Implementation and validation of an angular source for CT scan imaging in GATE 10

Thanks to David Sarrut
and Nils Krah

Gaëtan RAYMOND, PhD student

Anh Thu LÊ, PhD student

Workflow… without Siemens Healthineers technical data

GATE 10 | **Measurements** | **Collaborative study**

Monte-Carlo simulation | Experimental data | Comparison and optimisation

<u>Objective</u>: Improve GATE 10 simulation for CT scanner: Bowtie estimation

Material and methods (1)

HVL and CTDI values

X-ray spectrum generation

SpekPy v2.0

MC Opensource software based on GEANT4 toolkit (v 11.1) for simulations in medical imaging and radiotherapy.
OpenGATE collaboration · GitHub

GATE 10

Numpy

Data management
Analysis

python™

Material and methods (2)

Cylindrical PMMA Phantoms

CTDI Body (diameter = 32 cm)
CTDI Head (diameter = 16 cm)
14 cm Length

Ionization chamber DCT10
Active Length: 100 mm

+

CT scanner

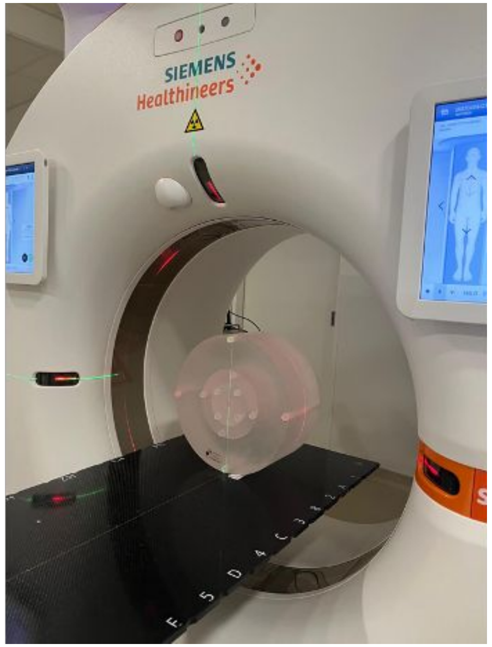
SOMATOM Go Sim

- range: 70 - 140 kVp
- Tin filter for high kV
- Dual Energy option

=

Measurements

$CTDI_{100}$: Average absorbed dose for a single axial acquisition (one rotation) inside 100 mm ionization chamber



All measurements were done at Gustave Roussy institute

Material and methods (3)

Half Value Layer (HVL)

HVL1 attenuation of 50%
HVL2 attenuation of 75%

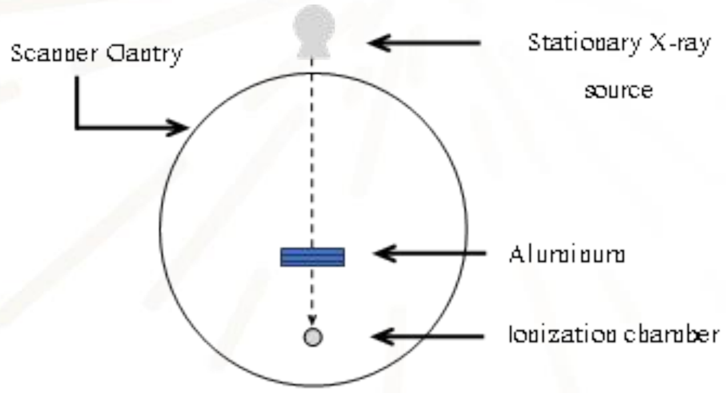
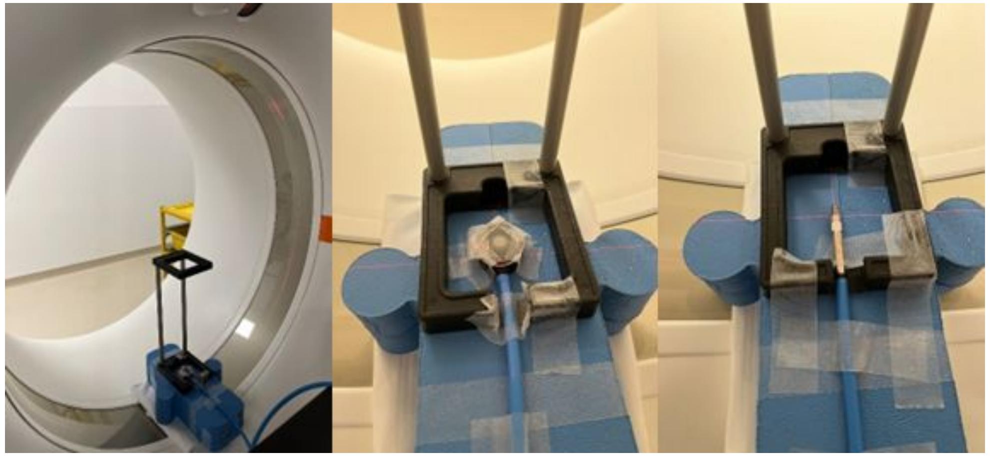


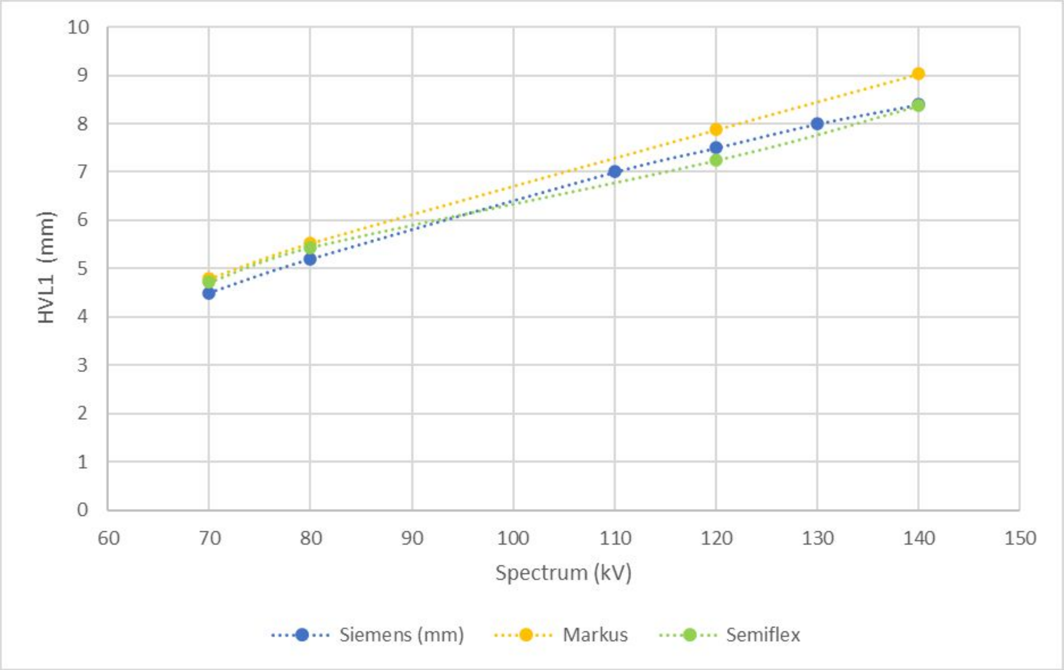
Diagram of the set up



HVL measurements set up with Markus and Semiflex chamber

Approximation and generation of X-ray energy spectrum

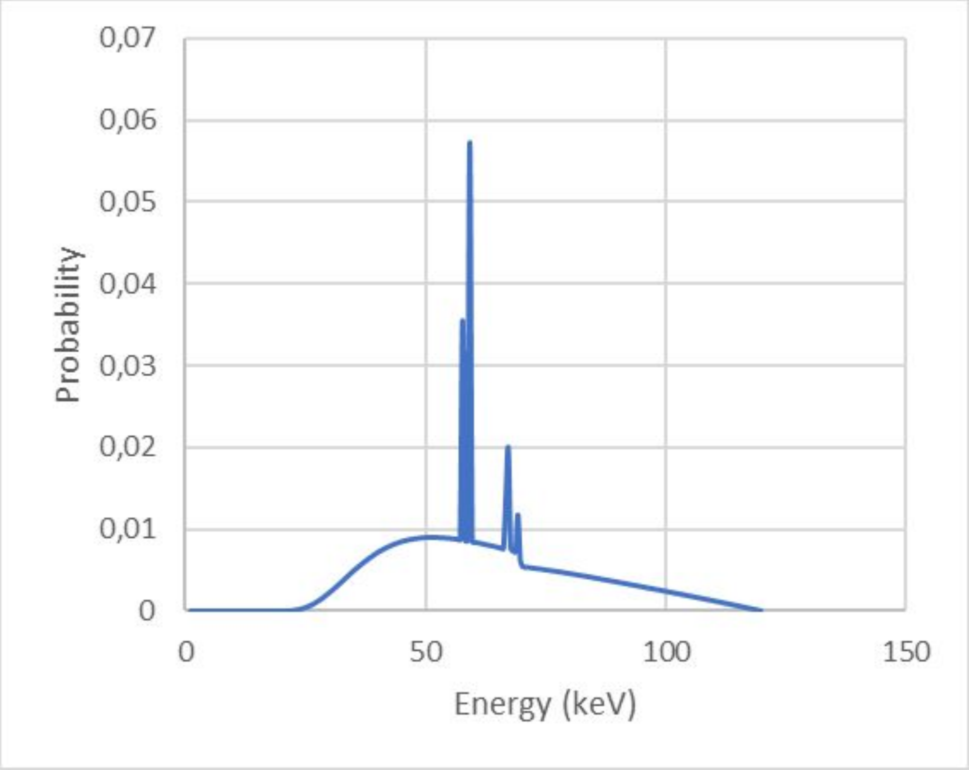
HVL1 depending on energy spectrum



Spectrum	HVL1 (mm)	HVL2 (mm)
120kV	7,24	15,08

➡ Semiflex ionization chamber closest results to Siemens data

Approximation and generation of X-ray energy spectrum



120 kVp X-ray spectrum (casim model)

SpekPy v2.0

MC based physics models available

Physics model	Comment	Target types	Photon dataset
casim	Default in SpekPy v2	W, Mo, Rh	PENELOPE
kqp	Highest accuracy model (slower)	W, Mo, Rh	PENELOPE

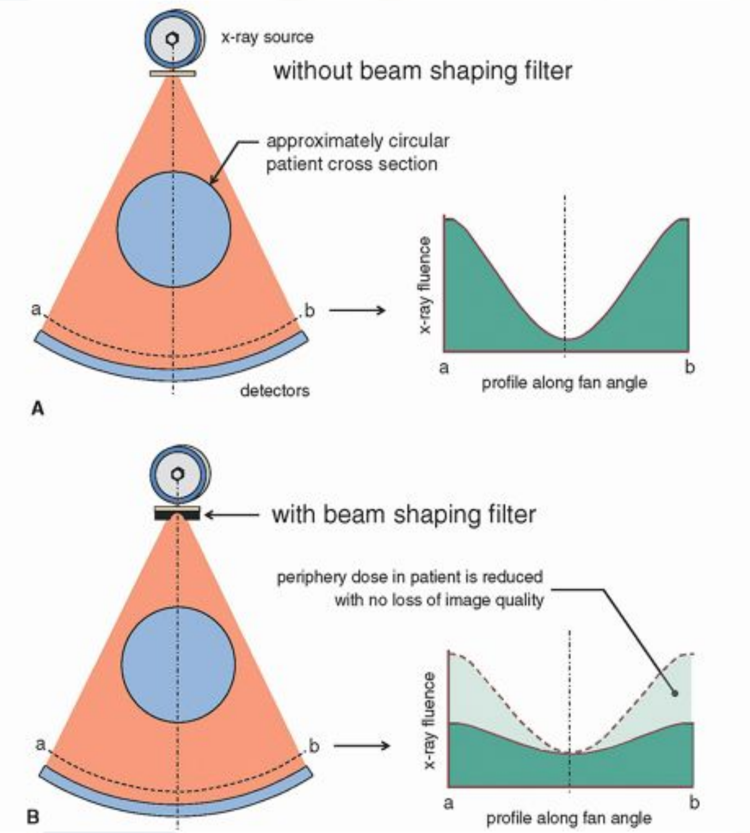
Python + GATE 10

Generating spectrum based on first HVL

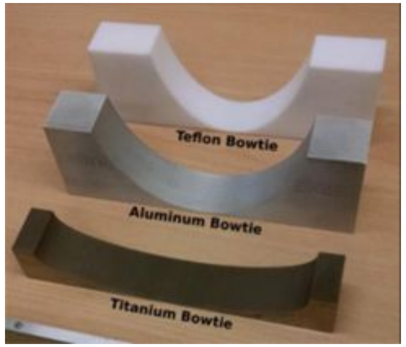
```
def spectrum_generation(kVp,theta_e_target):
    s=sp.Spek(kvp=kVp,th=theta_e_target)
    t=s.get_matl(matl='Al',hvl_matl='Al',hvl=7.5)
    s.filter('Air',0).filter('Al',t)
    data = s.get_spectrum(edges=False,flu=True,diff=True,sig=None)
    energy = data[0] * keV
```

Technical Note: SpekPy v2.0—a software toolkit for modeling x-ray tube spectra - Poludniowski - 2021 - Medical Physics - Wiley Online Library

CT components - bowtie filter



CT system without (A) and with (B) bowtie filter
figure from http://riadiologykey.com

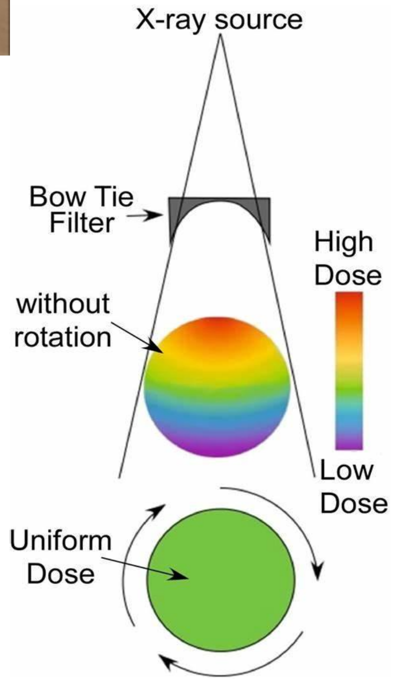


Description

Beam shaping filter with complex geometry and composition

Functionality

- Dose reduction at the periphery of the patient
- Equalization of the signal received by the detector
- Without loss of image quality



Smilowitz et al.(2018).Neuro-Oncology. 20. vi95-vi96. 10.1093/neuonc/noy148.398.

Bowtie filter properties from measurements

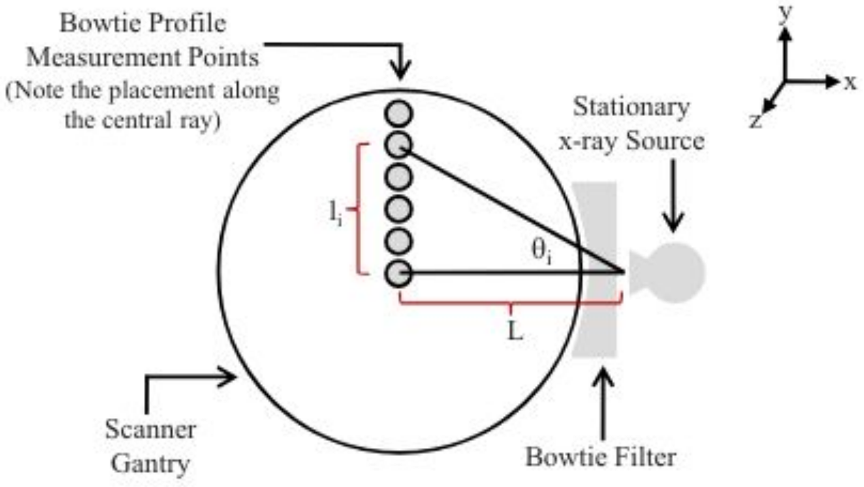


Diagram of bowtie profile measurements of attenuation across the fan beam
figure from Turner et al (2009), Med. Phy. 36 (6)

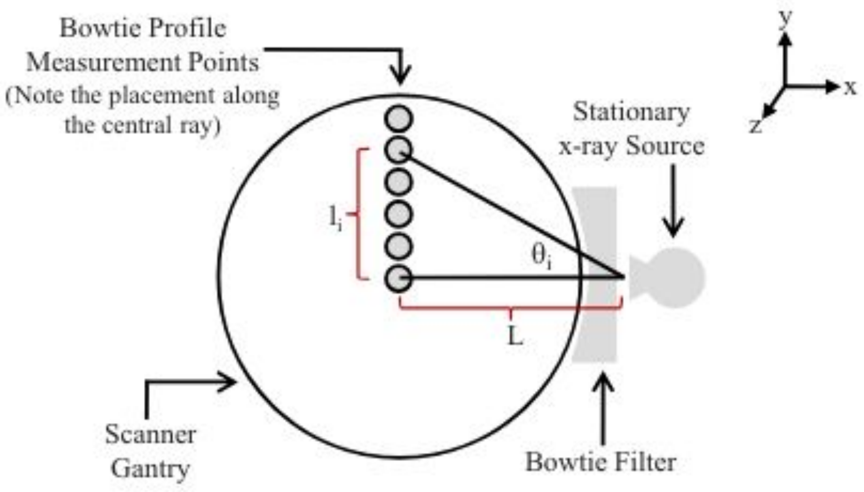
Semiflex Ionization Chamber 31021
Sensitive volume: 0.07 cm3

Measurements

- Every 5-10 mm in the +y direction, close to the isocenter (li <5 cm)
- Every 2-3 cm (li >5cm)
- Hypothesis: attenuation profile in the axial plane is symmetric about the axis passing through the source origin and the isocenter (θi=0°)

Turner et al (2009) Med. Phys. 36 (6)

Bowtie filter determination from measurements



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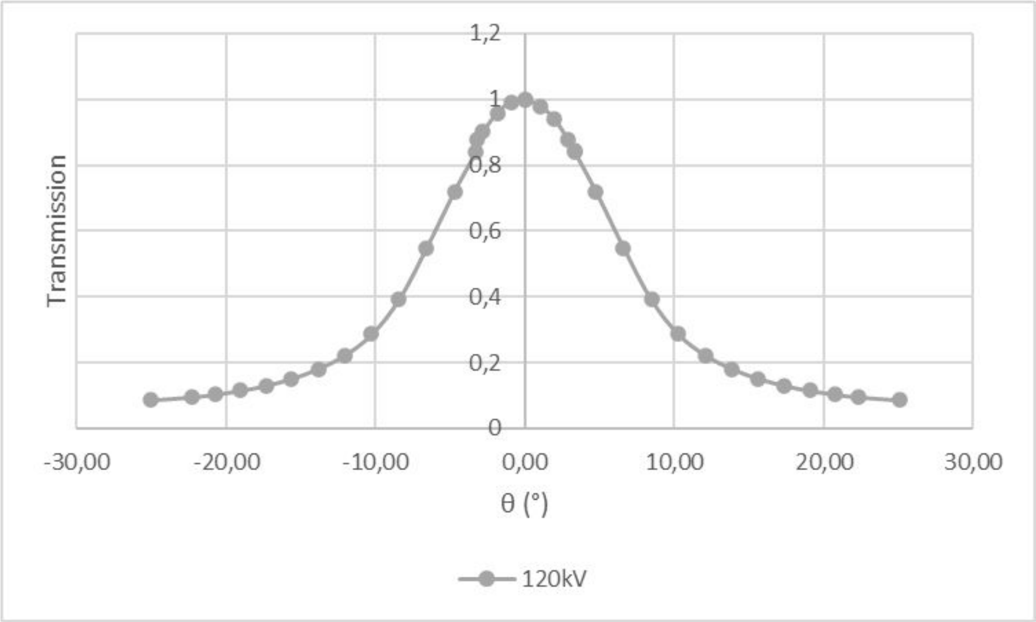


Angular distribution of transmission coefficients normalized with the measure at the isocenter

➡ Angular distribution directly integrated to GATE 10

Turner et al (2009) Med. Phys. 36 (6)

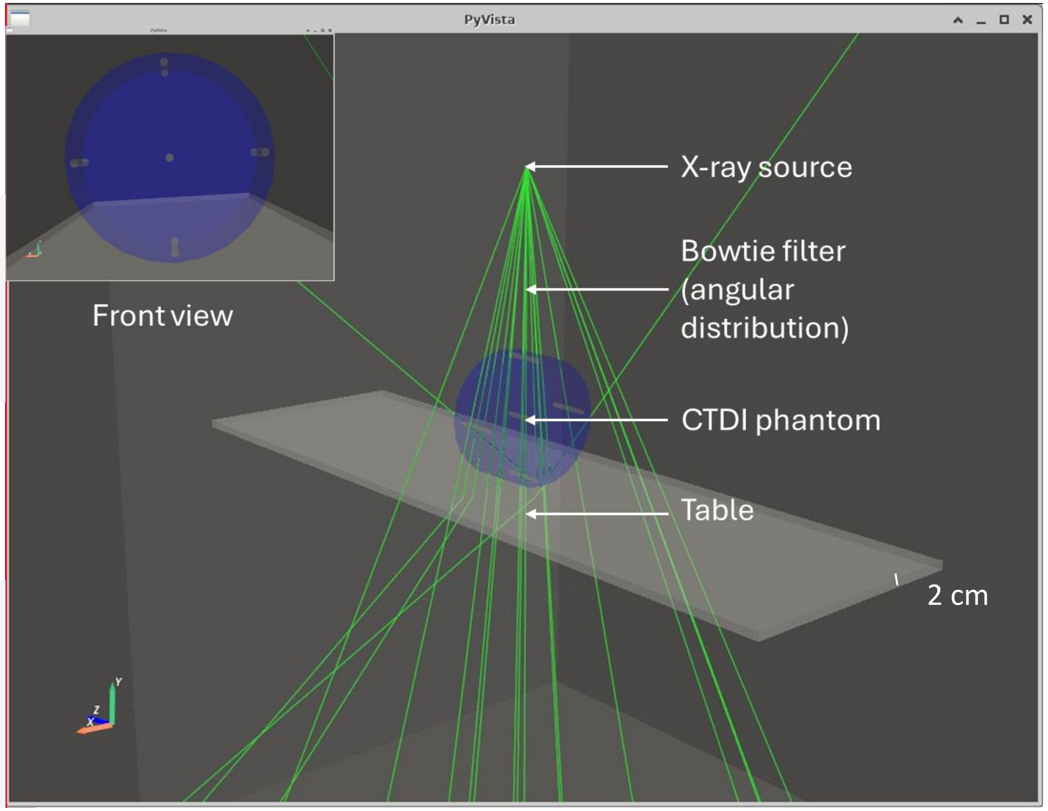
Implementation in GATE 10

Command lines:

```
source.direction.type = "histogram"
source.direction.histogram_theta_weight = [0, 1]
source.direction.histogram_theta_angle = [89.092 * deg, 90.908 * deg]
source.direction.histogram_phi_angle, source.direction.histogram_phi_weight =
fan_angle_conversion('data/bowtie_filter_attenuation_120kV.txt')
```

Cuts:

```
sim.physics_manager.physics_list_name = "G4EmStandardPhysics_option4"
sim.physics_manager.set_production_cut("world", "gamma", 0.1 * m)
sim.physics_manager.set_production_cut("world", "electron", 0.1 * m)
sim.physics_manager.set_production_cut("CTDI_ph", "gamma", 400 * um)
sim.physics_manager.set_production_cut("CTDI_ph", "electron", 200 * um)
```



R Kramer et al 2017 Phys. Med. Biol. 62 781

Preliminary results for CTDI body at 120 kVp

Position	CTDI 100 (normalized) σ < 5%				
Ratios (Centre ref)	GATE 10 Without Bowtie effect	Relative diff with measurements (%)	GATE 10 Bowtie effect	Relative diff with measurements (%)	Measurements
Centre	1.00	/	1.00	/	1.00
Top	3.74	84	1.65	-19	2.03
Left	3.45	78	1.60	-18	1.95
Bottom	2.78	70	1.30	-21	1.64
Right	3.43	78	1.58	-18	1.93

Collimation = 19.2 mm
1 rotation
1 second

Primaries: 41.10^6

Preliminary results for CTDI head at 120 kVp

Position	CTDI 100 (normalized) σ < 5%				
Ratios (Centre ref)	GATE 10 Without Bowtie effect	Relative diff with measurements (%)	GATE 10 Bowtie effect	Relative diff with measurements (%)	Measurements
Centre	1.00	/	1.00	/	1.00
Top	1.42	31	1.29	19	1.08
Left	1.28	25	1.14	12	1.02
Bottom	1.21	28	1.06	13	0.95
Right	1.28	23	1.12	8	1.04

Collimation = 19.2 mm
1 rotation
1 second

Primaries: 65.10^6

Conclusion and perspectives

- Bow Tie filter effect modelisation in GATE 10 (Merged)
- Better agreement between simulation and measurements for CTDI phantoms tests with Bow Tie effect
- Full Python workflow for CT scanner Monte Carlo dosimetry simulation

- Improve spectrum to match HVL1 and HVL2
- Extend study for other energy spectrum

Thanks !

Laboratoire de Physique de Clermont
Campus Universitaire des Cézeaux
4 Avenue Blaise Pascal
63178 Aubière Cedex, France

Gaëtan Raymond
PhD student

Mails : gaetan.raymond@clermont.in2p3.fr
gaetan.raymond@siemens-healthineers.com

Institut Gustave Roussy,
UMR 1030 Radiothérapie Moléculaire et Innovation Thérapeutique
114 rue Edouard Vaillant
94800 Villejuif, France

Anh Thu Lê
PhD student

Mail : Anhthu.LE@gustaveroussy.fr