: 0.0	cosBxz: 0.0
	cosBzx: 0.0	cosBzy: 1.	cosBzz: 0.0
BEAMPOS	Rin: 0.0	Rout: 1.01	Type: CYLI-VOL ▾
	Hin: 0.0	Hout: 2.8	

A More Complicated Example: Biasing

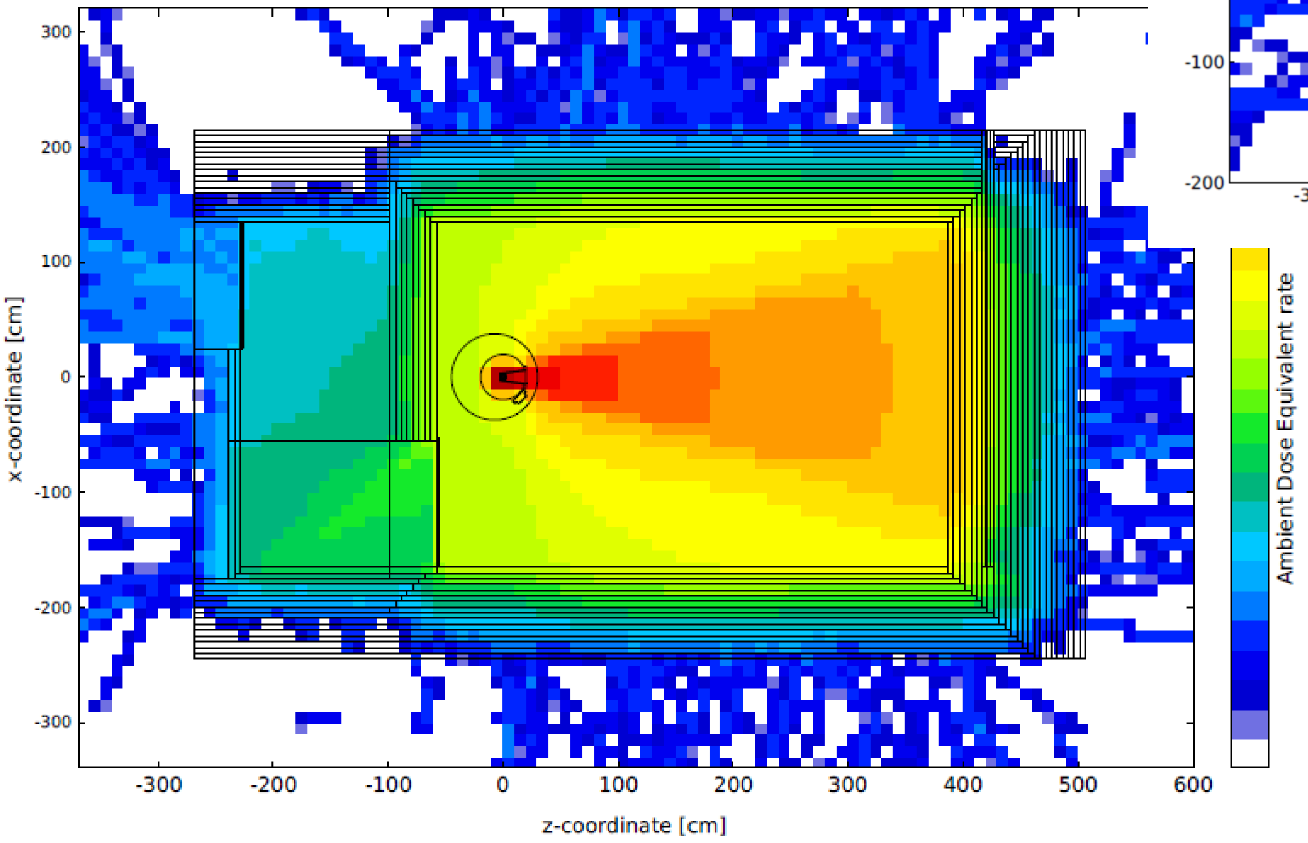
```
******************************************
*** SET ALL REGIONS TO IMP=0.0001
***
*** A progressive 2^n power is then
*** used for setting-up the biasing
******************************************

BIASING      Type: e-e+,γ ▾     RR:                   Imp: 1E-4
    Opt: PRINT ▾   Reg: vac ▾    to Reg: @LASTREG ▾  Step: 1.
*
* FRONT WALL
*
BIASING      Type: e-e+,γ ▾     RR:                   Imp: =1E-4*(2**1)
    Opt: PRINT ▾   Reg: Fwall1 ▾ to Reg: Fwall1 ▾    Step: 1.
BIASING      Type: e-e+,γ ▾     RR:                   Imp: =1E-4*(2**2)
    Opt: PRINT ▾   Reg: Fwall2 ▾ to Reg: Fwall2 ▾    Step: 1.
BIASING      Type: e-e+,γ ▾     RR:                   Imp: =1E-4*(2**3)
    Opt: PRINT ▾   Reg: Fwall3 ▾ to Reg: Fwall3 ▾    Step: 1.
BIASING      Type: e-e+,γ ▾     RR:                   Imp: =1E-4*(2**4)
    Opt: PRINT ▾   Reg: Fwall4 ▾ to Reg: Fwall4 ▾    Step: 1.
BIASING      Type: e-e+,γ ▾     RR:                   Imp: =1E-4*(2**5)
    Opt: PRINT ▾   Reg: Fwall5 ▾ to Reg: Fwall5 ▾    Step: 1.
```

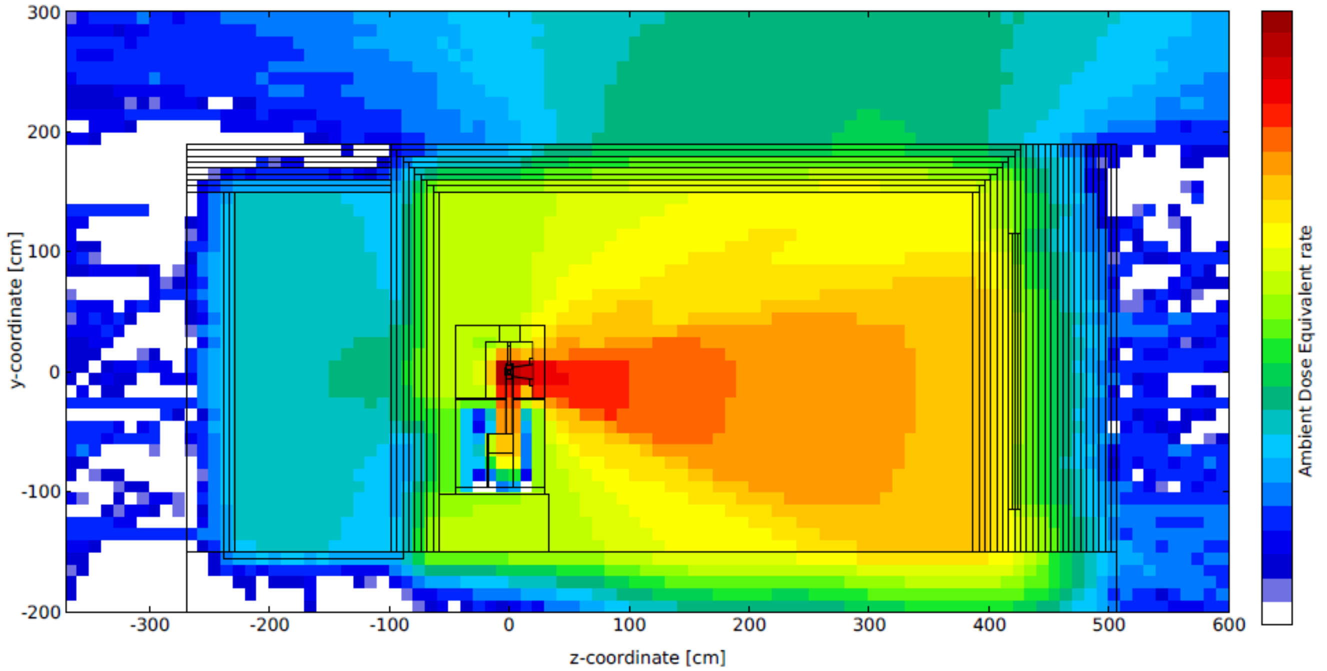


A More Complicated Example: Scoring

Results:

Horizontal view





Vertical view

Important Remarks

- When the radiation source is a radioactive isotope, special rules must be observed.
  - Note that if a stable isotope is input, nothing will occur, and no particle will be transported.
  - If **RADDECAY** (semi-analogue mode) is not requested, nothing will occur, and no particle will be transported (even if the isotope is radioactive).
  - If **DCYSCORE** (semi-analogue option) is not associated with any detectors, no scoring will occur.
  - All scoring will refer to the time integral of isotope activity specified in **HI-PROPE** (i.e. per decay, not the corresponding rates at particular decay times).
  - Commands **IRRPROF** and **DCYTIMES** are not allowed: decay secondaries are sampled over the whole decay time from zero to infinity.

Important Remarks

- FLUKA simulates the entire decay chain.
- In the semi-analogue mode, each single radioactive nucleus is treated in a Monte Carlo way, which means that the decay time is sampled between zero and infinity (it is not the half-life or lifetime).
- Also the daughters (considering the branching ratios) and the type of decay are randomly sampled.
- To isolate contributions from specific isotopes, you can use usrmed.f (activated via the **MAT-POP** card for selected materials).

```
INCLUDE 'trackr.inc'
IF (IAZTRK .NE. 90232) THEN
   WEE = ZERZER
END IF
```

Ex.: Th-232

- Instead, for time-dependent calculations (see **TCQUENCH**, **TIME-CUT**) it is to be noted that transport of isotope decay secondaries starts with an age equal to the time of decay.

Important Remarks

- Always remember to consider production and transport thresholds
  - Default PRECISIO has all transport threshold = 100keV, but neutrons (10-5 eV) and neutrinos (0, but they are discarded).
  - It is good practice to set production/transport thresholds explicitly using EMFCUT!
  - Consider your specific case (main gamma emission, etc)

FLUKA

Beam rotation

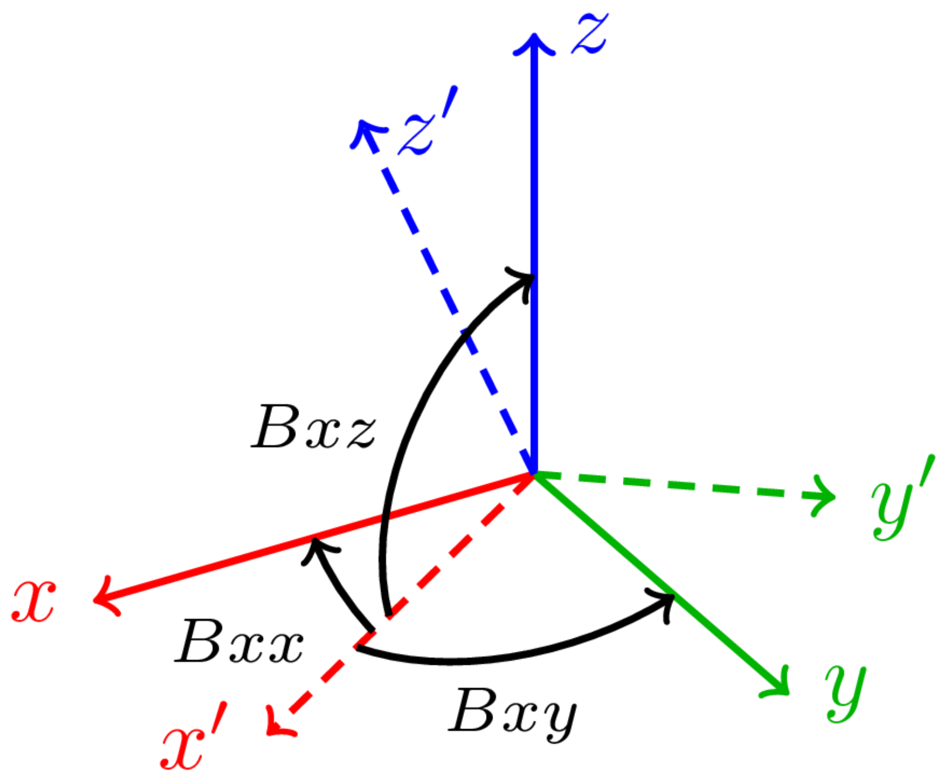
- Input card: **BEAMAXES**

BEAMAXES cosBxx: cosBxy: cosBxz:
cosBzx: cosBzy: cosBzz:

Defines the beam coordinate system (**x′, y′, z′**) with respect to the geometry one (**x, y, z**)

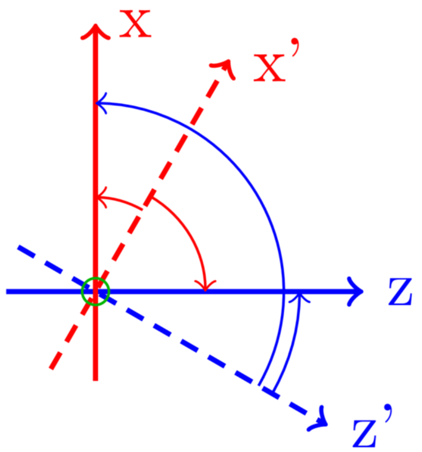
Input fields:

- **cosBxx**: cosine of the angle between **x′** and **x**
- **cosBxy**: cosine of the angle between **x′** and **y**
- **cosBxz**: cosine of the angle between **x′** and **z**
- **cosBzx**: cosine of the angle between **z′** and **x**
- **cosBzy**: cosine of the angle between **z′** and **y**
- **cosBzz**: cosine of the angle between **z′** and **z**

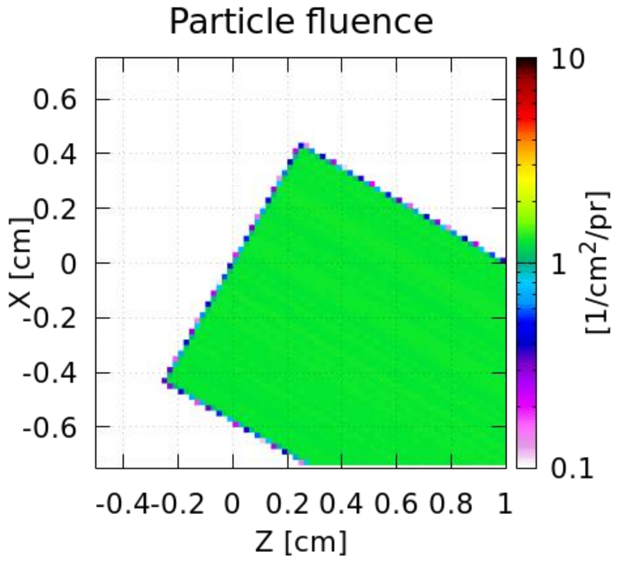


Beam rotation

- **Example 2:** R = 0.5 cm cylindrical beam | zero divergence | rotated around y axis by -30°



WHAT	Beam axis	Geo axis	Angle [°]	Cos(Angle)
cosBxx	x'	x	30	~0.866
cosBxy	x'	y	90	0
cosBxz	x'	z	-60	0.5
cosBzx	z'	x	120	-0.5
cosBzy	z'	y	90	0
cosBzz	z'	z	30	~0.866



BEAMAXES cosBxx: 0.86602540378 cosBxy: 0.0 cosBxz: 0.5
cosBzx: -0.5 cosBzy: 0.0 cosBzz: 0.86602540378