Radioactivity

23rd FLUKA Beginner's Course
Lanzhou University
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Residual radiation: evaluation and transport

Both PEANUT and the low-energy neutron algorithm allow the estimate of **residual nuclei**

- In the same simulation that produces radionuclides, it is possible the generation and transport of decay radiation (γ, β-, β+, α , X-rays conversion and Auger electrons)

- For that, a dedicated database of decay emissions is used, based mostly on information obtained from **NNDC**, sometimes supplemented with other data and checked for consistency.

www.nndc.bnl.gov

- Decay products are not correlated, meaning that, for instance, an α transition to level i in the daughter nucleus could be followed by γ rays competing to level j.

In all cases, **the primary transition is correctly sampled and never doubly counted**.
Particular care is taken in the simulation of β spectra, with the inclusion of Coulomb, recoil, and screening corrections.

Residual radiation: evaluation and transport

(1) semi-analytical mode ("Activation study case")

Monte Carlo to produce the residual nuclei

+ Bateman Equations
to evaluate decays and further residual nuclei
from the decay chain

(2) semi-analog mode

(**Radioactive sources**)

full Monte Carlo method

Residual radiation: evaluation and transport

(1) "Activation study" case

For an arbitrary irradiation pattern, the time evolution of the system (build-up and decay during the irradiation and cooling) is obtained <u>runtime</u> *for fixed cooling times* via the exact analytical solution of the **Bateman equations**:

$$\frac{dN_i}{dt} = -\sum_{j \neq i}\left[\lambda_{ji}^{d} + \bar{\sigma}_{ji}\bar{\varphi}\right]N_i + \sum_{j \neq i}\left[\lambda_{ij}^{d} + \bar{\sigma}_{ij}\bar{\varphi}\right]N_j$$

where for each radionuclide in the material:

λ_{ji}^{d} $\rightarrow$ decay probability of the residual nucleus i in the residual nucleus j

σ_{ji} $\rightarrow$ cross section for transmutation of the residual nucleus i in the residual nucleus j

$$\bar{\varphi} = \int \varphi(E)dE \qquad \bar{\sigma}_{ji} = \frac{1}{\bar{\varphi}}\int \varphi(E)\sigma_{ji}(E)dE$$

In the simplified case of residual nuclei of one type, without other residual nuclei decaying in that species, at the cooling time t_{cool} we find the known formula for the specific activity:

$$a(t_{cool}) = N\sigma\phi(1 - e^{-\lambda t_{irr}})e^{-\lambda t_{cool}}$$

Residual radiation: evaluation and transport

(2) Semi-analogue mode

Each radioactive nucleus is treated like all other unstable particles (pure Monte Carlo method: times are sampled randomly from the correspondent exponential distribution, radiation and daughters also randomly)

- all secondary particles/nuclei carry **time** stamp (“**age**”)

This mode is called semi-analogue because the radiation spectra are **inclusive** (no correlation in the emitted radiation! i.e. no correlated gamma cascade). In an event-by-event analysis a full correlation is not guarantee

In **all cases** FLUKA can perform the generation and transport of the decay radiation

As a consequence, in the same run **results for production of residuals, their time evolution and residual doses due to their decays** can be obtained, for an arbitrary number of decay times and for a given irradiation profile.

Implementation in FLUKA: main features

- Up to 7 different decay branching ratios for each isotope are included in the decay tree
- 51 different decay modes are supported, including all those with delayed particles,
- like β – n

- all gamma lines down to 0.1-0.01% branching, including X-ray lines following conversion electron emissions

- all beta emission spectra down to 0.1-0.01% branching: sampling of the beta+/- spectra includes screening Coulomb corrections

- Auger and conversion electrons

- **Isomers**: production can be controlled via what(2) in RADDECAY
  - Known isomeric states are included in the evolution.
  - for isomer production by neutrons below 20 MeV branchings are based on:

    on EAF-10 activation file for groupwise treatment

    on ENDF + RIPL-3 + models for pointwise treatment

- Different transport thresholds can be set for the prompt and decay radiation parts, as well as some (limited) biasing differentiation (see later)

Input options: overview

Input card: RADDECAY

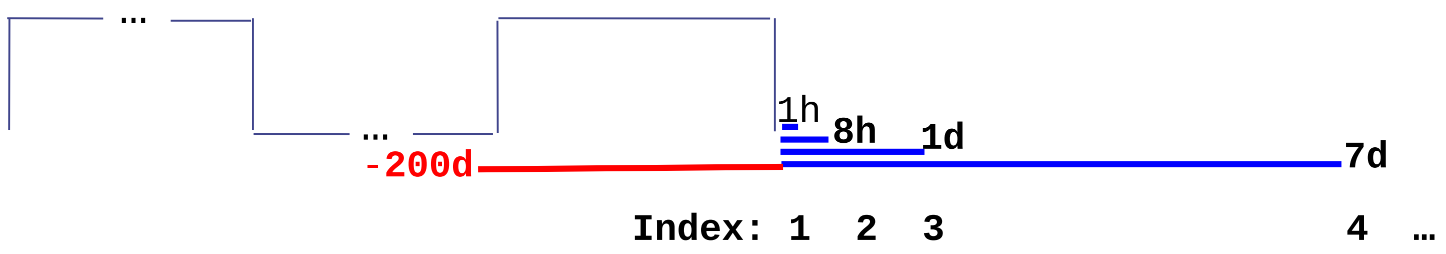
requests simulation of decay of produced radioactive nuclides and allows to modify biasing and transport thresholds (defined with other cards) for the transport of decay radiation

Input card: IRRPROFI

definition of an irradiation profile (irradiation times and intensities)

Input card: DCYTIMES

definition of decay (cooling) times



Input card: DCYSCORE

associates scoring detectors (radio-nuclides, fluence, dose) with different cooling times

Input card: AUXSCORE

allows to associate scoring estimators with dose equivalent conversion factors or/and to filter them according to (generalized) particle identity

allows to filter individually isotopes (ACTIVITY / ACTOMASS and USRBIN)

Particle types

Name	Number	Units	Description
DOSE	228	GeV/g	Dose (energy deposited per unit mass)
DOSE-EQ	240	pSv	Dose Equivalent (AUXSCORE)
ACTIVITY	234	Bq/cm^3	Activity per unit volume
ACTOMASS	235	Bq/g	Activity per unit mass
SI1MEVNE	236	cm^{-2}	Silicon 1 MeV-neutron equivalent flux
HADGT20M	237	cm^{-2}	Hadrons with energy > 20 MeV

Normalization

All quantities are expressed:

- per primary particle if they are <u>not</u> connected to a specific decay time
- per time unit (per s) if they are related to a specific decay time via DCYSCORE (and they are referred to this time)

Card: RADDECAY [1/2]


```
* 1) request radioactive decays
RADDECAY          1.0         0       3.0           0000099999          0
```

RADDECAY		Decays:	Active	Patch Isom:		Replicas:	3.0
h/μ Int:	ignore	h/μ LPB:	ignore	h/μ WW:	ignore	e-e+ Int:	ignore
e-e+ LPB:	ignore	e-e+ WW:	ignore	Low-n Bias:	ignore	Low-n WW:	ignore
		decay cut:	0.0	prompt cut:	99999.0	Coulomb corr:	

WHAT(1) **= 1** **radioactive decays activated <u>for requested cooling times</u>**

Decays: Active "activation study case": time evolution calculated analytically for *<u>fixed</u>* (cooling) times. Daughter nuclei as well as associated radiation is considered at these (fixed) times

> 1 **radioactive decays activated <u>in (semi-)analogue mode</u>**

Semi-Analogue each radioactive nucleus is treated like all other unstable particles (random decay time, daughters and radiation), all secondary particles/nuclei carry time stamp ("age")

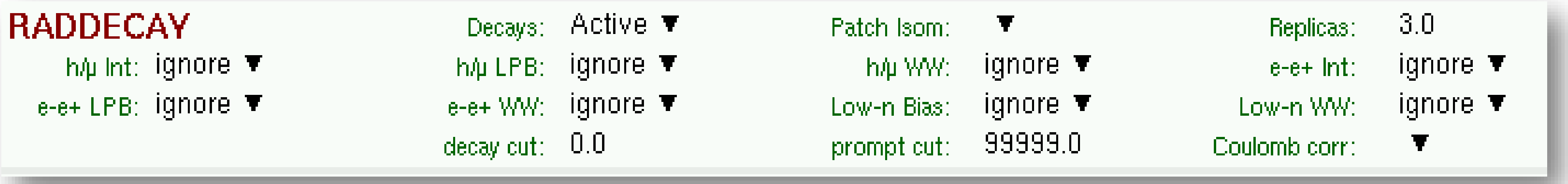
WHAT(2) **> 0** **isomer "production" activated**

Patch Isom: On

WHAT(3) **number of "replicas" of the decay of each individual nucleus**

Replicas: #

Card: RADDECAY [2/2]



WHAT(4) — **switch for applying various biasing features only to prompt radiation or only to particles from radioactive decays**

h/μ Int .. Low-n WW — 9 digits, each responsible for a different biasing

Example:

5th digit, e+/e-/gamma leading particle biasing applied
000010000 to prompt radiation only
000020000 to decay radiation only
000030000 to both

Default: 111111111 (or blank as above)

WHAT(5) — **multiplication factors to be applied to e+/e-/gamma transport energy cutoffs**

decay cut: # 10 digits, first five for decay radiation, second five for prompt
prompt cut: # radiation (see manual)

Special cases:

0000099999 kill EM cascade for prompt radiation
9999900000 kill EM cascade for residual radiation

Card: IRRPROFI

```
* 2) definition of irradiation pattern
*              180days     part/s    185days                180days     part/s
IRRPROFI     1.5552E7  5.9175E5  1.5984E7        0.0  1.5552E7  5.9175E5
```

```
          180days   part/s   185days         180days   part/s
IRRPROFI
                                   Δt: 1.5552E7                  p/s: 5.9175E5
                                   Δt: 1.5984E7                  p/s: 0.0
                                   Δt: 1.5552E7                  p/s: 5.9175E5
```

WHAT(1,3,5) **irradiation time (second)**

Δt: #

WHAT(2,4,6) **beam intensity (particles per second)**

p/s # Note: zero intensity is accepted and can be used
e.g., to define beam-off periods

Note: Several cards can be combined up to a maximum of 2500 irradiation intervals.

Example (see above):

180 days		185 days	180 days
5.9×10^5 p/s	0 p/s (beam-off)		5.9×10^5 p/s

Card: DCYTIMES

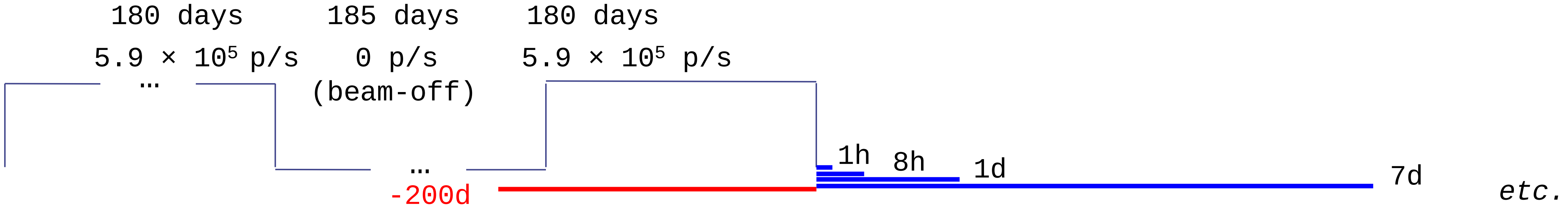
```
* 3) definition of cooling times
*              1hour    8hours      1day     7days     1month    4months
DCYTIMES       3600.    28800.    8.64E4   6.048E5   2.592E6  1.0368E7
```

	1hour	8hours	1day	7days	1month	4months
DCYTIMES	t1: 3600.	t2: 28800.	t3: 8.64E4			
	t4: 6.048E5	t5: 2.592E6	t6: 1.0368E7			

WHAT(1) – WHAT(6) **cooling time (in seconds) after the end of the irradiation**
t1 .. t6 Note: Several cards can be defined.

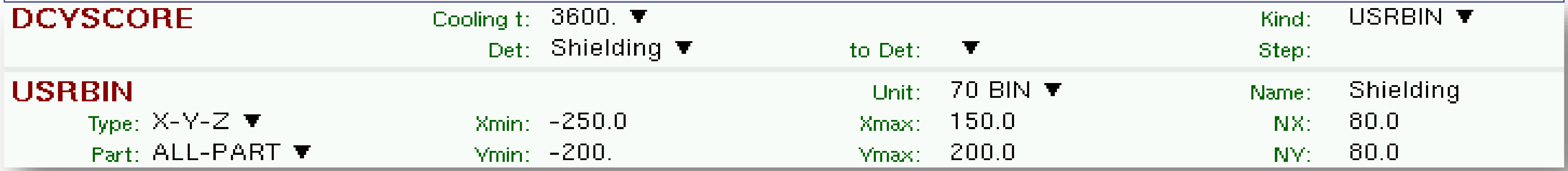
Each cooling time is assigned an index, following the order in which it has been input. This index can be used in option DCYSCORE to assign that particular cooling time to one or more scoring detectors. A negative decay time is admitted: scoring is performed at the chosen time "during irradiation"

Example (see above):



Card: DCYSCORE [1/2]


```
* Associate scoring with different cooling times
DCYSCORE         1.0                      Shielding                   USRBIN
USRBIN          10.0      201.     -70.0     150.0     200.0    5000.0Shielding
USRBIN        -250.0     -200.       0.0      80.0      80.0       1.0&
```



WHAT(1)		**Cooling time index to be associated with the detectors**
Cooling:	#	Drop down list of available cooling times
WHAT(4)..WHAT(5)		**Detector index / name of kind (SDUM / Kind)**
Det .. to Det		Drop down list of available detectors of kind (Kind)
WHAT(6)		**step lengths in assigning indices**
Step	#	
SDUM		**Type of estimator**
Kind		RESNUCLE, USRBIN/EVENTBIN, USRBDX, USRTRACK...

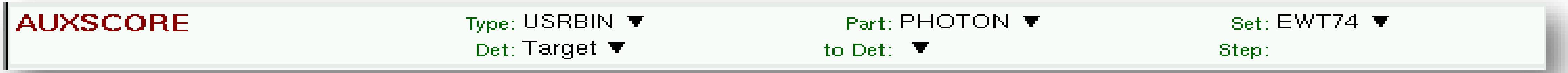
Units: All quantities are expressed per unit time. For example: RESNUCLE Bq
USRBIN fluence rate /

Card: DCYSCORE [2/2]

In the *semi-analogue decay mode*, estimators can include the decay contribution (on top of the prompt one) through association by DCYSCORE <u>with a cooling time index $\leq$ -1.0</u>

Card: AUXSCORE [1/2]

```
* associate scoring with dose equivalent conversion factors
AUXSCORE      USRBIN PHOTON                          Target                          EWT74
```



WHAT(1) — **Type of estimator to associate with**
Type: drop down list of estimator types (USRBIN, USRBDX…)

WHAT(2) — **particle or isotope to filter scoring**
Part: # Particle or particle family list. If empty then flair will prompt for Z, A, and State for filtering on specific isotopes

WHAT(4,5) — **Detector range**
Det .. to Det: Drop down list to select detector range of type WHAT(1)

WHAT(6) — **Step in assigning indices of detector range**
Step: #

SDUM — **Conversion set for dose equivalent (DOSE-EQ) scoring**
Set: Drop down list of available dose conversion sets

Possibility to select an individual isotope (ACTIVITY or ACTOMASS with USRBIN)

Available conversion coefficients

The following
dose conversion coefficients sets
are available:

1) Effective dose sets from ICRP74 and Pelliccioni data calculated with ICRP radiation weighting factors Wr
   (a) **EAP74** : Anterior-Posterior irradiation
   (b) **ERT74** : Rotational irradiation geometry
   (c) **EWT74** : WORST possible geometry for the irradiation

2) Effective dose sets from ICRP74 and Pelliccioni data calculated with the Pelliccioni radiation weighting factors Wr
   (a) **EAPMP** : Anterior-Posterior irradiation
   (b) **ERTMP** : Rotational irradiation geometry
   (c) **EWTMP** : WORST possible geometry for the irradiation

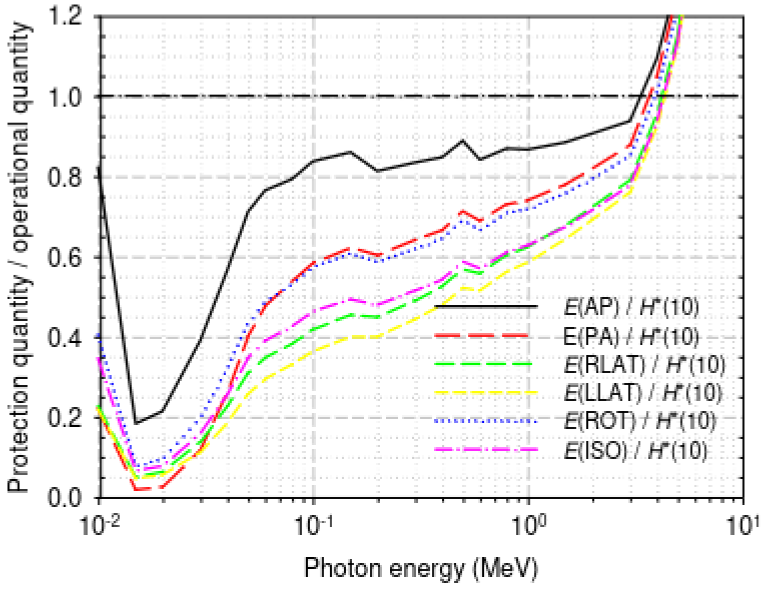
3) Ambient Dose from ICRP116
   (a) **AMBDS** **[Default]**
   → **H***

4) Ambient dose equivalent from ICRP74 and Pelliccioni data
   (a) **AMB74**
   → **H*(10)**

5) Ambient dose equivalent with old "GRS"-conversion factors
   (a) **AMBGS**

About the protection quantities

ICRP Publication 116



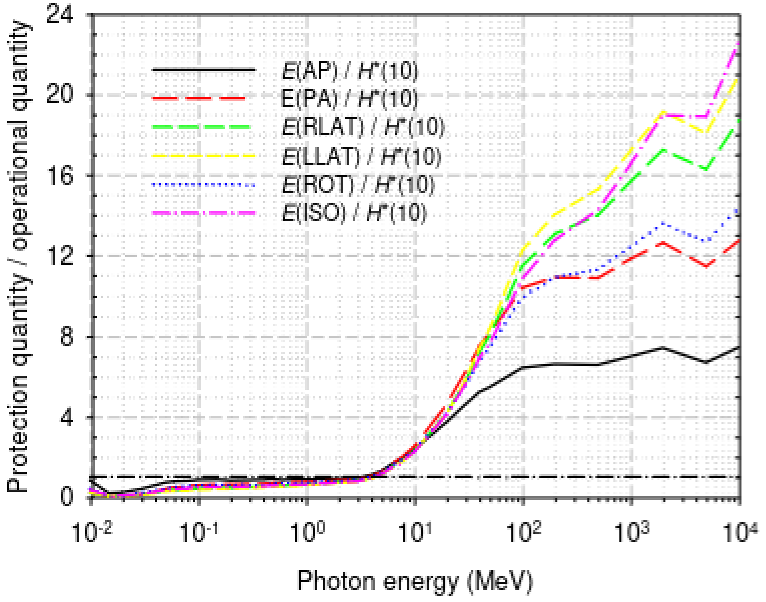


Fig. 5.2 ICRP116
Ratios of photon effective dose to ambient dose equivalent (Ferrari and Pelliccioni, 1994a; Pelliccioni, 2000) for mono-energetic photons

- Ambient Dose (H*), despite the similar name, is a completely different quantity wrt Ambient Dose Equivalent (H*(10))

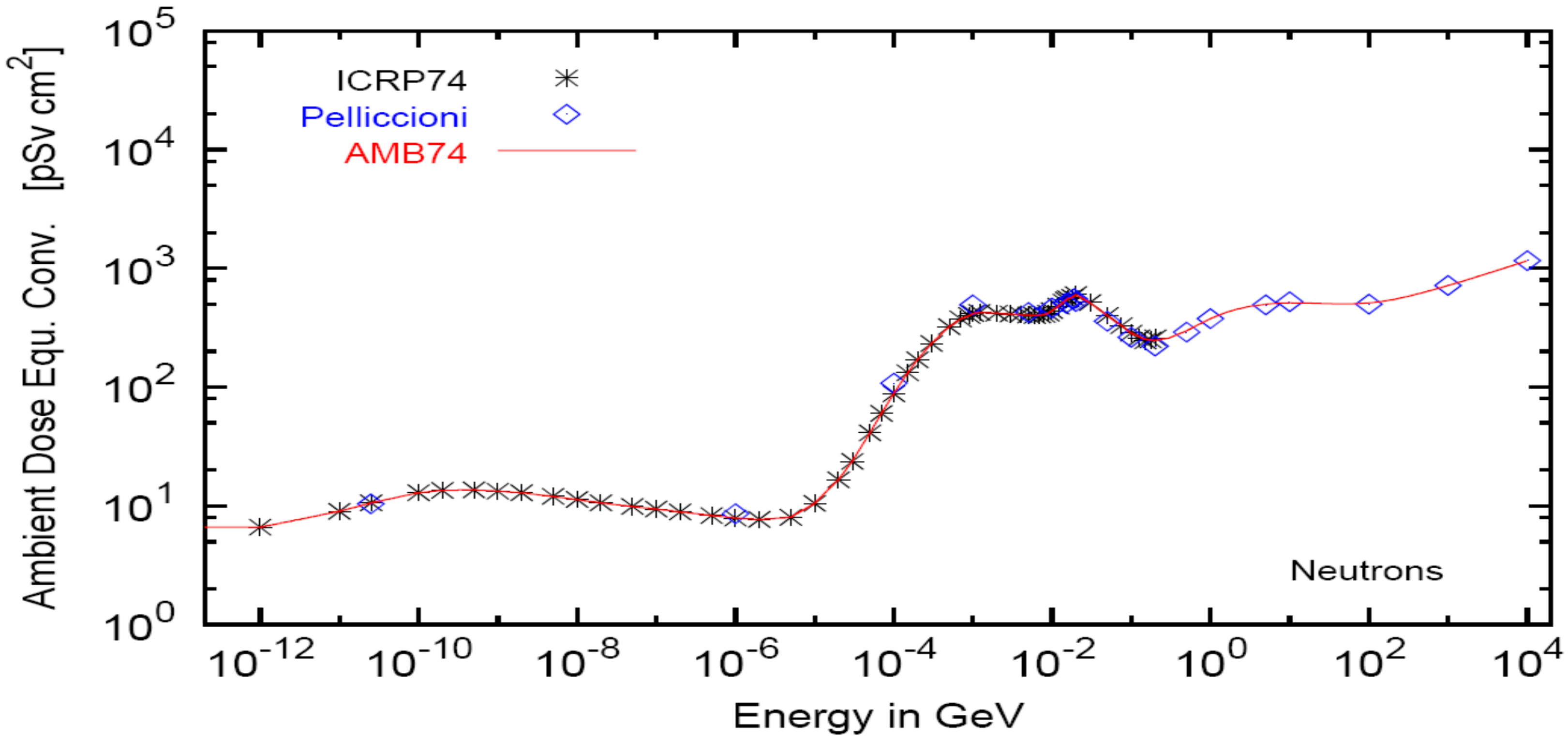
H*(10) was defined as the equivalent dose measured at 1 cm depth on the axis of the ICRU sphere for an ”aligned and expanded” beam, H* is the maximum Effective Dose among the possible irradiation geometries (AP, PA, ROT).

Quoting from ICRU95:

"The quantity for assessing potential effective dose in a given area (predominantly prospectively) is named **ambient dose H***, and is defined at all energies of the particles considered as the maximum of the values of effective dose for the different directions of an incident radiation field on an anthropomorphic phantom as published in ICRP Publication 116 (2010)."

Conversion coefficients

Conversion coefficients from fluence to ambient dose equivalent are based on ICRP74 values and values calculated by M.Pellicciони. They are implemented for protons, neutrons, charged pions, muons, photons, electrons (conversion coefficients for other particles are approximated by these). AMB74 is the default choice for dose equivalent calculation.



Fluence-to-Effective Dose Coefficients

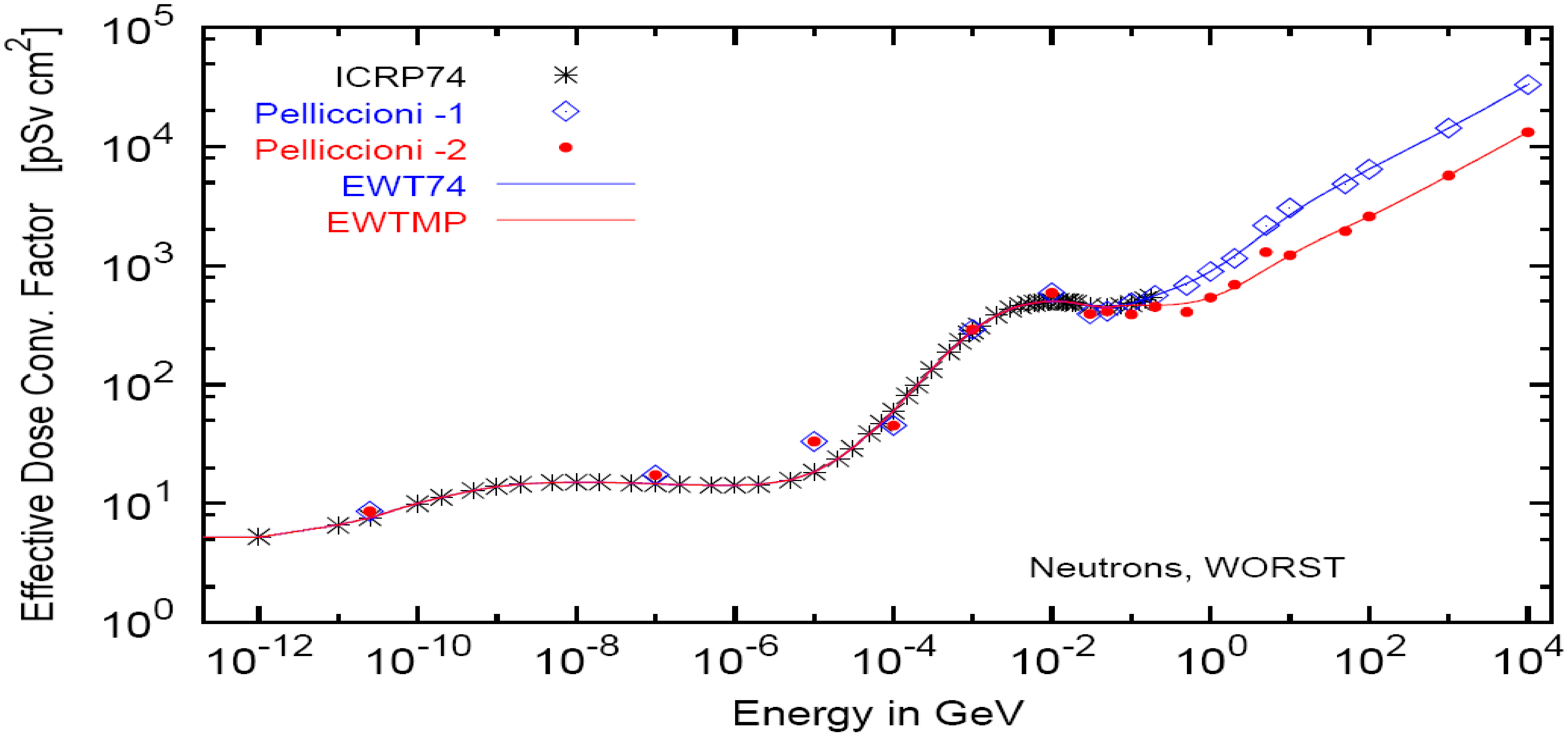
- Conversion coefficients from fluence to effective dose are implemented for three different irradiation geometries:
- - anterior-posterior
  - - rotational
  - - WORST (“Working Out Radiation Shielding Thicknesses”) is the maximum coefficient of anterior-posterior, posterior-anterior, right-lateral and left-lateral geometries. It is recommended to be used for shielding design.

- Implemented for radiation weighting factors recommended by ICRP60 (e.g., SDUM=ETW74) and recommended by M.Pelliccioni (e.g., SDUM=EWTMP). The latter anticipate the 2007 recommendations of ICRP

- Implemented for protons, neutrons, charged pions, muons, photons, electrons (conversion coefficients for other particles are approximated by these)

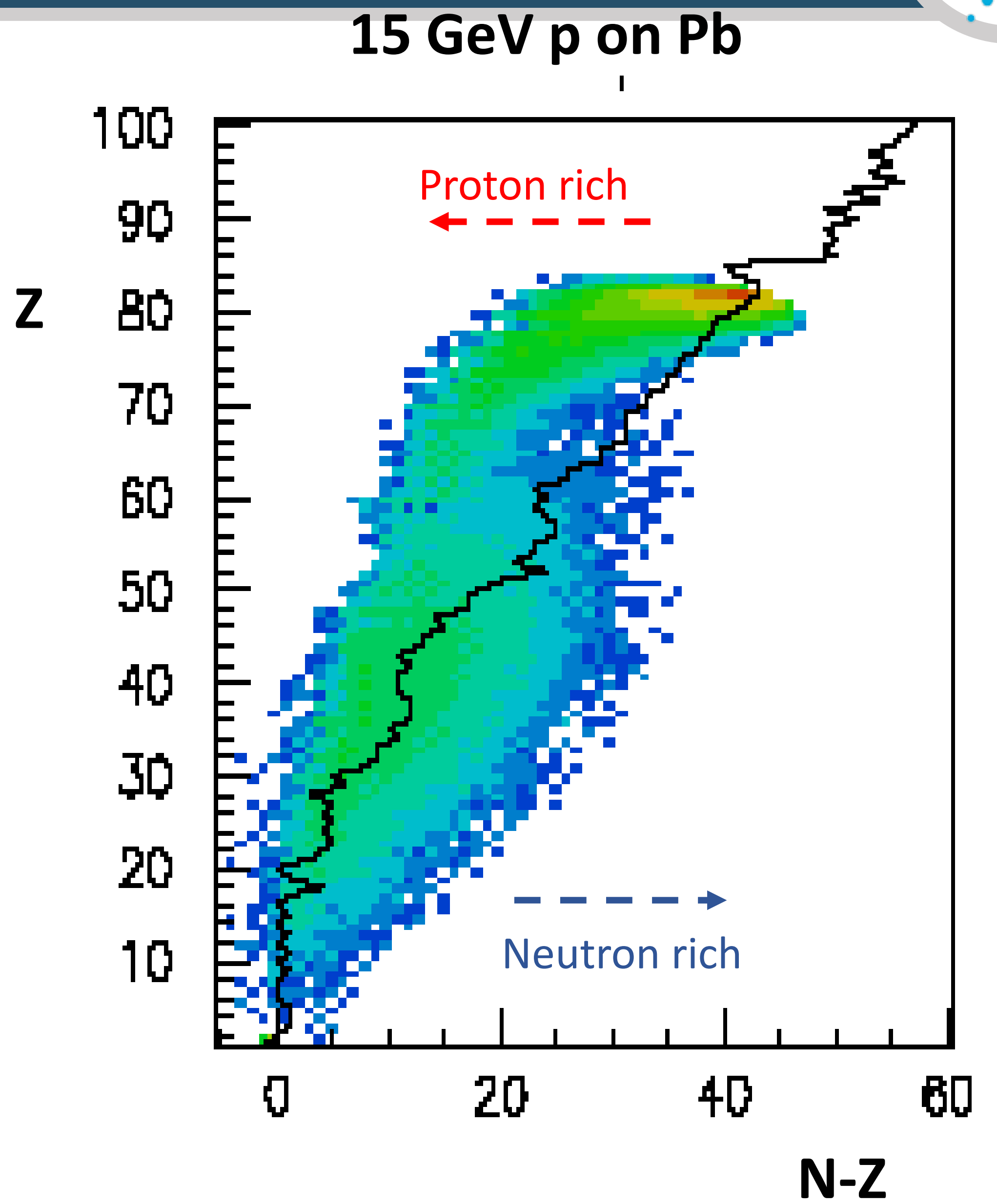
- Warning!! A tentative *very approximate* coefficient is now applied to heavy ions for H*

Fluence-to-Effective Dose Coefficients



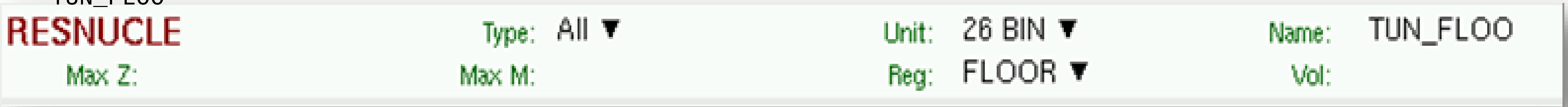
Residual Nuclei

- The production of residuals is the result of the last step of the nuclear reaction, thus it is influenced by all the previous stages
- Residual mass distributions can be very well reproduced
- Individual residuals near to the compound mass are usually well reproduced
- The production of specific isotopes may be influenced by additional problems which have little or no impact on the emitted particle spectra (Sensitive to details of evaporation, Nuclear structure effects, Lack of spin-parity dependent calculations in most MC models)



Card: RESNUCLEi [1/3]


```
RESNUCLE          3.0      -26.         0          0      FLOOR
TUN_FLOO
```



Scoring of residual nuclei or activity on a region basis

WHAT(1) **type of products to be scored**

Type: 1.0 spallation products (except from low-energy neutron interactions)

2.0 products from low-energy neutron interactions (provided the information is available)

3.0 all residual nuclei are scored (if available, see above)

<= 0.0 resets the default (= 1.0)

WHAT(2) **logical output unit (Default = 11.0)**

Unit:

WHAT(3) **Maximum atomic number Z of the residual nuclei distribution**

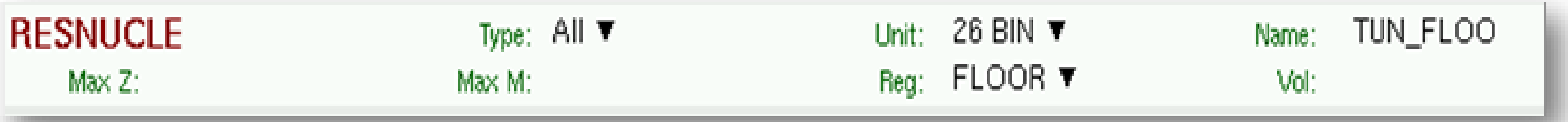
Max Z: Default: according to the Z of the element(s) of the material assigned to the scoring region

WHAT(4) **Maximum M = N - Z - NMZ_min**

Max M: of the residual nuclei distribution (NMZ_min = -5)

Default: maximum value according to the A, Z of the element(s) of the material assigned to the scoring region.

Card: RESNUCLEi [2/3]



WHAT(5) scoring region number/name
Reg: (Default = 1.0 ; -1.0 or @ALLREGS all regions)

WHAT(6) volume of the region in cm^3
Vol: (Default = 1.0)

SDUM character string identifying the detector
Name: (max. 10 characters)

Notes:

1. In the case of heavy ion projectiles the default NMZ, based on the region material, is not necessarily sufficient to score all the residual nuclei, which could include possible ion fragments
2. Residual nuclei from low-energy neutron interactions are only scored if that information is available in the low-energy neutron data set (see Manual) for groupwise, always for pointwise
3. Protons are scored, together with ^{2}H, ^{3}H, ^{3}He, ^{4}He, at the end of their path

Card: RESNUCLEi [3/3]


```
  **** Isotope Yield as a function of Mass Number ****
  ****           (nuclei / cmc / pr)               ****


  A_min: 1 -  A_max: 198

  A:          186  1.5870372E-08 +/-   9.9000000E+01 %
  A:          185  3.7605012E-09 +/-   9.9000000E+01 %
  A:          184  1.4581326E-08 +/-   9.9000000E+01 %
  A:          183  1.0712972E-08 +/-   9.9000000E+01 %
  A:          182  7.4882118E-09 +/-   9.9000000E+01 %
...

  **** Isotope Yield as a function of Atomic Number ****
  ****           (nuclei / cmc / pr)                 ****


  Z_min: 1 -  Z_max: 78

  Z:           74  5.2413383E-08 +/-   9.9000000E+01 %
  Z:           42  3.0072785E-07 +/-   9.9000000E+01 %
  Z:           41  4.7906228E-08 +/-   9.9000000E+01 %
  Z:           40  3.7605012E-09 +/-   9.9000000E+01 %
  Z:           38  3.7605012E-09 +/-   9.9000000E+01 %
...

 **** Residual nuclei distribution  ****
  ****    (nuclei / cmc / pr)        ****


  A \ Z   68         69         70         71         72         73         74         75         76         77         78
 186   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   1.59E-08   0.00E+00   0.00E+00   0.00E+00   0.00E+00
     +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/-99.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 %
 185   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   3.76E-09   0.00E+00   0.00E+00   0.00E+00   0.00E+00
     +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/-99.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 %
 184   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   1.46E-08   0.00E+00   0.00E+00   0.00E+00   0.00E+00
     +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/-99.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 %
 183   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   1.07E-08   0.00E+00   0.00E+00   0.00E+00   0.00E+00
     +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/-99.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 % +/- 0.0 %
...
```

Units:
- nuclei/cm3 per primary particle
  if RESNUCLEi is not connected
  to a cooling time
- Bq /cm3 for a specific cooling time
  assigned via DCYSCORE

Provided the correct volume is input in the RESNUCLEi card, otherwise it is per region if V=1

Card: PHYSICS

Please activate the following two cards if residuals are of interest:

switch to activate the evaporation of heavy fragments (up to A=24)

```
PHYSICS     3.0                                                      EVAPORAT
PHYSICS     1.0                                                      COALESCE
```

special options for coalescence treatment

ISOTOPE ‘beam’

to simulate a radioactive source:

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 base of cylinder at origin

```
BEAM                                                                       ISOTOPE
HI-PROPE        27.0      60.0
BEAMPOS          0.0       0.0       0.1       0.0       0.0       0.0
BEAMPOS          0.0       1.0       0.0       0.2       0.0       0.0CYLI-VOL
```

→ request decay by the RADDECAY card

Semi-analogue example: a therapeutic source of ^{131}I

Define the beam characteristics
BEAM Beam: Momentum ▼ p: Part: ISOTOPE ▼
Δp: Flat ▼ Δp: Δϕ: Flat ▼ Δϕ:
Shape(X): Rectangular ▼ Δx: Shape(Y): Rectangular ▼ Δy:

HI-PROPE Z: 53 A: 131 Isom:

Define the beam position
BEAMPOS x: y: z:
cosx: cosy: Type: POSITIVE ▼

Define the beam position
BEAMPOS Rin: 0 Rout: 5 Type: SPHE-VOL ▼

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

Black body
SPH blkbody x: 0.0 y: 0.0 z: 0.0
R: 100000.0

Void sphere
SPH void x: 0.0 y: 0.0 z: 0.0
R: 10000.0

Void sphere
SPH target x: 0.0 y: 0.0 z: 0.0
R: 5.0

END

Black hole
REGION BLKBODY Neigh: 5 Volume:
expr: +blkbody -void

Void around
REGION VOID Neigh: 5 Volume:
expr: +void -target

Target
REGION TARGET Neigh: 5 Volume:
expr: +target

END

Semi-analogue example: a therapeutic source of 131I

Requests simulation of radioactive decays and sets the corresponding biasing and transport conditions

RADDECAY		Decays:	Semi-Analogue ▼	Patch Isom:	▼	Replicas:	
h/µ Int:	ignore ▼	h/µ LPB:	ignore ▼	h/µ WW:	ignore ▼	e-e+ Int:	ignore ▼
e-e+ LPB:	ignore ▼	e-e+ WW:	ignore ▼	Low-n Bias:	ignore ▼	Low-n WW:	ignore ▼
		decay cut:	0.0	prompt cut:	0.0	Coulomb corr:	▼
TCQUENCH		t cut-off:	3600	Birks c1:		Birks c2:	
		Bin:	1hpdose ▼	to Bin:	▼	Step:	
USRBIN				Unit:	21 BIN ▼	Name:	1hpdose
Type:	X-Y-Z ▼	Xmin:	-5	Xmax:	5	NX:	100
Part:	DOSE ▼	Ymin:	-5	Ymax:	5	NY:	100
		Zmin:	-5	Zmax:	5	NZ:	100
USRBIN				Unit:	21 BIN ▼	Name:	physdose
Type:	X-Y-Z ▼	Xmin:	-5	Xmax:	5	NX:	100
Part:	DOSE ▼	Ymin:	-5	Ymax:	5	NY:	100
		Zmin:	-5	Zmax:	5	NZ:	100

Associates selected scoring detectors with user-defined decay times

DCYSCORE		Cooling t:	Semi-Analogue ▼	Kind:	USRBIN ▼		
		Det:	1hpdose ▼	to Det:	physdose ▼	Step:	

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

ASSIGNMA		Mat:	BLCKHOLE ▼	Reg:	BLKBODY ▼	to Reg:	▼
		Mat(Decay):	▼	Step:		Field:	▼
ASSIGNMA		Mat:	VACUUM ▼	Reg:	VOID ▼	to Reg:	▼
		Mat(Decay):	▼	Step:		Field:	▼
ASSIGNMA		Mat:	WATER ▼	Reg:	TARGET ▼	to Reg:	▼
		Mat(Decay):	▼	Step:		Field:	▼

GEOMETRY modifications

FLUKA.contains the possibility of selectively changing a region material (and/or switching on/off possible fields) when transporting radioactive decay products.

Radioactive decay products originating from that regions are ignored. This is helpful for situations where the emissions of an activated object in a complex environment have to be evaluated standalone.

Through Input card: ASSIGNMA

(a (single-element or compound) material is assigned to each geometry region)

Example

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
ASSIGNMA        GOLD      REG1      REG2      1.0       0.0     VACUUM
```

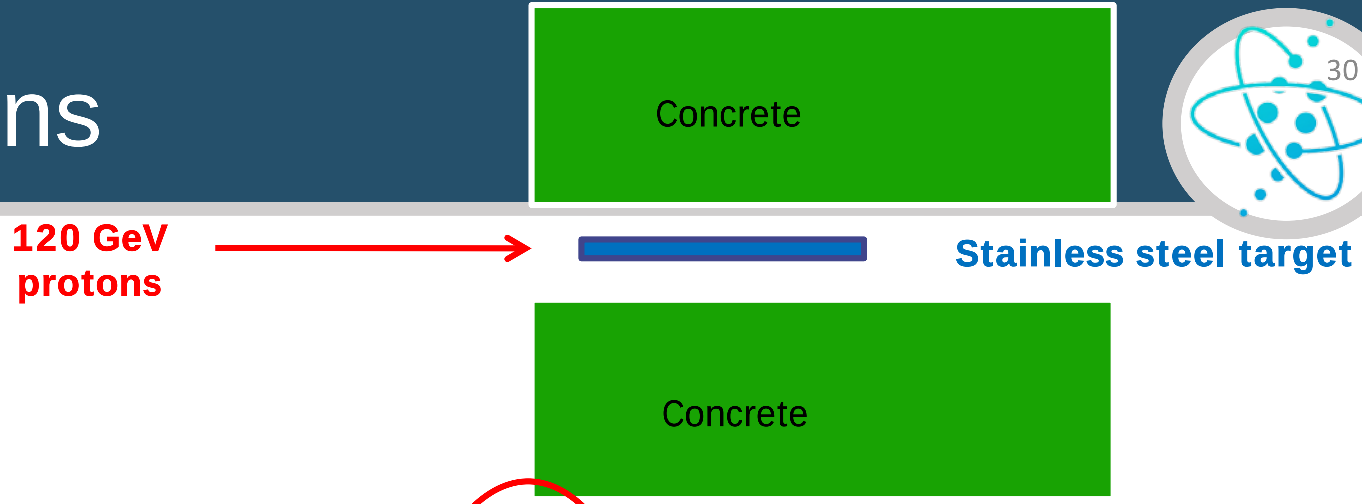
MATERIAL — from REGION — to REGION — in steps of — no field — MATERIAL for decay products, it can be whichever material

WHAT(5) = 1/2/3: a magnetic/electric/both field(s) is(are) present in the region(s) defined by WHAT(2), (3), and (4), for both prompt and radioactive decay products

= 4/5/6: same as above, but for prompt products only

= 7/8/9: same as above, but for radioactive decay products only

GEOMETRY modifications



1) Target only (shielding set to vacuum)

```
ASSIGNMA    BLCKHOLE   EXTVOID
ASSIGNMA      VACUUM   VACTRGT
ASSIGNMA      SS316L    TARGET
ASSIGNMA    CONCRETE  SHIELDIN                                                      VACUUM
*  ..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
```

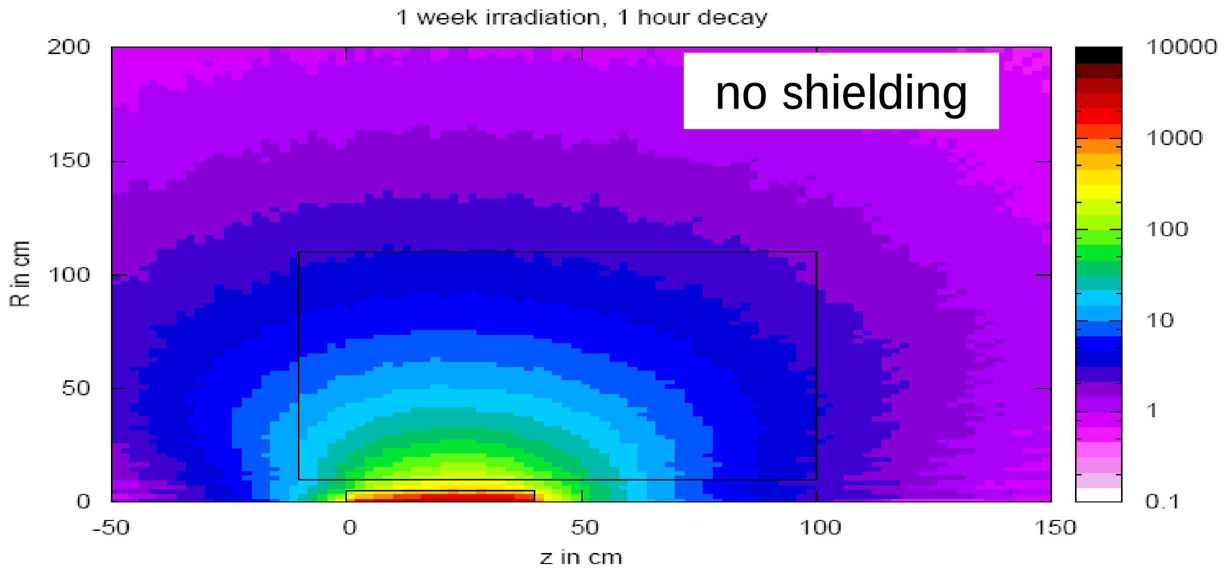
2) Shielding only (target set to vacuum)

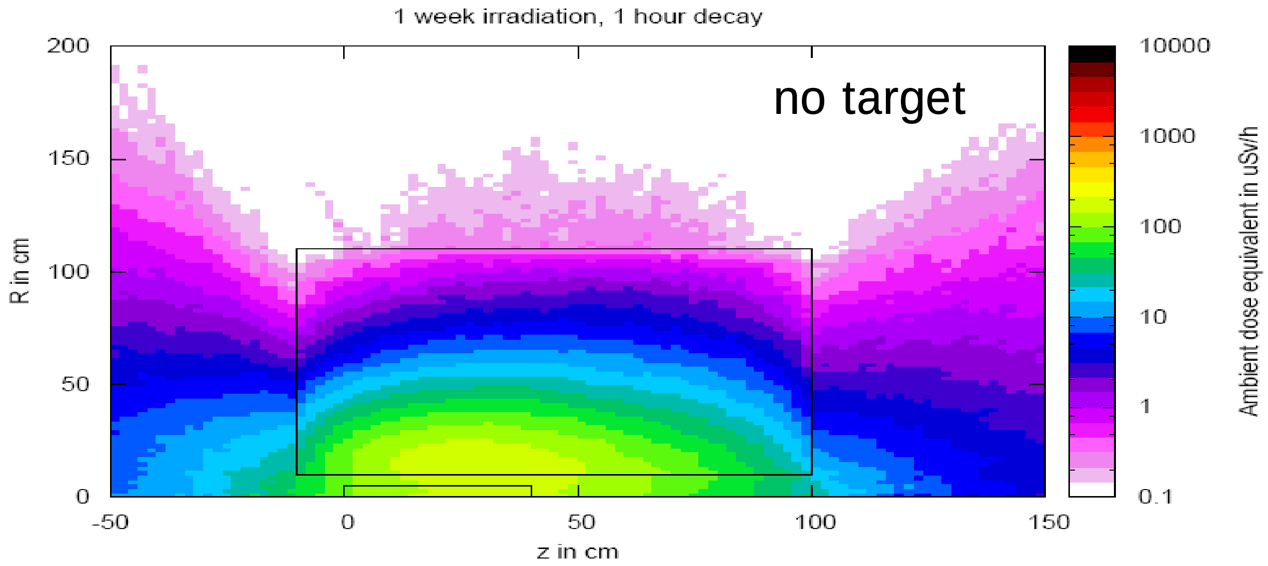
```
ASSIGNMA    BLCKHOLE   EXTVOID
ASSIGNMA      VACUUM   VACTRGT
ASSIGNMA      SS316L    TARGET                                                      VACUUM
ASSIGNMA    CONCRETE  SHIELDIN
*  ..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
```

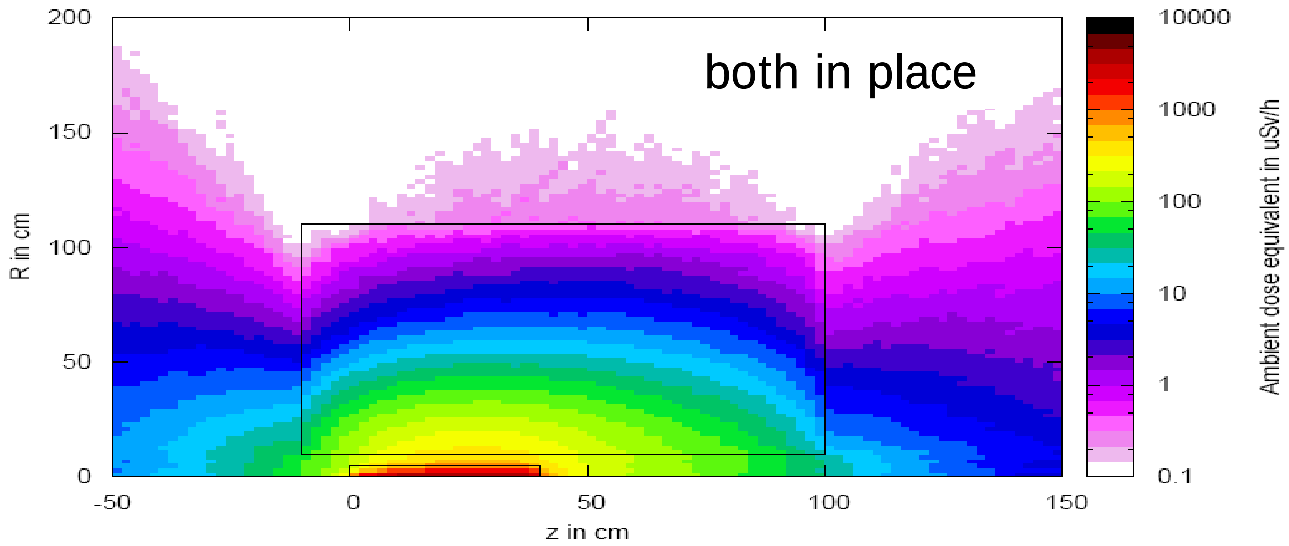
3) Target and shielding

```
ASSIGNMA    BLCKHOLE   EXTVOID
ASSIGNMA      VACUUM   VACTRGT
ASSIGNMA      SS316L    TARGET
ASSIGNMA    CONCRETE  SHIELDIN
*  ..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
```

GEOMETRY modifications







Thanks for your attention!