Accurate Monte Carlo modeling of biomedical cyclotrons: optimization of FLUKA physics and transport parameters for dosimetry, shielding and activation calculations

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Outline

- Introduction
- Creation and validation of a Monte Carlo model of a biomedical cyclotron:
  - *Modeling*
  - *Optimization of the MC model*
  - *Production of ^{18}F*
  - *Measurements of the ambient neutron dose equivalent*
- Applications:
  - *Production of medical radioisotopes*
  - *Planning of a new cyclotron facility*
  - *Assessment of air activation: production of ^{41}Ar*
  - *Modeling of a proton therapy degrader*
- General problems encountered during MC modeling

Cyclotrons in medical field

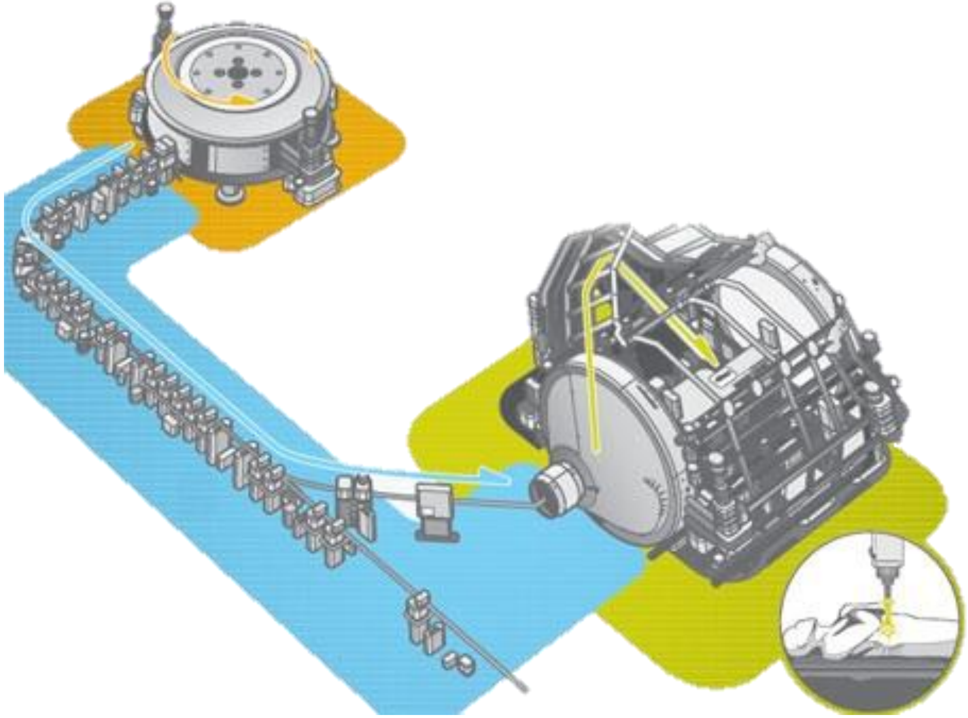
^{18}F ^{15}O

^{11}C ^{13}N

+

Non-standard radionuclides

Cyclotrons in medical field



FLUKA in Medical Physics

Prediction of ^{89}Zr production using the Monte Carlo code FLUKA

A. Infantino [a], G. Cicoria [b], D. Pancaldi [b], A. Ciarmatori [b], S. Boschi [c], S. Fanti [b], M. Marengo [b], D. Mostacci [a,*]

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Applied Radiation and Isotopes 69 (2011) 1134–1137

Clinical CT-based calculations of dose and positron emitter distributions in proton therapy using the FLUKA Monte Carlo code

K Parodi[1,3], A Ferrari[2], F Sommerer[2] and H Paganetti[1]

[1] Massachusetts General Hospital and Harvard Medical School, 02114 Boston, USA
[2] CERN, 1211 Geneva 23, Switzerland

Phys. Med. Biol. **52** (2007) 3369–3387

Estimation of neutron production from accelerator head assembly of 15 MV medical LINAC using FLUKA simulations

B.J. Patil [a], S.T. Chavan [b], S.N. Pethe [b], R. Krishnan [b], V.N. Bhoraskar [a], S.D. Dhole [a,*]

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[b] SAMEER, IIT Powai Campus, Mumbai 400 076, India

Nuclear Instruments and Methods in Physics Research B 269 (2011) 3261–3265

FLUKA Benchmarks

That's the point

FLUKA: Performances and Applications in the Intermediate Energy Range

A. Fassò A. Ferrari, J. Ranft, P.R. Sala

planned in the near future. Shielding designers are confronted with a double challenge, due to *i)* the lack of reliable data in the energy range 20 MeV–1 GeV (source terms, attenuation lengths, angular and energy distributions of secondary particles) and *ii)* the difficulty of assessing correctly the large shield thicknesses required by the high beam intensity of most of the planned facilities. Compared with both the

Recently, new possibilities have emerged in this domain with the improvements of the code FLUKA in the range of energies below 1 GeV. For many years that program has been known as one of the main tools for designing shielding of proton accelerators in the multi-GeV energy range (its hadron event generator [10] has been adopted by the majority of the existing high-energy transport codes [11, 12, 13], including those used for particle physics simulations [14, 15]). In the last years, however, FLUKA has gone through an important process of transformation which has converted it from a specialized to a multi-purpose program, not restricted to a limited family of particles or to a particular energy domain.

Nuclear Instruments and Methods in Physics Research A 562 (2006) 814–818

Validation of the FLUKA Monte Carlo code for predicting induced radioactivity at high-energy accelerators

M. Brugger, A. Ferrari, S. Roesler*, L. Ulrici

Phys. Med. Biol. 55 (2010) 5833–5847

Benchmarking nuclear models of FLUKA and GEANT4 for carbon ion therapy

T T Böhlen[1,2], F Cerutti[1], M Dosanjh[1], A Ferrari[1], I Gudowska[2], A Mairani[3] and J M Quesada[4]

Nuclear Instruments and Methods in Physics Research A 581 (2007) 511–516

FLUKA Monte Carlo simulations and benchmark measurements for the LHC beam loss monitors

L. Sarchiapone[a,*], M. Brugger[a], B. Dehning[a], D. Kramer[a], M. Stockner[b], V. Vlachoudis[a]

FLUKA Benchmarks

PET/SPECT cylotrons
(10-70 MeV)

Proton Therapy cyclotrons
(250 MeV)

Ion Therapy cyclotrons
(400 MeV)

TRIUMF cyclotron
(500 MeV)

Proton Synchrotron Booster (CERN)
(1.4 GeV)

Proton Synchrotron (CERN)
(25 GeV)

LHC (CERN)
(4 TeV)

Energy ↔ Velocity

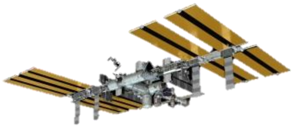
Bike
(15-70 km/h)

Sport Car
(250 km/h)

Kimi Raikkonen
(F1 GP Monza 2005 370.1 km/h)

Maglev Train
(China 2003, 501 km/h)

F-14 TOMCAT
(980-2400 km/h)



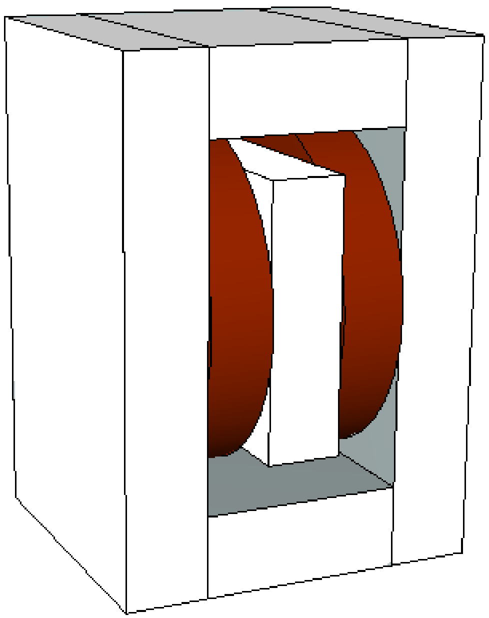
ISS
(~ 27500 km/h)

Millennium Falcon
Speed of Light

Sources:
ISS: http://www.esa.int/Our_Activities/Human_Spaceflight/International_Space_Station/ISS_International_Space_Station
CERN acceleratos: http://home.web.cern.ch/about/accelerators
TRIUMF: www.triumf.ca
Maglev: http://en.wikipedia.org/wiki/Maglev
Kimi: http://www.formulapassion.it/2014/08/f1-monza-record-del-tempio-della-velocita/
F14: http://www.museumofflight.org/aircraft/grumman-f-14a-tomcat

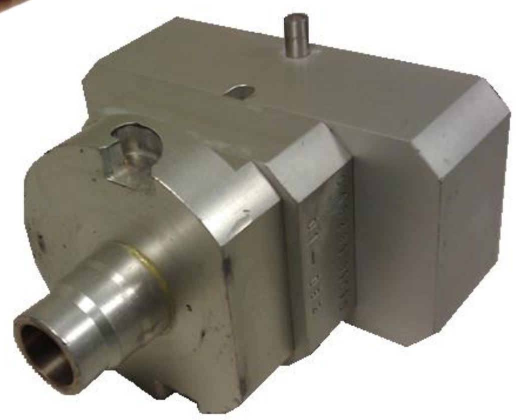
Note:
(WRONG) Assumption 1 MeV = 1 km/h
1 MeV proton → ~ 50×10^6 km/h

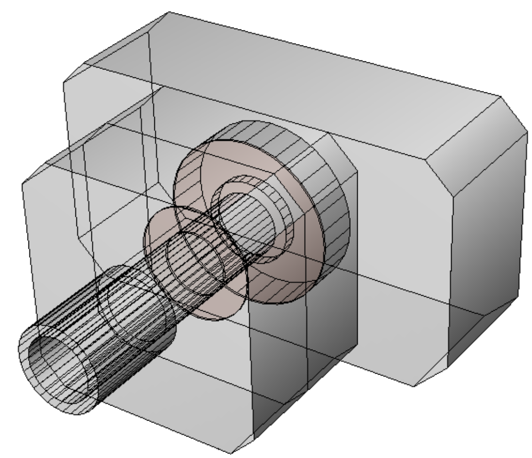
GE PETtrace cyclotron



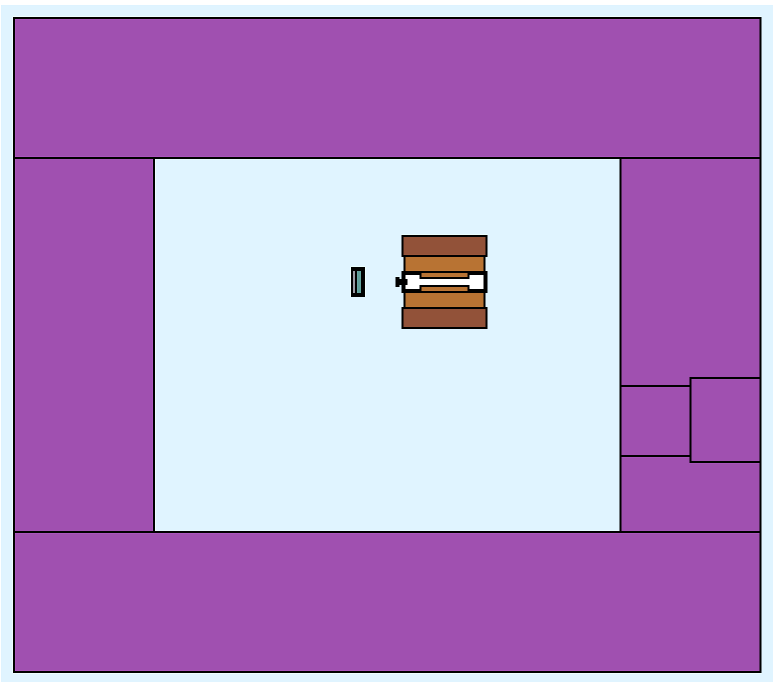
3D Monte Carlo model of the PETtrace cyclotron (GE Healthcare, Uppsala, Sweden)

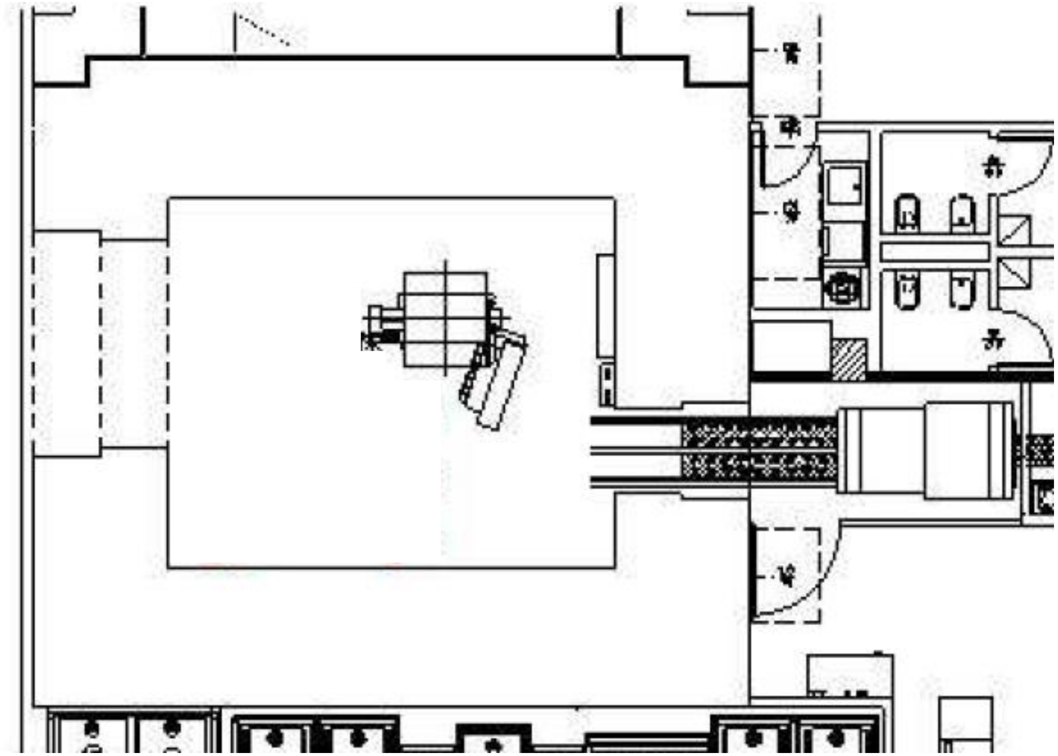
3D Monte Carlo model of the $^{18}F^{-}$ target (GE Healthcare, Uppsala, Sweden)





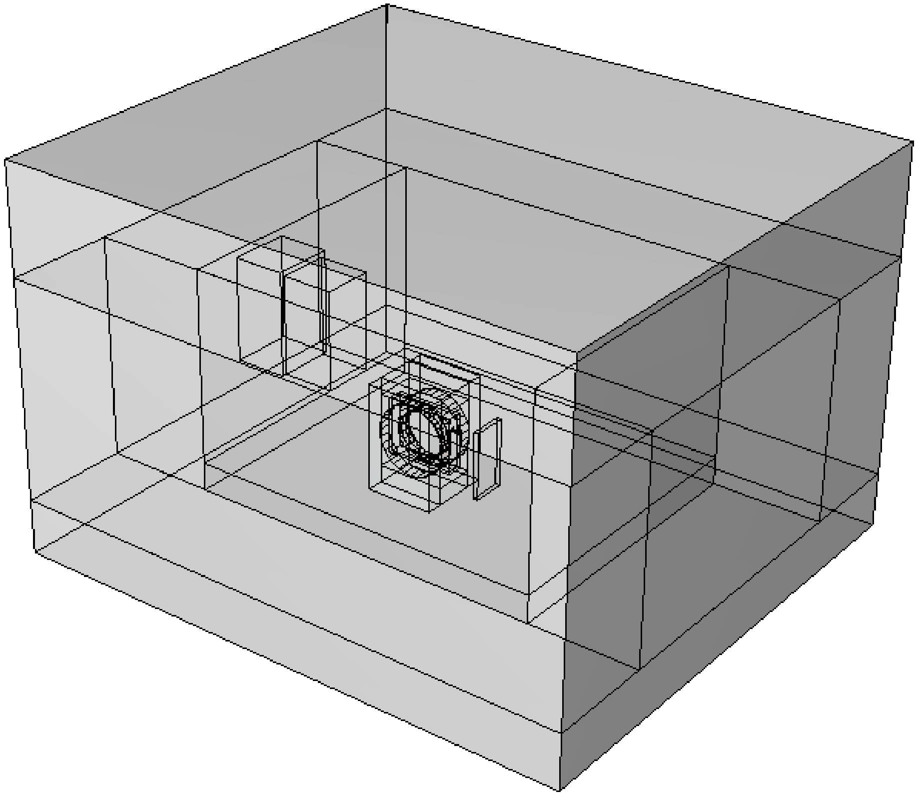
Model of the Bunker

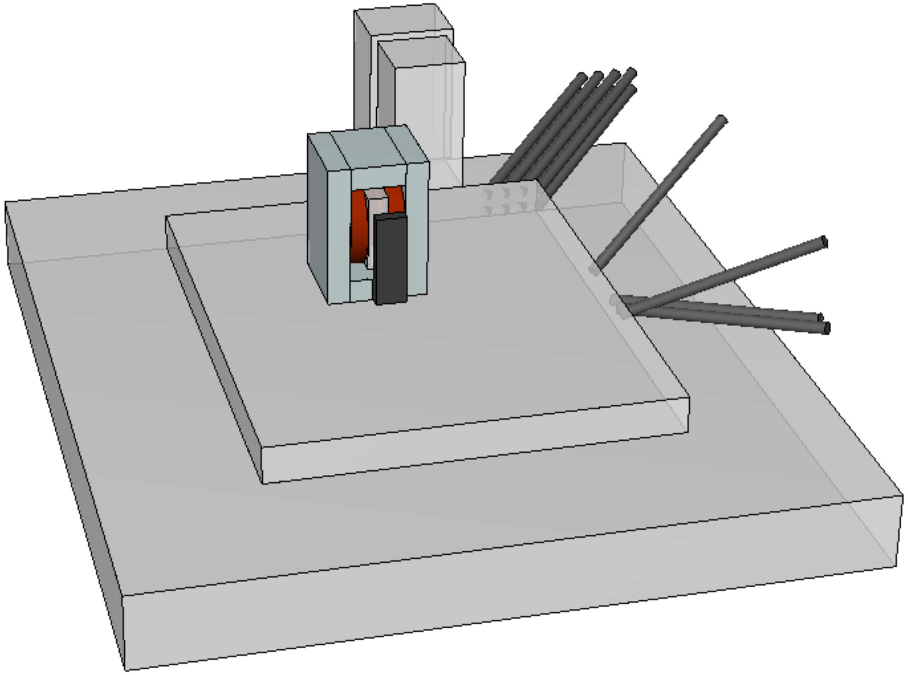




Section of the FLUKA Monte Carlo model and comparison with the original technical drawing of the bunker.

Model of the Bunker





3D Monte Carlo model of the S. Orsola-Malpighi cyclotron vault.
Detail of the pipes that contain the delivery lines, the RF cables, the control cables, etc.

Validation: Production of ^{18}F

Three different set of defaults, predefined transport settings for the most common problems, were compared to find the optimal combination of physical and transport parameters and cpu-time usage.

- NEW-DEFA in which reasonable minimal set of physical mechanisms are enabled;
- HADROTHE for hadrotherapy calculations;
- PRECISO for maximum precision simulations.

Processor: i7-3630QM
N° core: 4 (8 thread)
N° runs: 8

The saturation yield for the very well-known reaction *$^{18}O(p,n)^{18}F$* calculated with FLUKA was compared with the experimental value and the recommended saturation yield (A_2) in the IAEA database for medical radioisotopes production. A target of a water solution (1.3 g) 97% enriched in ^{18}O and a 16,5 MeV pencil beam were simulated in a geometry independent case.

IAEA A_2 @ 16,5 MeV → *13078 ± 10% MBq/μA*

Validation: Production of ^{18}F

$$A(EOB) = A_{sat} \cdot \left(1 - e^{-\lambda \cdot t_{irr}}\right)$$

$$Y = \frac{A_{sat}}{I_{irr}} = \frac{A(EOB)}{I_{irr} \cdot \left(1 - e^{-\lambda \cdot t_{irr}}\right)}$$

Note:
- *Y corresponds to IAEA A_2 value*
- *A(EOB)=A(1h-1μA) corresponds to IAEA A_1 value*

DEFAULTS	***NEW-DEFA***	***NEW-DEFA***	***NEW-DEFA***	***HADROTHE***	***HADROTHE***	***PRECISIO***	***PRECISIO***
TRANSPORT	PART-THR: as default (10 MeV)	PART-THR: 0.1 MeV	PART-THR: 1 MeV for protons	PART-THR: as default (0.1 MeV)	PART-THR: 10 MeV	PART-THR: as default (0.1 MeV)	PART-THR: 10 MeV
Simulation Time [h]	1.05	5.04	**3.12**	25.17	3.43	25.48	2.26
Ysat ^{18}F [MBq/μA]	6521 ± 6	13166 ± 9	13161 ± 9	13169 ± 10	6508 ± 5	13200 ± 10	6486 ± 6
A_2/Y_{FLUKA}	2.01 ± 0.20	0.99 ± 0.10	**0.99 ± 0.10**	0.99 ± 0.10	2.01 ± 0.20	0.99 ± 0.10	2.02 ± 0.20

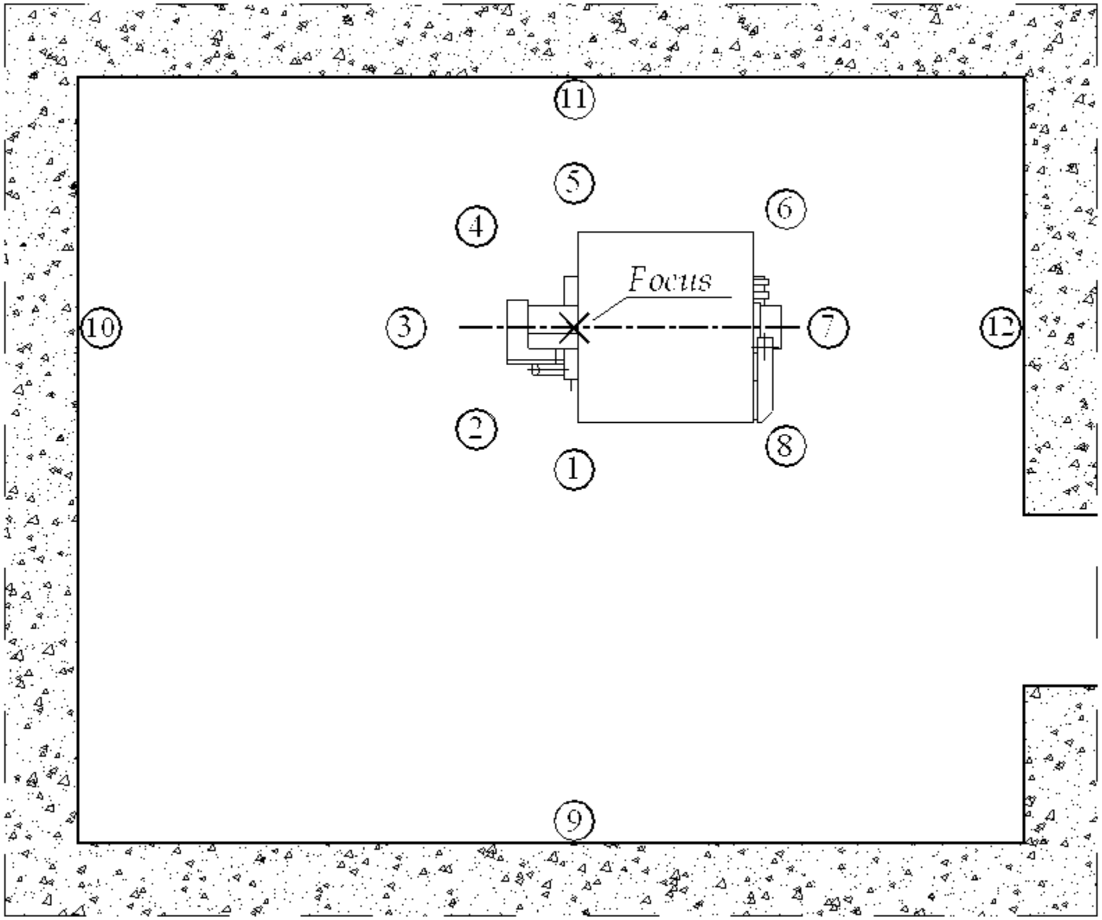
Note: 10^9 primary particles simulated.

Y_{exp} [MBq/μA]	***Y_{exp}/Y_{FLUKA}***
8600 ± 400	0.65 ± 0.03

Ref: Infantino, A., Marengo, M., Baschetti, S., Cicoria, G., Longo Vaschetto, V., Lucconi, G., Massucci, P., Vichi, S., Zagni, F., Mostacci, D., 2014. Accurate Monte Carlo modeling of cyclotrons for optimization of shielding and activation calculations in the biomedical field. Radiation Physics and Chemistry, Manuscript submitted for publication.

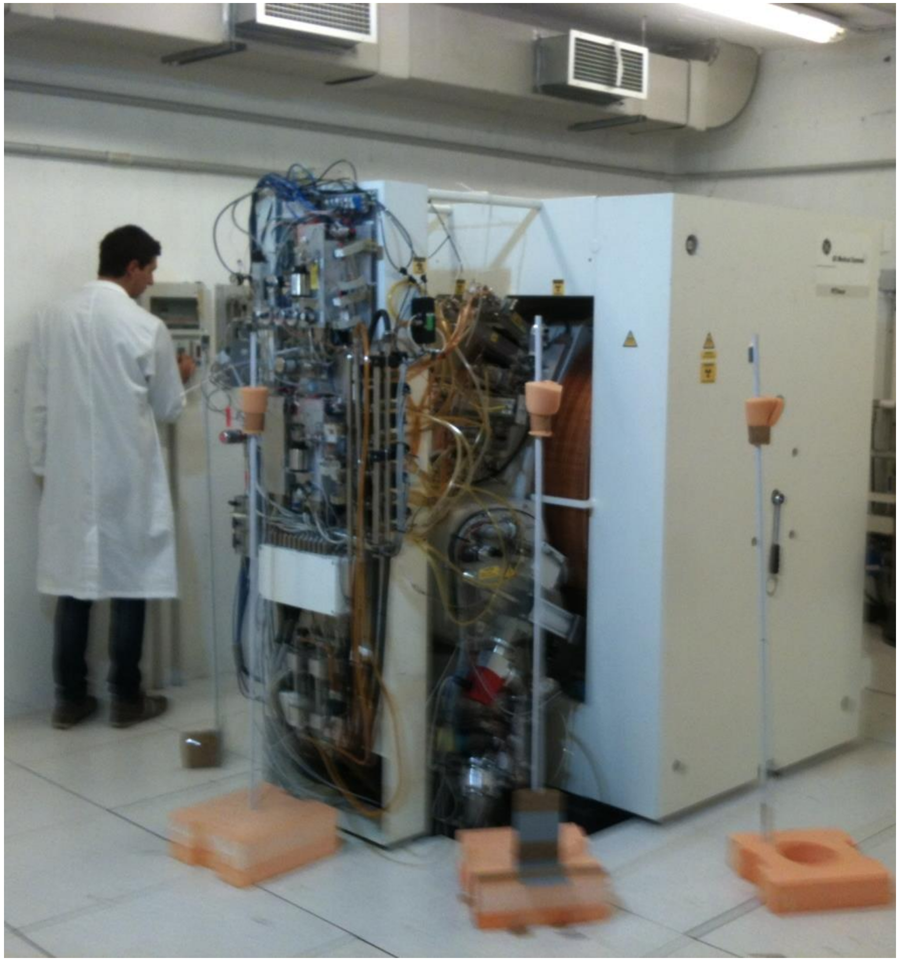
Validation: neutron dose

R. Gallerani et al. *Neutron production in the operation of a 16.5 MeV PETtrace cyclotron*. Progress in Nuclear Energy. 50, 939-943, **2008**.



- ✓ Measurements of ambient dose equivalent H*(10), from thermal and fast neutrons;
- ✓ 12 points located along 8 directions;
- ✓ A set of 3 dosimeters for fast neutrons (CR-39) and 3 for thermal neutrons (GR-200 and GR-207), was used at each measurement point.

Validation: neutron dose

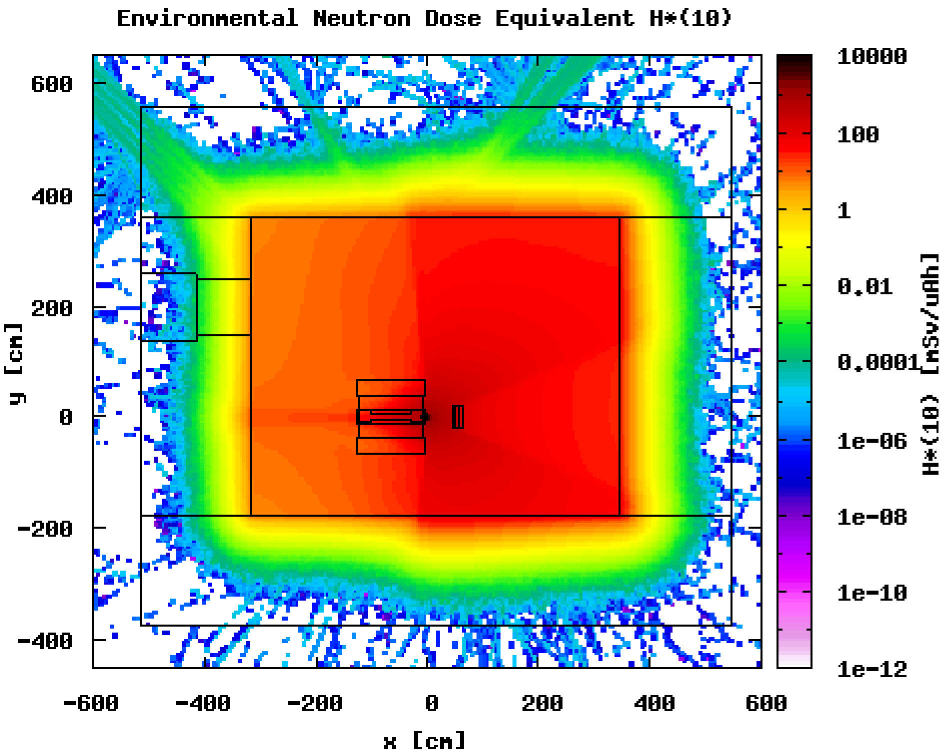


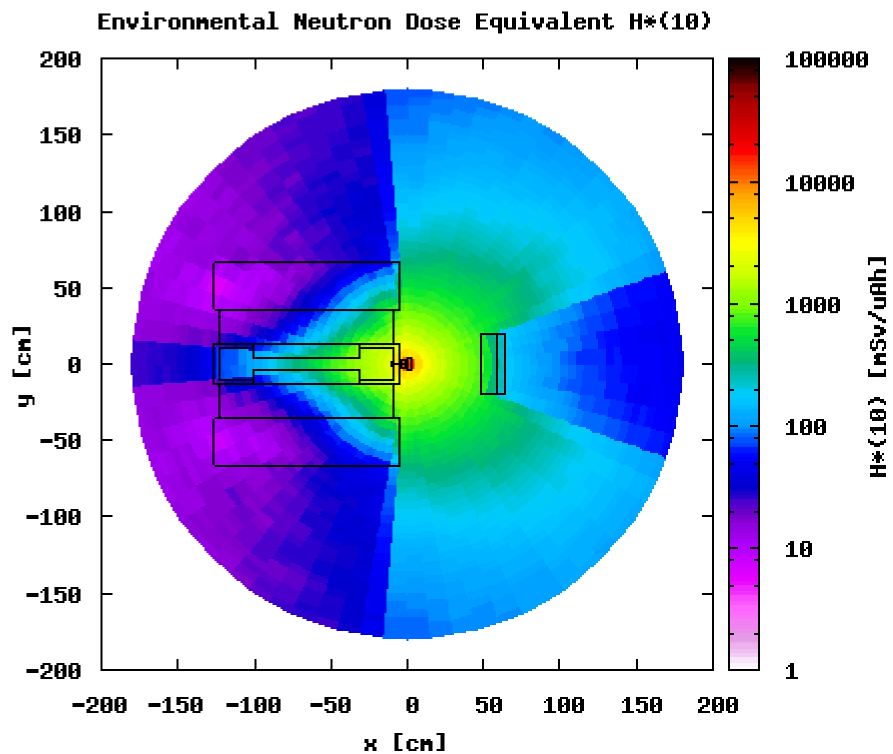
- ✓ Measurements performed at the same points as in *R. Gallerani et al*.
- ✓ A neutron rem-counter FHT-752 (Thermo Scientific) based on a BF_3 proportional-counter and a PE-moderator, calibrated in H*(10).
- ✓ A set of 12 dosimeters for fast neutrons (CR-39).
- ✓ Irradiation tests were conducted with values of integrated current between 0.005 and 0.0016 μAh.

FHT-752

CR-39

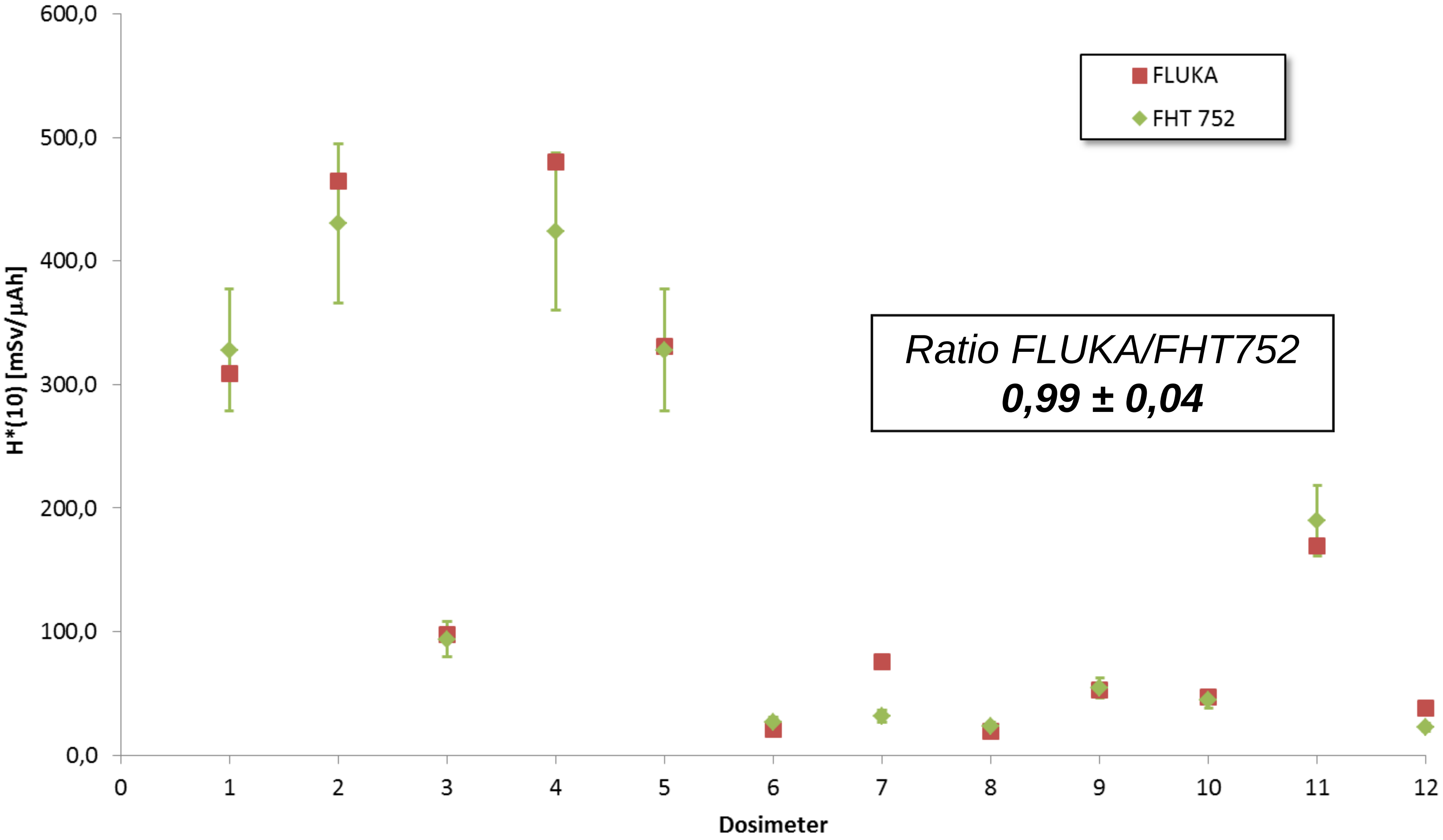
Results of the Simulations





Assessment of the neutron dose field around the GE PETtrace cyclotron.
Left: Neutron dose field over the bunker (5 cm pitch cartesian mesh).
Right: Detail of the neutron dose field around the cyclotron (cylindrical mesh)

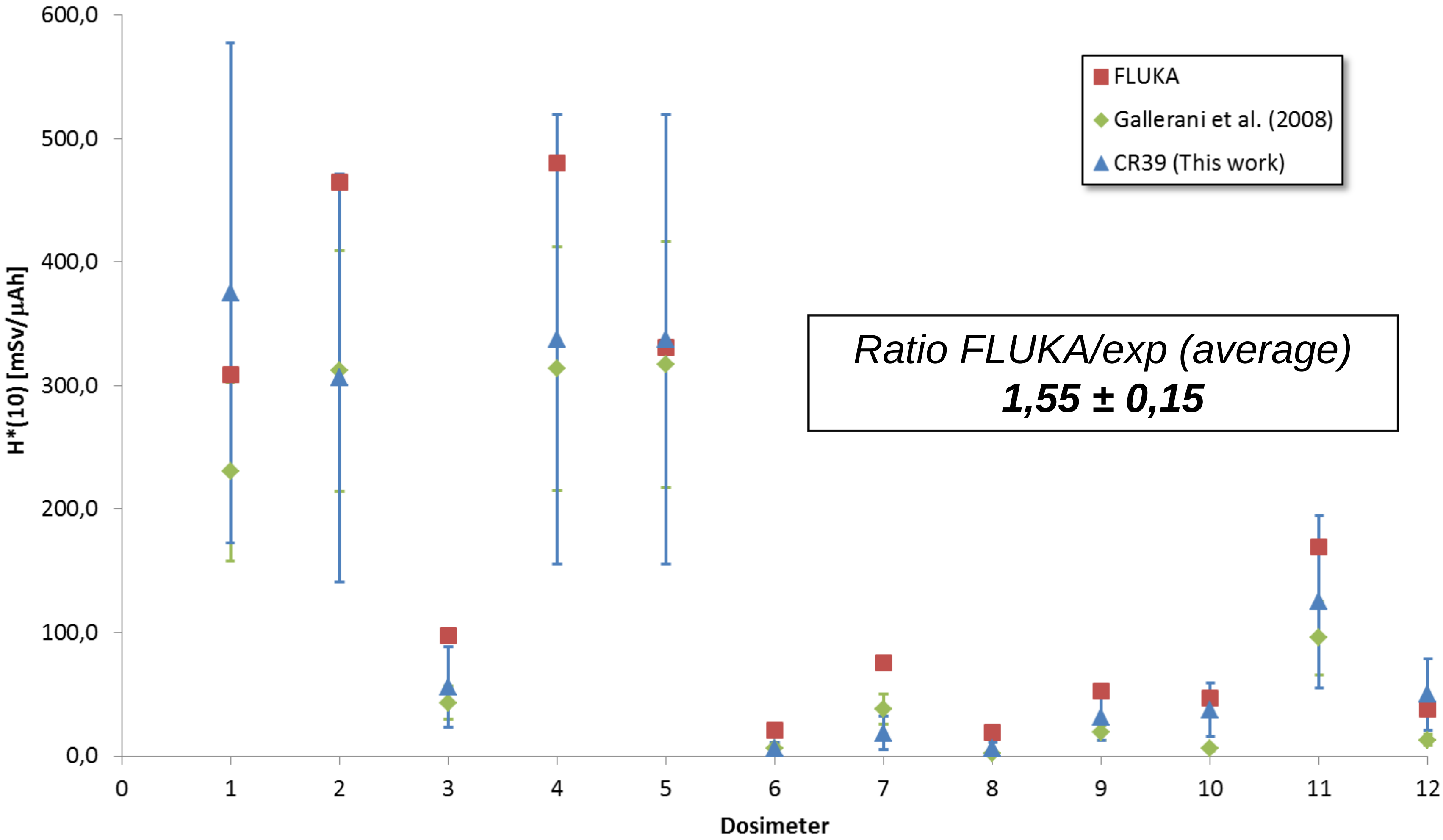
Simulations vs. Measurements



Ratio FLUKA/FHT752
0,99 ± 0,04

Note: Monte Carlo uncertainties have a stochastic nature (random uncertainties)

Simulations vs. Measurements

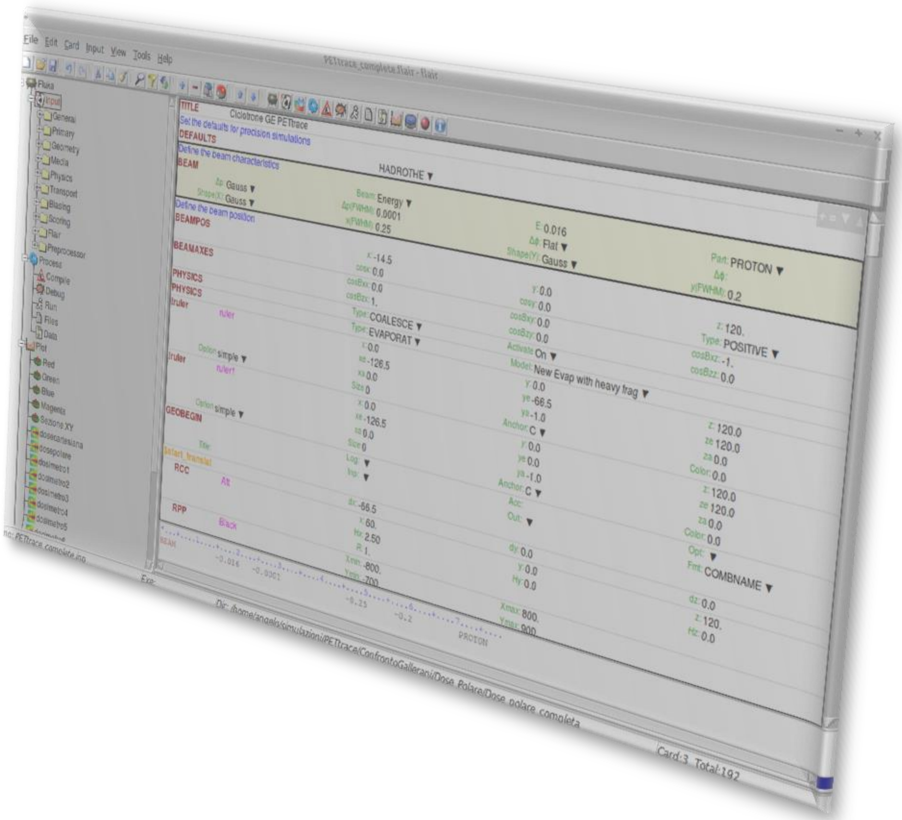


Ratio FLUKA/exp (average)
1,55 ± 0,15

Note: Monte Carlo uncertainties have a stochastic nature (random uncertainties)

Input Parameters

- ***DEFAULTS:*** NEW-DEFA.
  - Transport of electrons, positrons and photons enabled
  - Low energy neutron (≤20 MeV) transport on down to thermal energies included;
  - Delta ray production enabled
  - Heavy particle bremsstrahlung activated with explicit photon production above 1 MeV;
  - Heavy particle e+/e- pair production activated with full explicit production
  - … and more
- ***PHYSICS & TRANSPORT:***
  - Coalescence and Evaporation enabled;
  - EMFCUT (e & γ thresholds)
  - Protons transported down to 1 MeV;
  - FLUKAFIX set to 0.01 (not always)
  - Irradiation profile of 1h @ 1μA proton current.
- ***SCORING:***
  - ✓ DOSE-EQ from neutrons/photons (USRBIN)
  - ✓ Activation (RESNUCLE)
  - ✓ Proton/Neutron spectra (USRTRACK)
  - ✓ Proton current (USRBDX)
- ***PRIMARY:*** 10^9 primary particles simulated.



Production of radioisotopes

Prediction of ^{89}Zr production using the Monte Carlo code FLUKA

A. Infantino [a], G. Cicoria [b], D. Pancaldi [b], A. Ciarmatori [b], S. Boschi [c], S. Fanti [b], M. Marengo [b], D. Mostacci [a,*]

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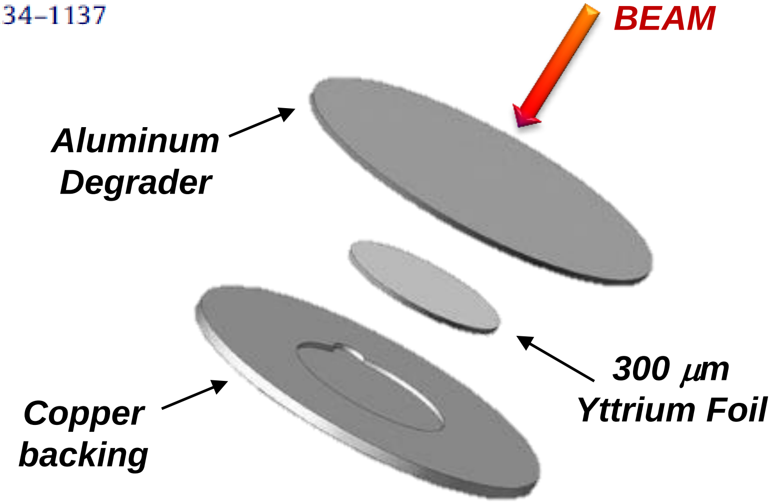
[c] *PET Radiopharmacy Unit, Department of Nuclear Medicine, University Hospital, S.Orsola—Malpighi, Bologna, Italy*

Applied Radiation and Isotopes 69 (2011) 1134–1137



Isotope	Y_{FLUKA} [MBq/μA]	*Y_{exp} [MBq/μA]	Y_{exp}/Y_{FLUKA}	*Y_{TALYS} [MBq/μA]	Y_{TALYS}/Y_{FLUKA}
Zr-89	2200 ± 200	2400 ± 200	1.09 ± 0.15	2300 ± 200	1.07 ± 0.16

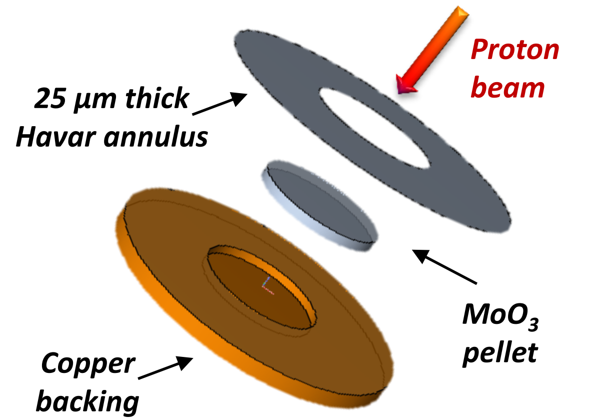
*Ref: A. Ciarmatori, G. Cicoria, D. Pancaldi, A. Infantino, S. Boschi, S. Fanti, M. Marengo. *Some experimental studies on ^{89}Zr production*. Radiochimica Acta, 99, 1-4, **2011**.

Production of ^{99m}Tc

Simulation setup

- 100 μm thick ^{nat}Mo foil
- 100 μm thick 99.01 % enriched ^{100}Mo foil
- 1 mm thick $^{nat}MoO_3$ pellet
- 1 mm thick 99.01 % enriched $^{100}MoO_3$ pellet (including impurities reported in the batch certificate)

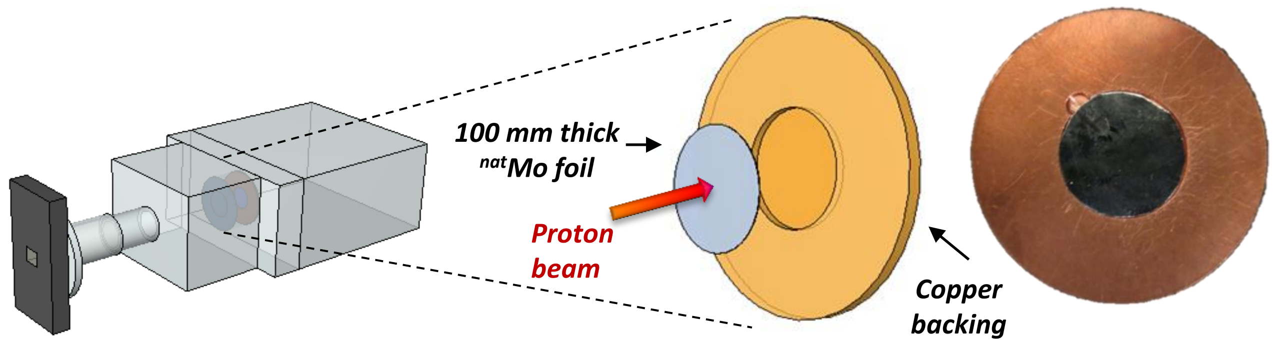
MATERIAL	Name: 98Mo	#	ρ: 10.22
Z: 42.	Am:	A: 98.	dE/dx: ▼
LOW-MAT	Mat: 98Mo ▼	LowMat: Mo. Natural Molybdenum (2), 296K ▼	
MATERIAL	Name: 99Mo	#	ρ: 10.22
Z: 42.	Am:	A: 99.	dE/dx: ▼
LOW-MAT	Mat: 99Mo ▼	LowMat: Mo. Natural Molybdenum (2), 296K ▼	
MATERIAL	Name: 100Mo	#	ρ: 10.22
Z: 42.	Am:	A: 100.	dE/dx: ▼
LOW-MAT	Mat: 100Mo ▼	LowMat: Mo. Natural Molybdenum (2), 296K ▼	
MATERIAL	Name: Monat	#	ρ: 10.22
Z:	Am:	A:	dE/dx: ▼
COMPOUND	Name: Monat ▼	Mix: Mass ▼	Elements: 7..9 ▼
f1: 14.84	M1: 92Mo ▼	f2: 9.25	M2: 94Mo ▼
f3: 15.92	M3: 95Mo ▼	f4: 16.68	M4: 96Mo ▼
f5: 9.55	M5: 97Mo ▼	f6: 24.13	M6: 98Mo ▼
f7: 9.63	M7: 100Mo ▼	f8:	M8: ▼
f9:	M9: ▼		



Target assembly for irradiation of MoO_3 pellets

Beam parameters:

$FWHM_x$=0.71 cm, $FWHM_y$=0.51 cm, $FWHM_{\Delta E}$=0.0785 MeV, $FWHM_{\Delta \Phi}$=0.001 mrad
On average 79.8 % of the proton current extracted hits the target material (~20 % on the collimator).



Solid target station and target assembly employed in preliminary tests: 100 μm thick foil of ^{nat}Mo

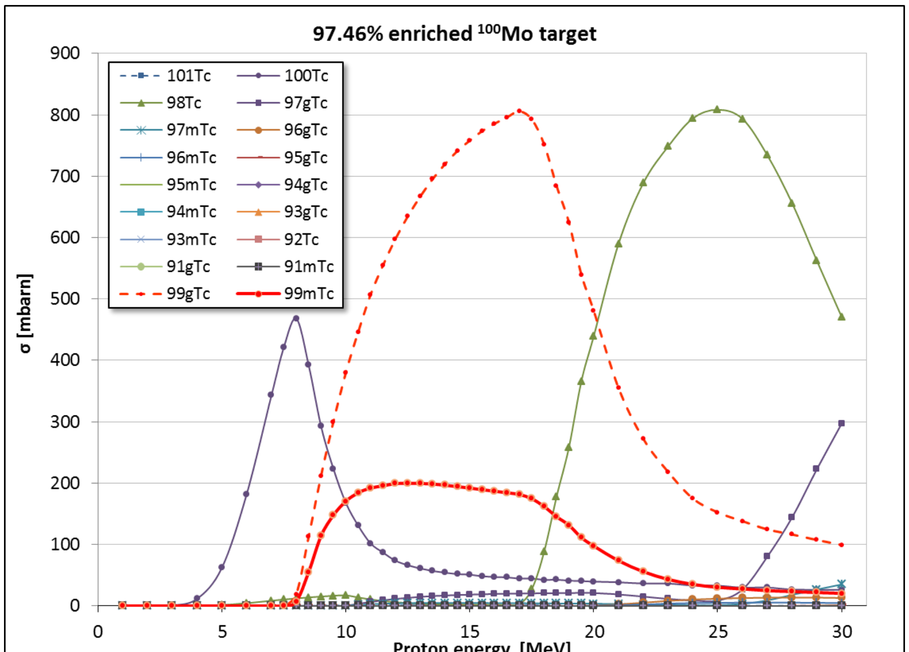
Production of ^{99m}Tc

WHAT(2) = flag for "patching" isomer production, <u>while waiting for a better production model</u>

<u>Source:</u> FLUKA manual 2011, RADDECAY card.

"Patching isomers" in FLUKA will simply split the production of a specific isotope in (half-half) between ground and isomeric state (if it exists)".

<u>Source:</u> http://www.fluka.org/web_archive/earchive/new-fluka-discuss/4688.html



$$A_{sat} = \int_{E_{out}}^{E_{in}} n_x \phi(E) \sigma_{xy}(E) dE$$

$^{100}Mo(p,2n)^{99m}Tc$

$^{98}Mo(p,\gamma)^{99m}Tc$

$$A_{sat} \cong \rho V N_A \left[\sum_{i=E_{out}}^{E_{in}} \phi(E_i) \left(\sum_{j=Ch_1}^{Ch_M} \sigma_j(E_i) \frac{\omega_j}{A_j} \right) \right]$$

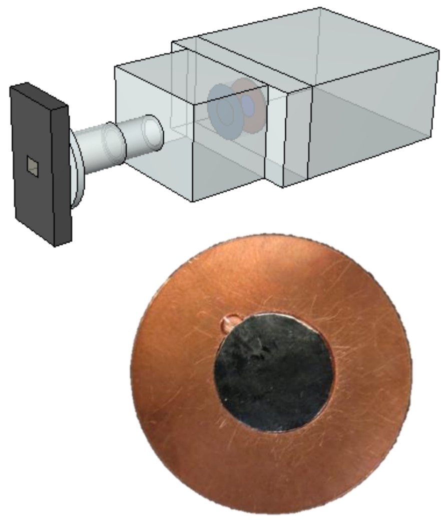
Useful to have the possibility to decide the branching ratio!

Production of ^{99m}Tc

PRELIMINARY RESULTS

	100 µm thick ^{nat}Mo foil experimental values	100 µm thick ^{nat}Mo foil Monte Carlo simulations*	Ratio Exp/FLUKA
Isotope	**Y_s (MBq/µA)**	**Y_s (MBq/µA)**	
Tc-99m	$(1.102 \pm 0.015)\cdot 10^2$	$(7.30499 \pm 0.00018)\cdot 10^1$	1.51 ± 0.02
Tc-97m	$(1.7 \pm 0.9)\cdot 10^2$	$(1.81584 \pm 0.00004)\cdot 10^2$	0.9 ± 0.5
Tc-96m	$(3.75 \pm 0.13)\cdot 10^2$	$(1.53227 \pm 0.00004)\cdot 10^2$	2.45 ± 0.08
Tc-96	$(3.88 \pm 0.04)\cdot 10^2$	$(2.84431 \pm 0.00003)\cdot 10^2$	1.364 ± 0.014
Tc-95m	$(1.66 \pm 0.02)\cdot 10^2$	$(1.63320 \pm 0.00004)\cdot 10^2$	1.016 ± 0.012
Tc-95	$(4.48 \pm 0.05)\cdot 10^2$	$(4.79743 \pm 0.00012)\cdot 10^2$	0.934 ± 0.010
Tc-94m	$(2.62 \pm 0.05)\cdot 10^2$	$(8.9225 \pm 0.0002)\cdot 10^1$	2.94 ± 0.06
Tc-94	$(1.60 \pm 0.02)\cdot 10^2$	$(4.25356 \pm 0.00010)\cdot 10^2$	0.376 ± 0.005
Tc-93m	$(1.12 \pm 0.04)\cdot 10^1$	$(1.75946 \pm 0.00004)\cdot 10^1$	0.64 ± 0.02
Tc-93	$(6.09 \pm 0.10)\cdot 10^1$	$(9.5201 \pm 0.0002)\cdot 10^1$	0.725 ± 0.011
Tc-92	$(2.9 \pm 0.6)\cdot 10^2$	$(2.27032 \pm 0.00005)\cdot 10^2$	1.3 ± 0.3
Nb-95	$(1.20 \pm 0.04)\cdot 10^1$	3.34993 ± 0.00005	3.58 ± 0.12
Nb-92m	3.96 ± 0.14	7.02240 ± 0.00017	0.56 ± 0.02
Mo-99	6.18 ± 0.10	2.95731 ± 0.00007	2.09 ± 0.03

**Calculated convoluting the proton flux with cross section (TALYS).*



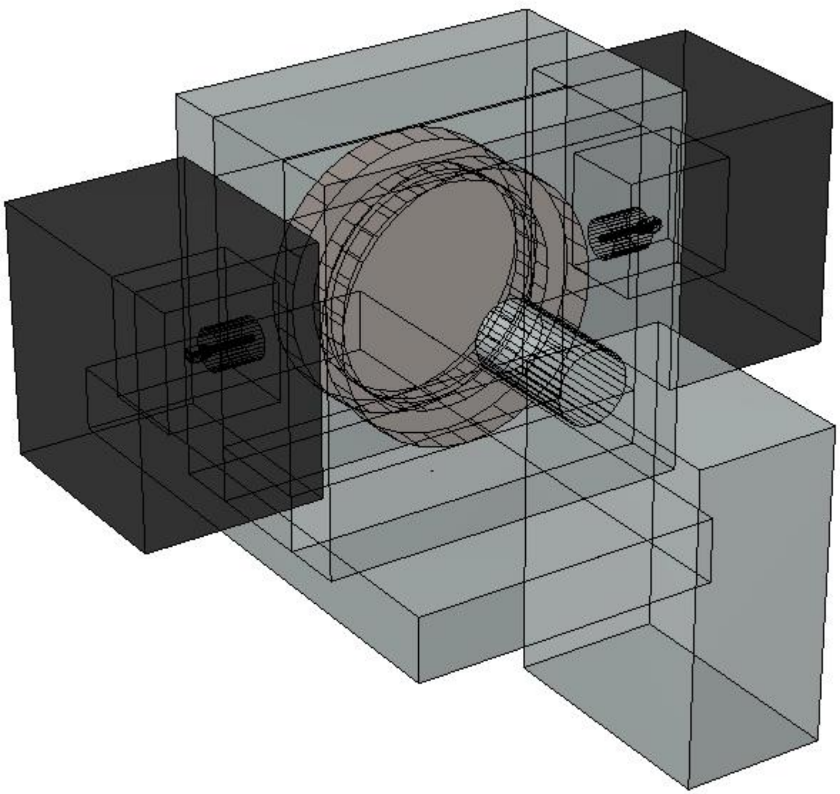
Target assembly: copper backing and 100µm thick natural-Mo foil.

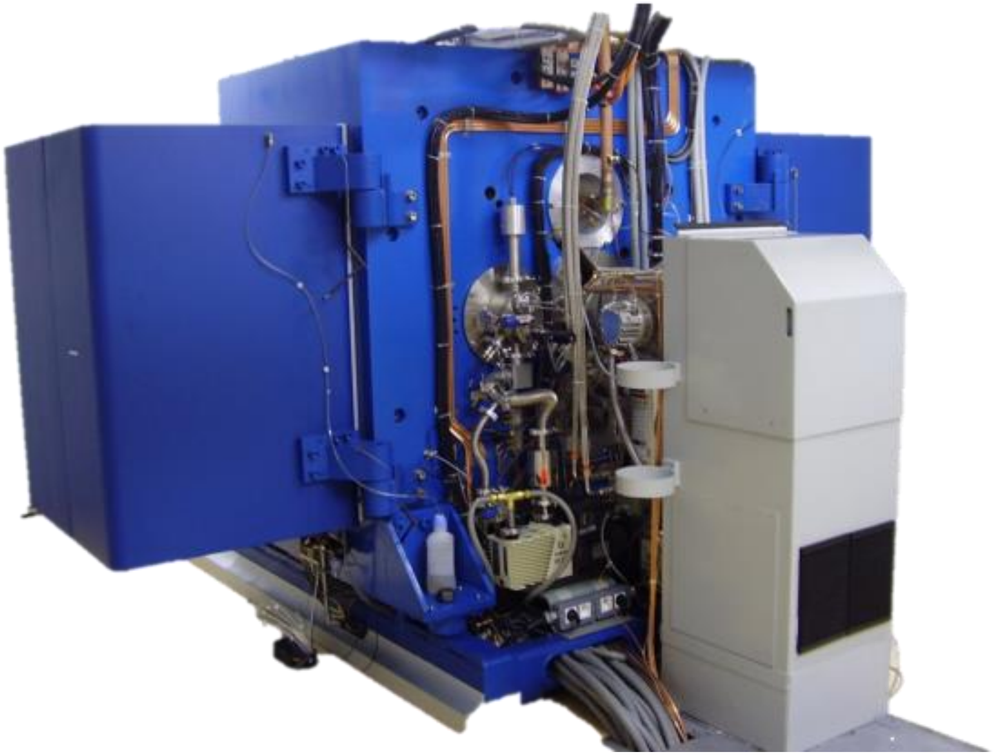
On Average:

0.664 ± 0.003

G. Lucconi, F. Carnaccini, E. Galloni, A. Infantino, F. Zagni, G. Cicoria, D. Pancaldi, M. Marengo. Development of a solid target for cyclotron production of 99mTc. Eur J Nuc Med Mol Imaging 41 (Suppl 2):S151-S705 **2014**.

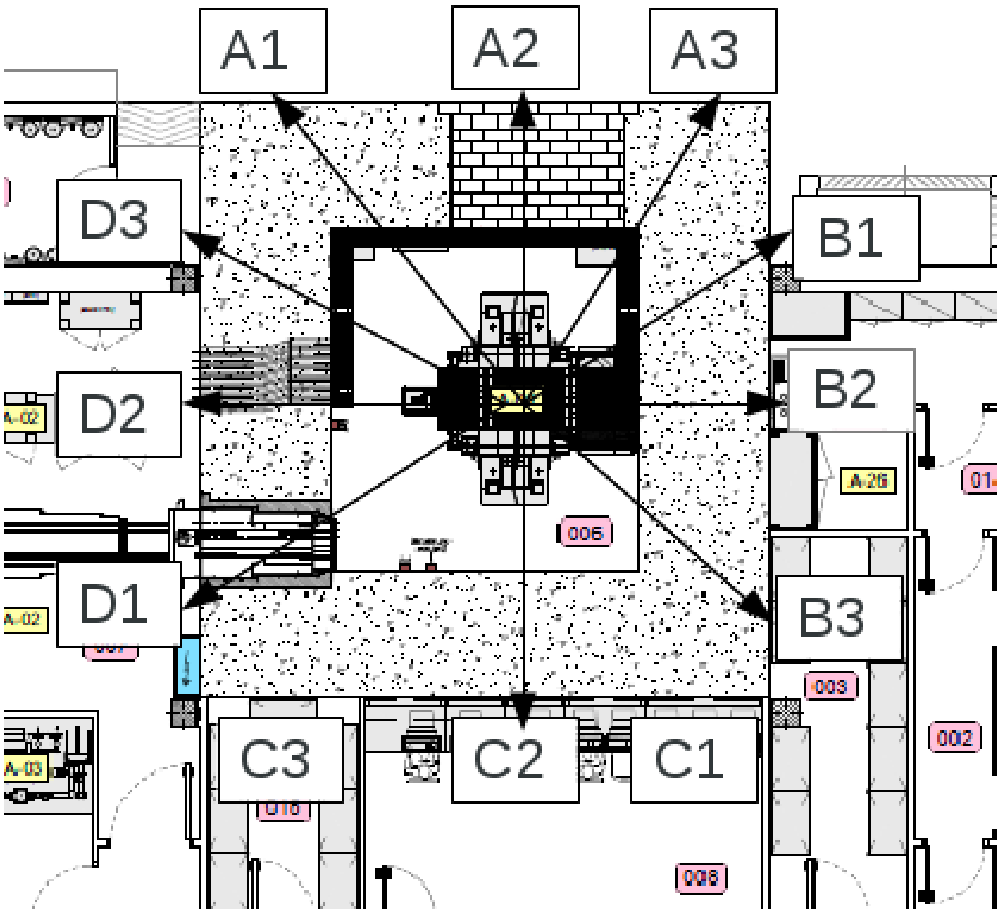
Planning of cyclotron facilities



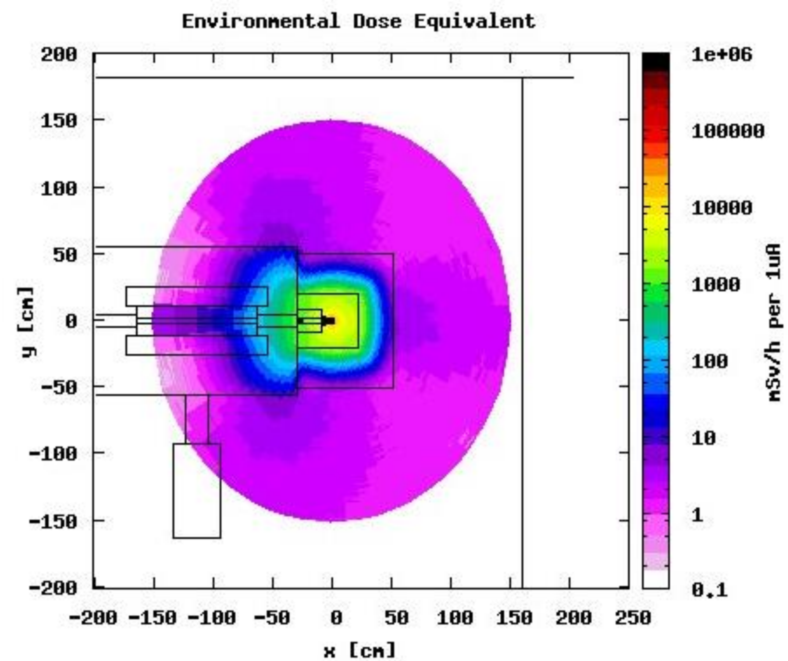


3D Monte Carlo model of the TR19 cyclotron
(ACSI, Richmond, Canada).

Planning of cyclotron facilities



Original technical drawing of the «Sacro Cuore – Don Calabria» Hospital PET facility. Negrar (VR), Italy.

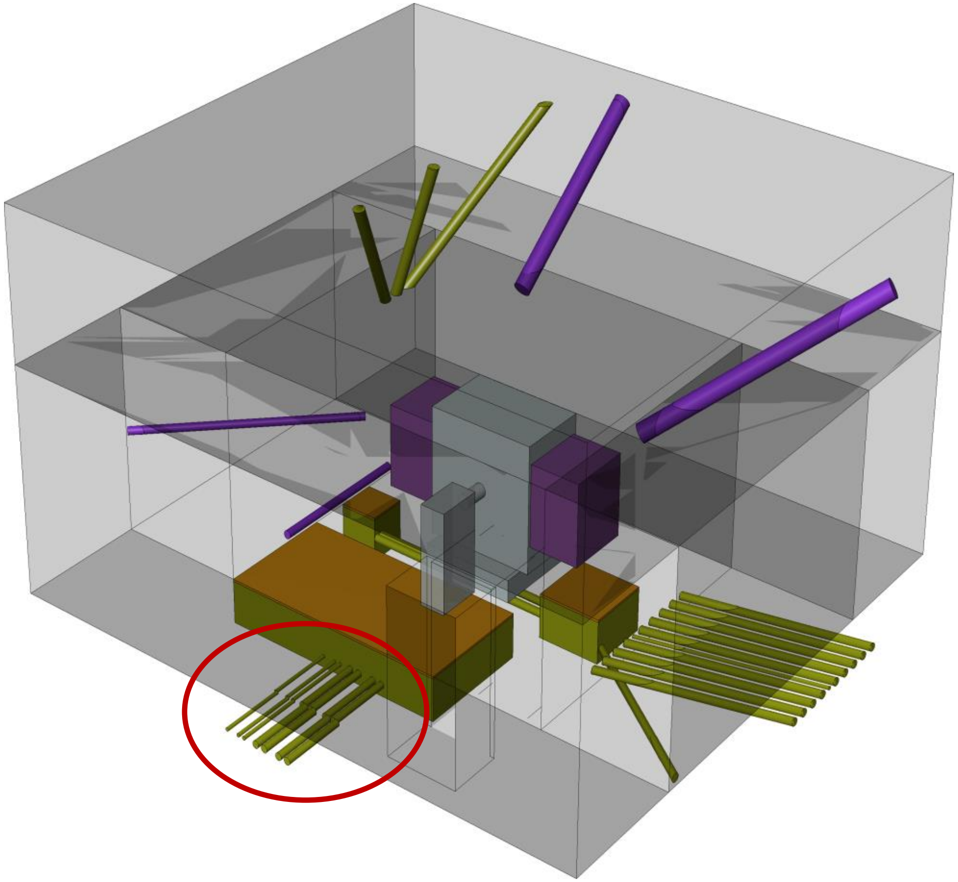


$$B = \frac{H_{lim}(\vartheta, d)}{H_{exp}(\vartheta, d)} \Rightarrow n_{TVL} = log_{10}\left(\frac{1}{B}\right)$$

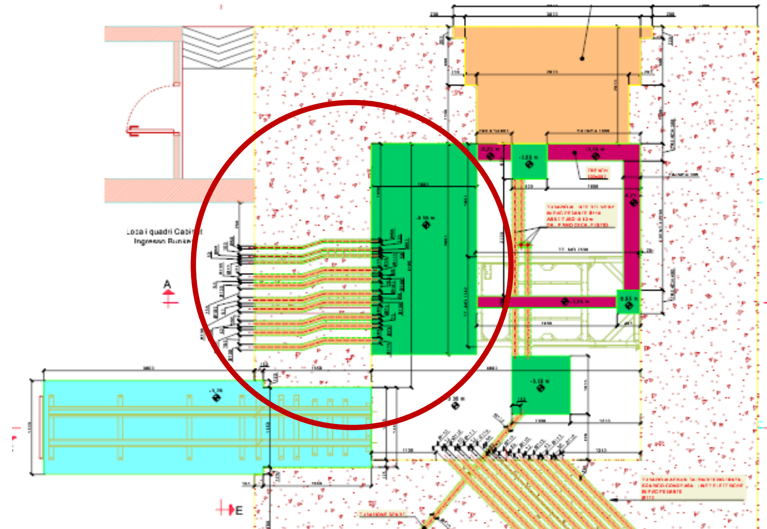
$$t_{bar} = TVL_1 + (n-1) \cdot TVL_e$$

(Approach based on NCRP 151)

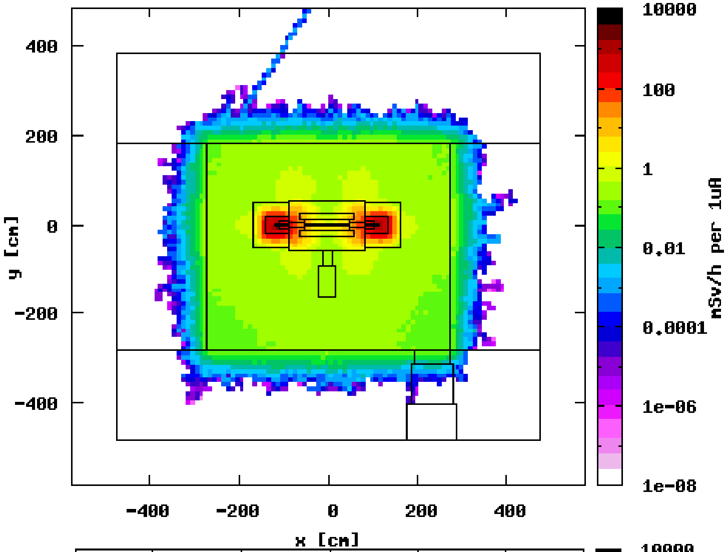
Planning of cyclotron facilities

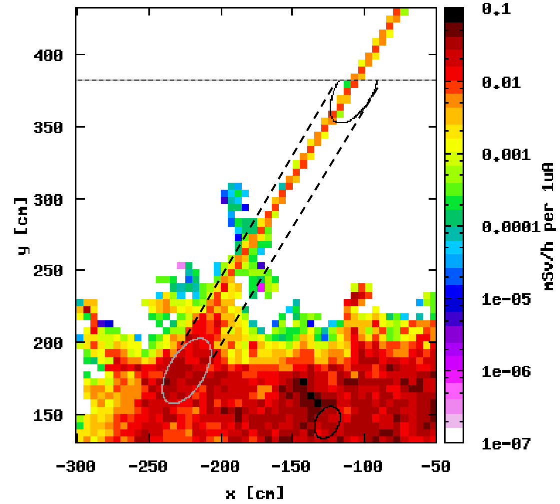


Detail of the floating floor, the walls and the ducts containing the delivery lines, the RF cables, the control cables, etc.

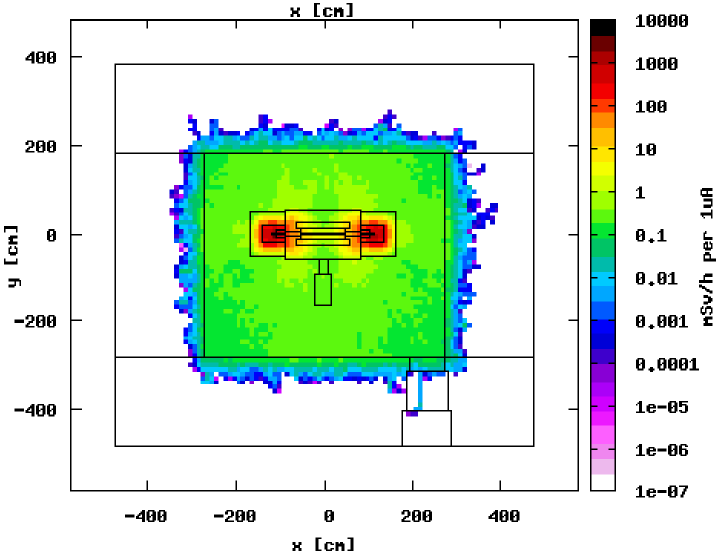


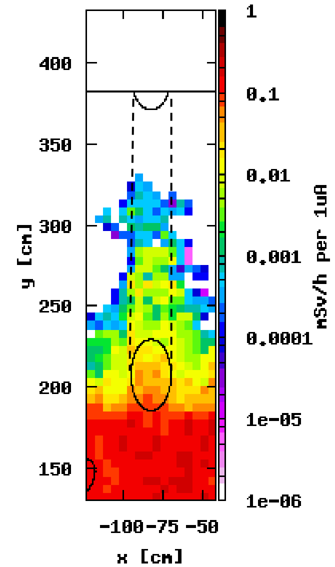
Planning of cyclotron facilities





First version of the duct design





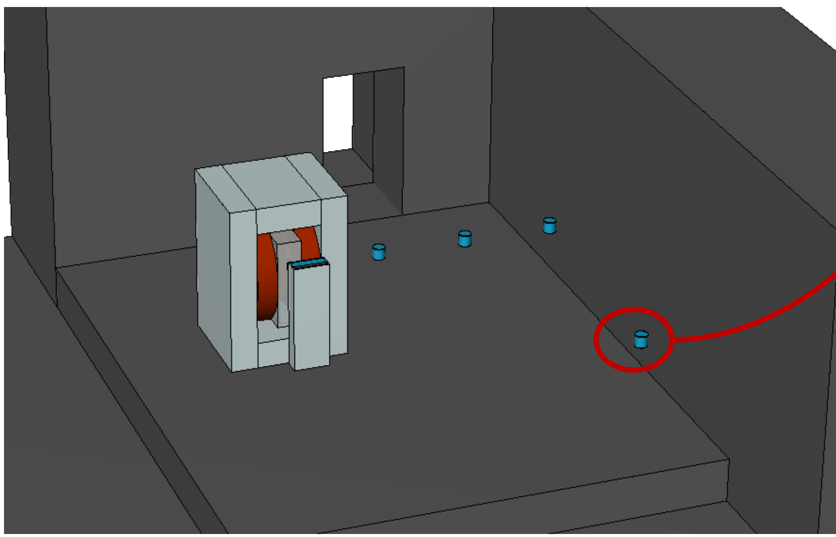
Second version of the optimized duct design

Activation of Air: ^{41}Ar

$^{40}Ar(n,\gamma)^{41}Ar$

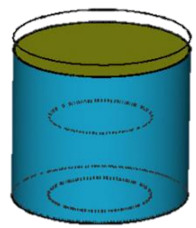
^{41}Ar ($t_{1/2}$ = 109.34 min) is produced by the activation of air due to secondary thermal neutron flux during irradiation.

$\sigma_{(n,\gamma)}$ ~ 660 mb @ 0.025 eV (ENDF/B-VII.0)



Monte Carlo model of one of the experimental setup adopted.

Simulation setup



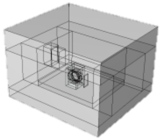
- ✓ *Direct assessment (RESNUCLE) and convolution Fluence-Cross Section*
  - ➢ **Total net air volume** (assessed using SimpleGeo, ~120 m^3);
  - ➢ **Marinelli beakers** (1000 cm^3) in different position;
  - ➢ **Volumes of 1 m^3** centered in the Marinelli's positions;

$$A_{sat} \cong \rho V \omega_x \frac{N_A}{A_x} N_P \sum_{i=260}^{1} F(E_i)\sigma_{xy}(E_i)\Delta E_i$$

"In the FLUKA neutron cross section library, the energy range up to 20 MeV is divided into 260 energy groups of approximately equal logarithmic width (31 of which are thermal)."

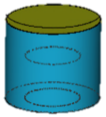
Source: FLUKA manual 2011

Activation of Air: ^{41}Ar



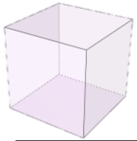
Total volume

C_{FLUKA} [Bq/dm³*μAh]	2.18 ± 0.11
C_{exp} [Bq/dm³*μAh]	0.784 ± 0.012
C_{FLUKA}/C_{exp}	***2.78 ± 0.15***



Marinelli beakers

Beaker	*FD/Exp*	*FC/Exp*
1	n/a	3.58 ± 0.18
2	n/a	3.51 ± 0.20
3	n/a	3.56 ± 0.19
4	n/a	3.36 ± 0.19



Volumes 1m³

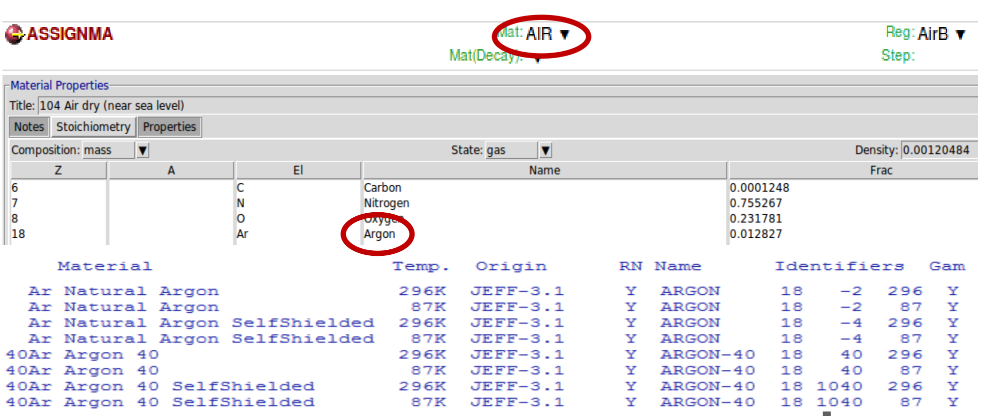
Beaker	*FD/Exp*	*FC/Exp*
1	7 ± 4	3.01 ± 0.14
2	3.5 ± 1.2	3.13 ± 0.16
3	3.0 ± 1.3	3.05 ± 0.14
4	2.6 ± 0.8	2.99 ± 0.16

Note: FD = FLUKA Direct assessment; FC = FLUKA Convolution fluence-CS

Open questions:

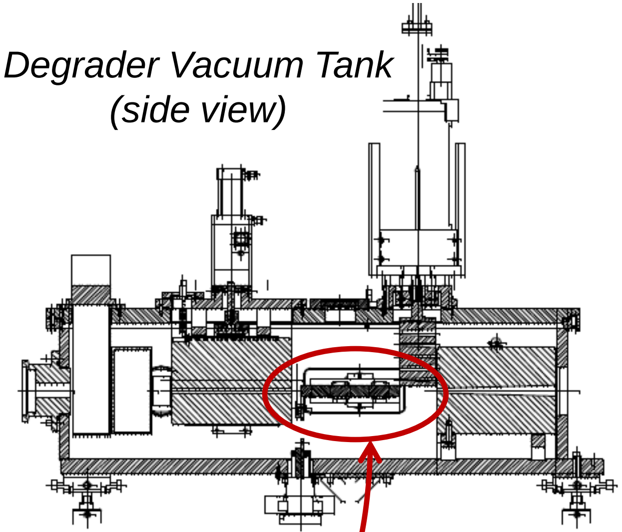
- What kind of CS are used for Argon selecting «AIR» as material?
- Self-Shielded case? (*Manual, 10.1.1 Possible artefacts*)

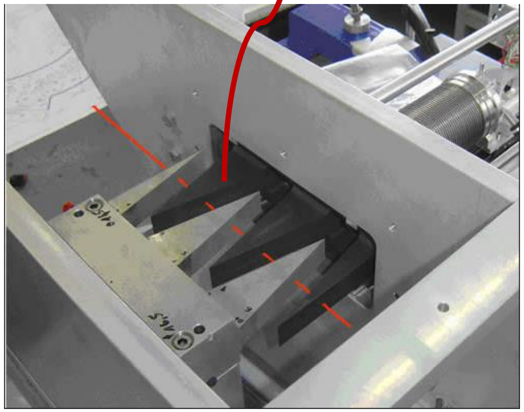
(ongoing testing…)



Proton Therapy: Degrader

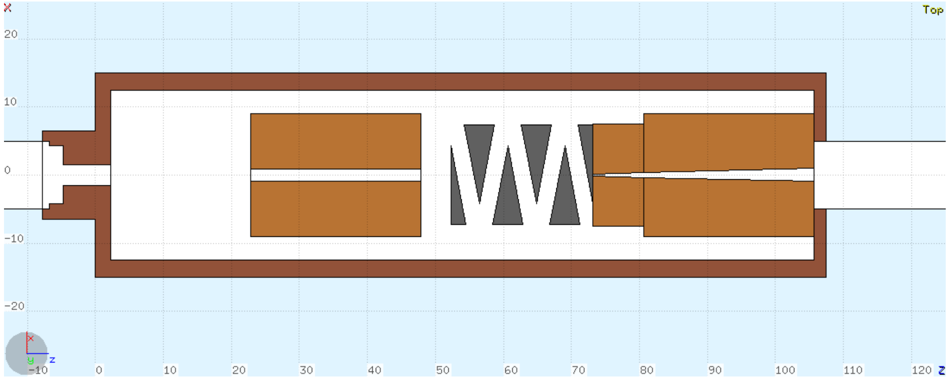
Degrader Vacuum Tank (side view)

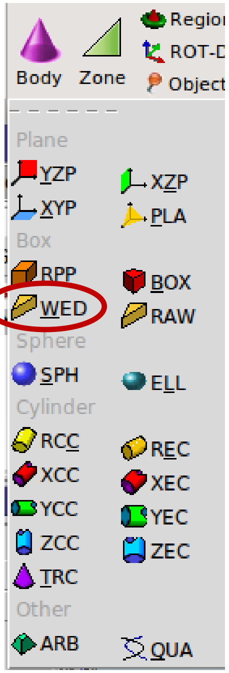




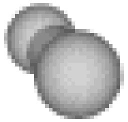
Detail of the wedges (graphite)

FLUKA MC model created using Flair (top view)

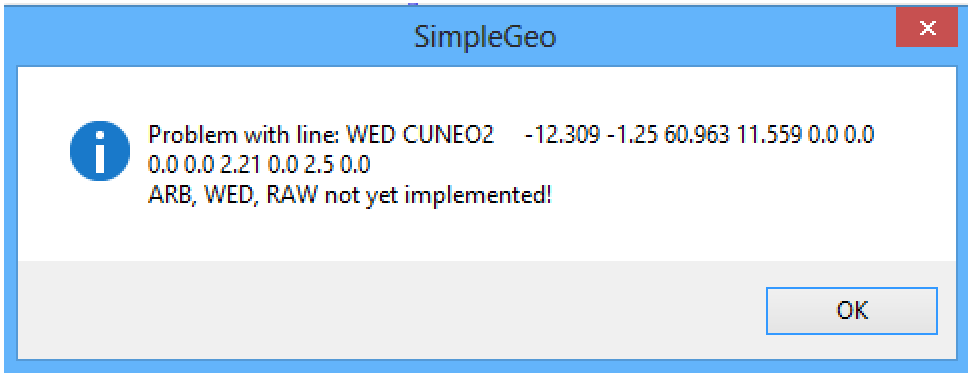


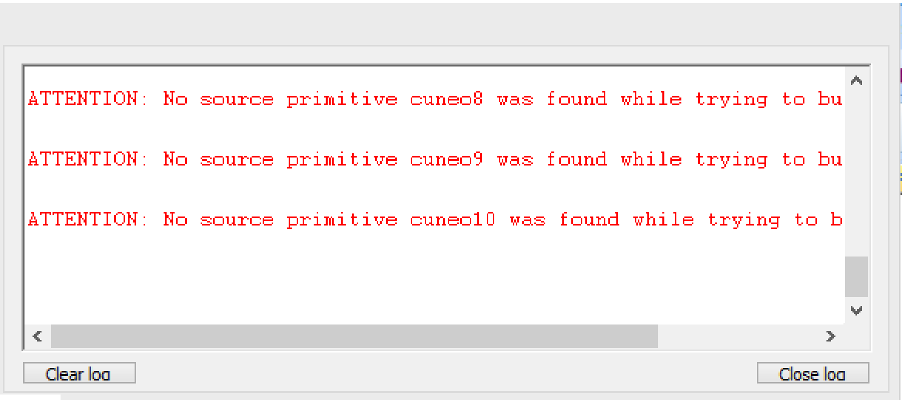


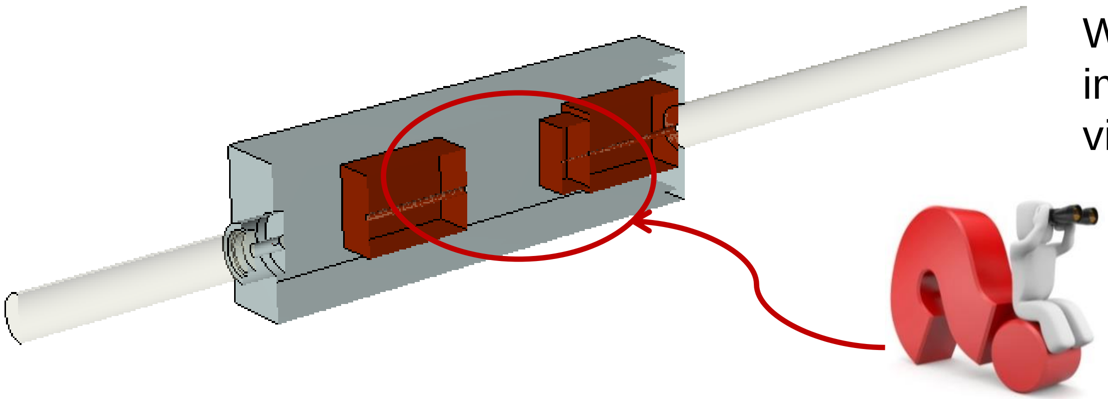
What happen if we try to export the model in <u>SimpleGeo</u>?



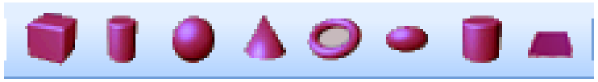
Proton Therapy: Degrader







Wedge and other Flair body are not (yet) implemented in SimpleGeo (and viceversa i.e. Torus)

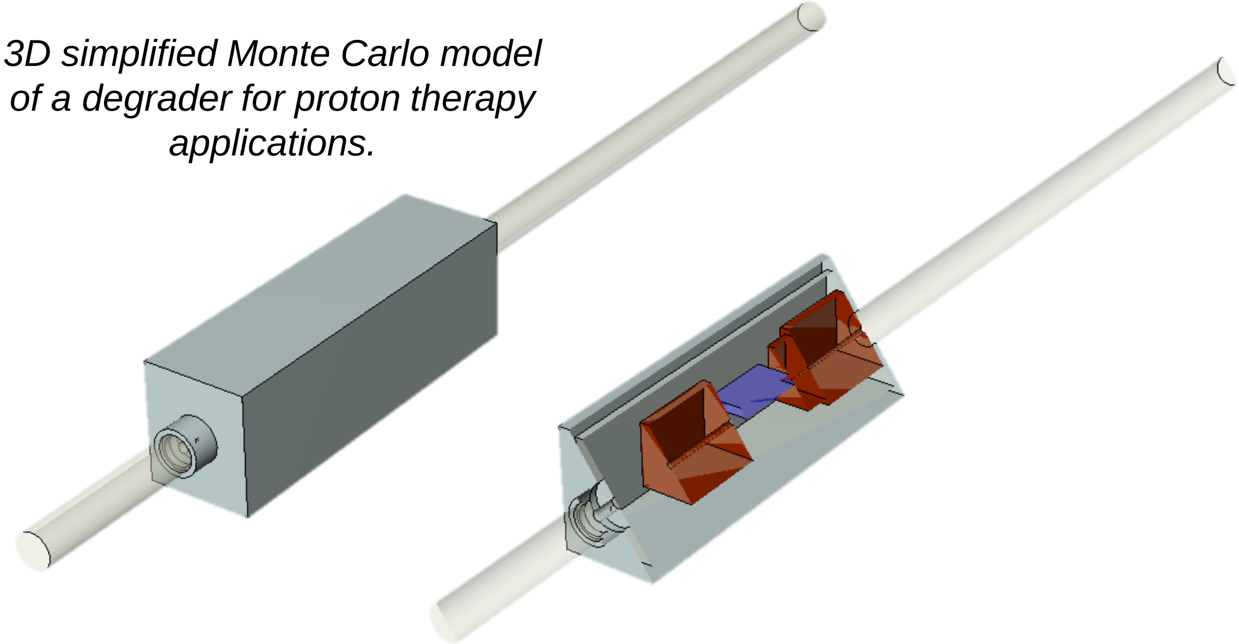


Other incompatibilities/problems found are:

- Import of a geometry with ROT-DEFINI/translat defined
- DaVis3D: import USRBIN with RΦZ mesh
- PIPSICAD3D: Problem in running PipsiCAD_SimpleGeo.linux interface (useful if directly implemented in Flair!!!)

Proton Therapy: Degrader

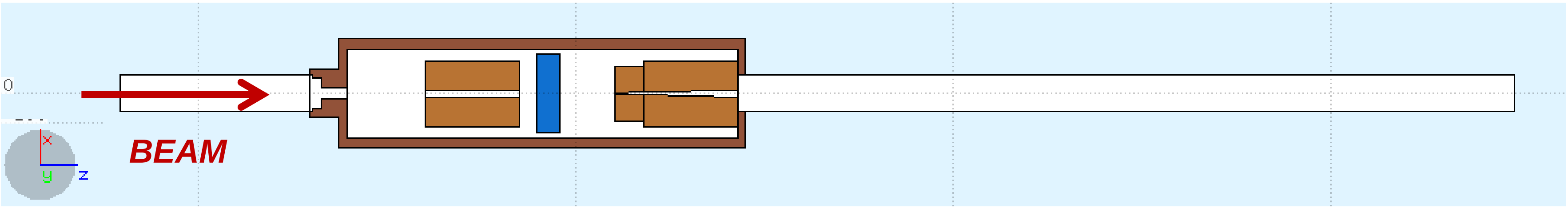
3D simplified Monte Carlo model of a degrader for proton therapy applications.



Wedge thickness modelled

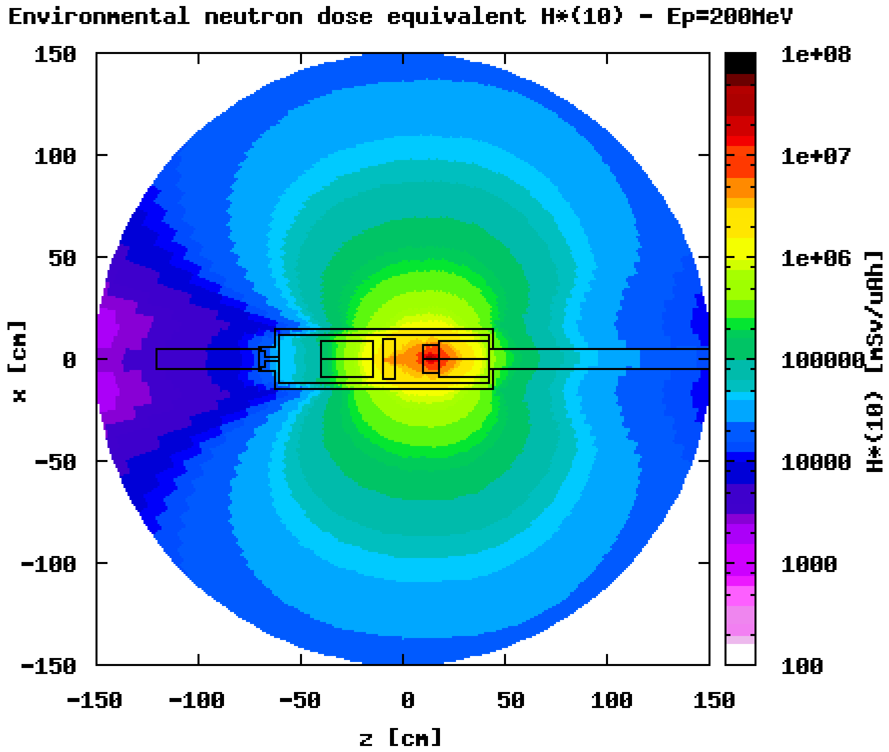
Outcoming Proton Energy [MeV]	Crossed wedge thickness [cm]*
70	16.691
120	13.452
140	11.816
180	8.304
200	5.910

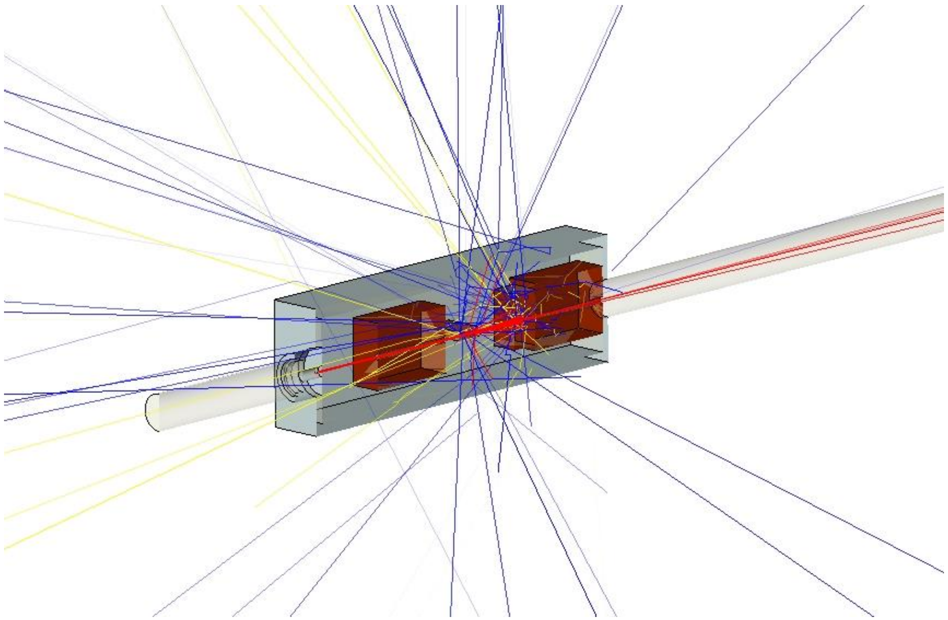
**Calculated using SRIM*



Section of the FLUKA Monte Carlo model of the degrader.

Proton Therapy: Degrader





Preliminary assessment of the neutron dose field around a proton therapy degrader: results obtained simulating an outcoming proton energy of 200 MeV.

***PIPSICAD 3D plugin**. Tracks indicate the different particle produced during irradiation: protons (red), electrons (green), photons, (yellow) and neutrons (blue). Fade of tracks enabled.*

Main problems encountered

- ***<u>Activation from protons below 20 MeV</u>***
  - *Some differences from experimental and simulated results in particular for liquid and gaseous materials*
  - *Thermal and Fluid-dynamics effects? Chemical reactions with target material/target body? (Real) Low Energy regime?*
  - *Isomers: accounting a correct production branching ratio*
- ***<u>Activation from neutrons below 20 MeV</u>***
  - *Production of ^{41}Ar. Simulations convergent in the different cases but:*
    - *Possible artefacts? Self-Shielding? Only a problem of the material definition?*
- ***<u>Compatibility Flair/SimpleGeo</u>***
  - *Body missing between the two programs (wedges, torus, etc)*
  - *Problems in running at best some plugins (importing RΦZ mesh, running of PipsiCAD_SimpleGeo.linux interface)*

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