

Biological dose estimation for proton and carbon ion treatment plans using the GATE platform

E. Salles, A. Pereda, Y. Ali, H. Fuchs, S. Jedidi, B. Knausl, D. Georg, J. M. Létang, E. Testa, M. Beuve and
L. Maigne*

Lydia.Maigne@clermont.in2p3.fr

Multi-scale approach

$$\text{BIOLOGICAL DOSE} = \text{RBE} \times \text{PHYSICAL DOSE}$$

Nano/micro scale

Predict biological effect at low scale



mMKM

(Kase et al., 2006)

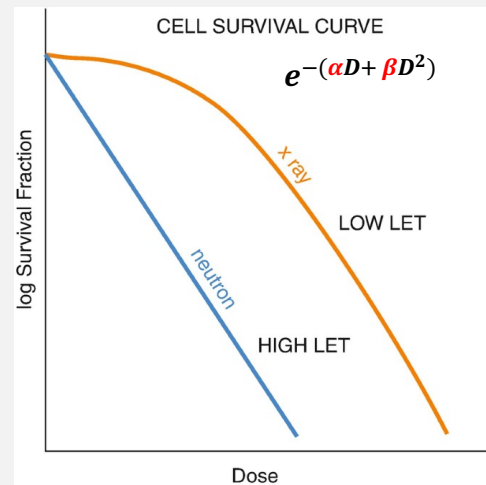


NanOx

(Cunha et al., 2017)

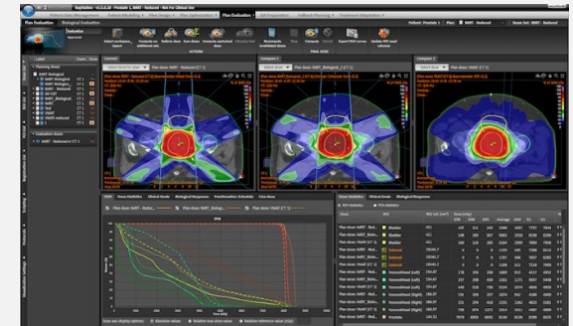
Cellular scale

Cell survival estimation



Macro scale

Treatment plan on patient



BioDoseActor - Version 1

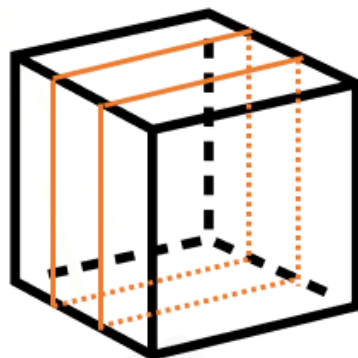
Water medium

$$\rho_{\text{voxel}} = \rho_{\text{water}}$$



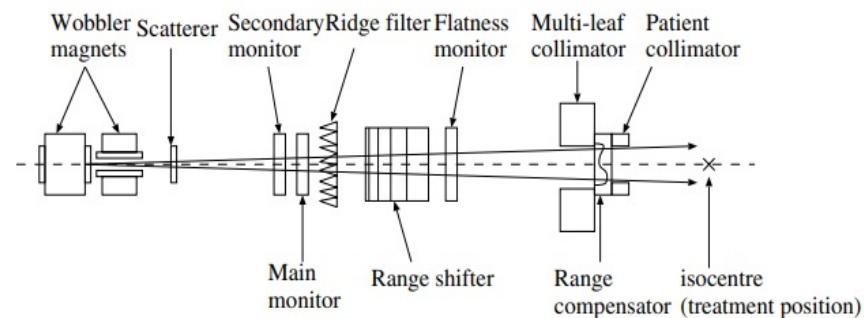
In slices

$\mu\text{m} - \text{mm}$



Passive modulation

HIBMC 320 MeV/u Carbon Ion Beam Line



Estimate of the Biological Dose in Hadrontherapy Using GATE

by  Yasmine Ali ¹  Caterina Monini ¹  Etienne Russeil ²  Jean Michel Létang ³  Etienne Testa ¹  Lydia Maigne ^{2,*}  and  Michael Beuve ¹ 

¹ Institut de Physique des 2 Infinis de Lyon, Université Claude Bernard Lyon 1, CNRS/IN2P3, 4 rue Enrico Fermi, 69622 Villeurbanne, France

² Laboratoire de Physique de Clermont, Université Clermont Auvergne, CNRS/IN2P3, 4 Avenue Blaise Pascal, 63178 Aubière, France

³ CREATIS, Université Claude Bernard Lyon 1, CNRS UMR5220, Inserm U1294, INSA-Lyon, Université Lyon 1, 69373 Lyon, France

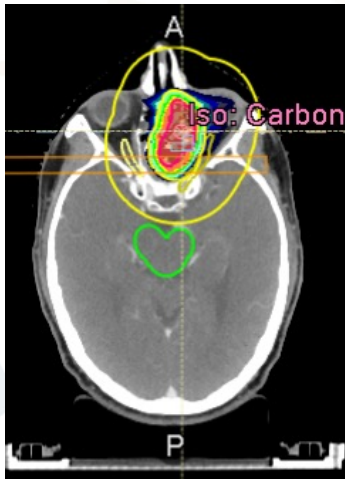
* Author to whom correspondence should be addressed.

Academic Editors: Dimitris Emfietzoglou and Sebastian Incerti

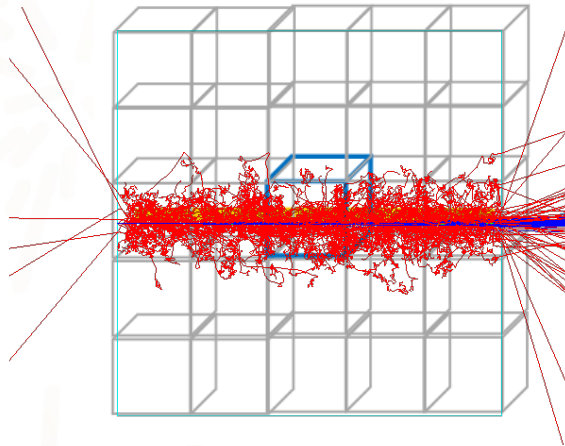
Cancers 2022, 14(7), 1667; <https://doi.org/10.3390/cancers14071667> 

BioDoseActor - Version 2

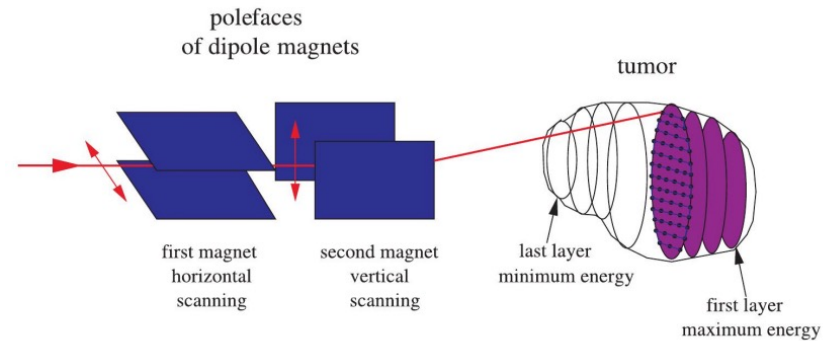
CT patient



Ion tracking in every voxel



Pencil beam scanning



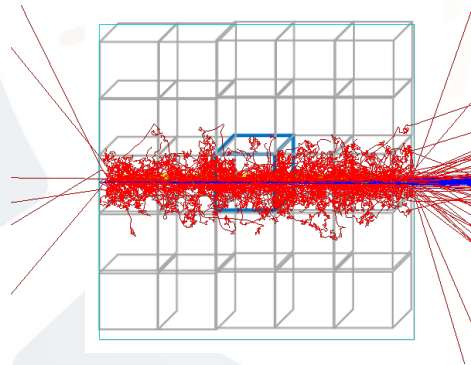
BioDoseActor - Process

Compatible with GATE 9.2

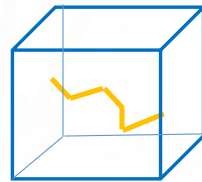
INITIALISATION

Linear interpolation of α , β coefficients

C++ map

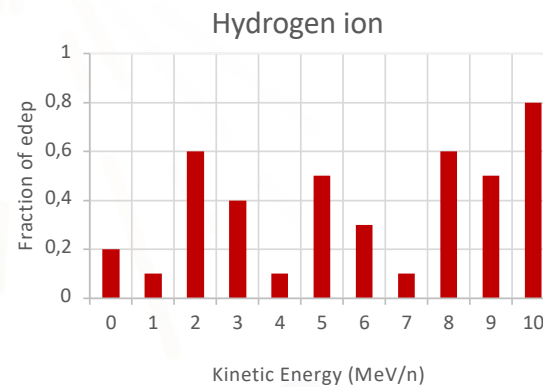


IN EVERY VOXEL



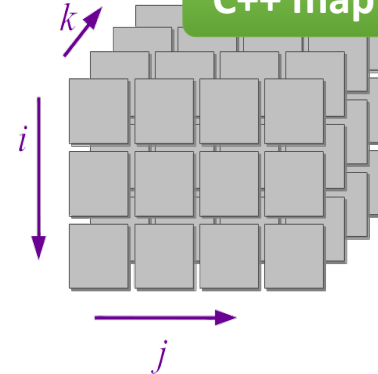
ENERGY ?

PARTICLE ?



DATA PROCESSING

C++ map



$$\alpha_{mix} = \sum_{k=1}^N f_k \alpha_k$$

$$\beta_{mix} = \sum_{k=1}^N f_k \sqrt{\beta_k}$$

OUTPUT

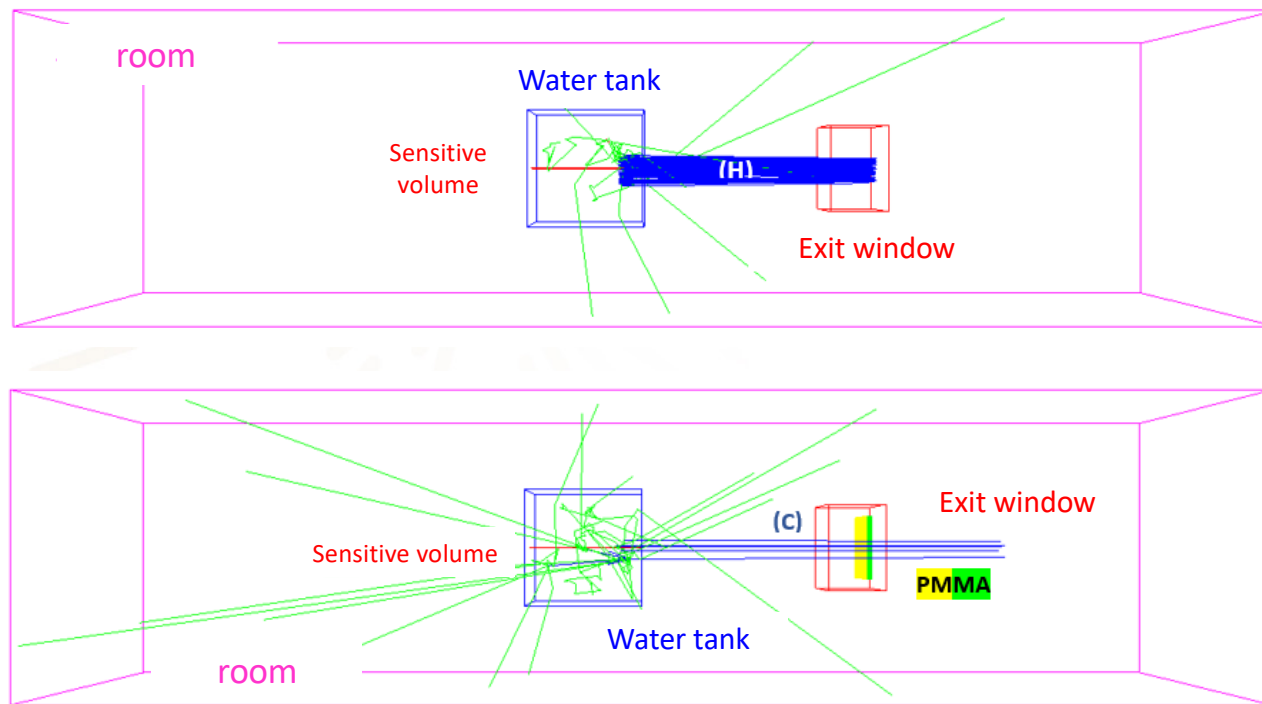
$$D_{bio} = f(\alpha_{mix}, \beta_{mix}, D_{phy})$$

MHD images





GATE_p & C-ion clinical PBS beams in water



Human Salivary Gland (HSG)

Pencil Beam Scanning

(H) : 95.9 – 113 MeV

(C) : 120 – 402 MeV/u

Water box: 40 x 40 x 40 cm³

Sensitive volume: 3 x 3 x 400 mm³

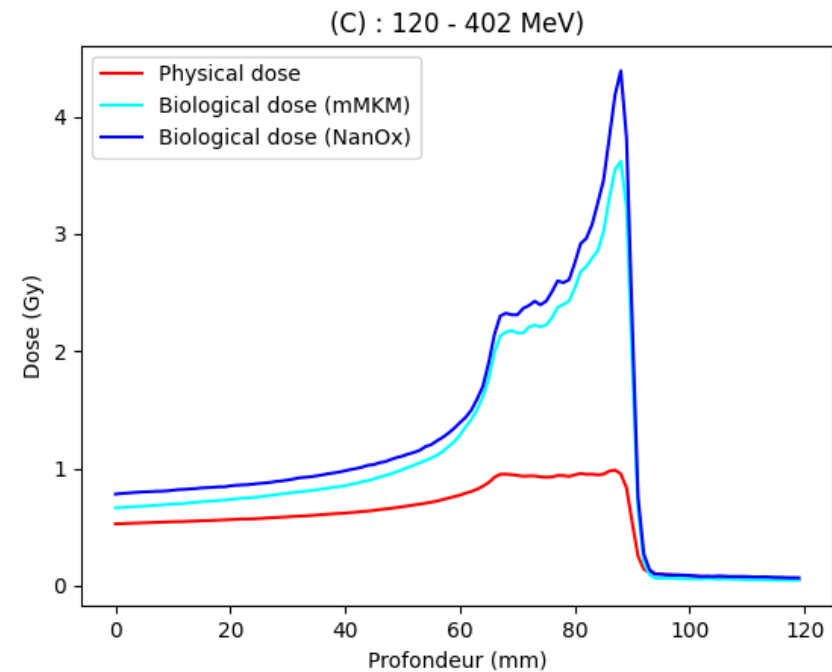
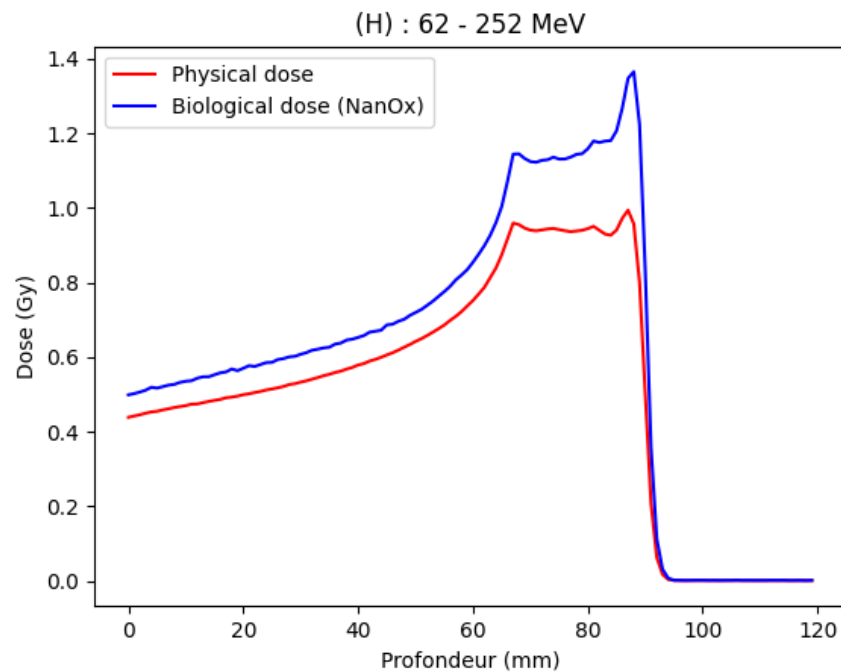
Voxel size: 1 1 1 mm³

PhysicsList:

(H) QGSP_BIC_EMZ

(C) Shielding_EMZ

Results

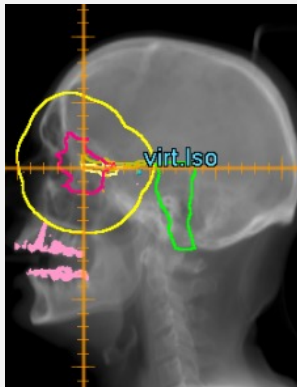


Clinical treatment plans

GTV : chordoma in sino-nasal region

Patient

Patient CT scan
HU calibration
RT plan



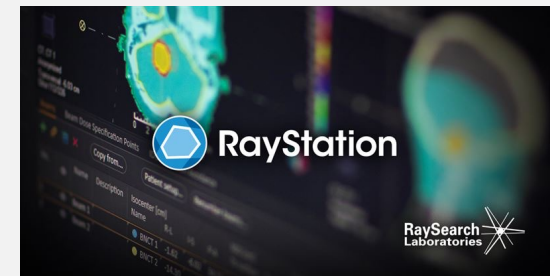
PBS beams

PBS beam description

```
#SPOT
1
#Energy
113
#x ; y ; weight
8.201 -88.519 3.63005e+06
```

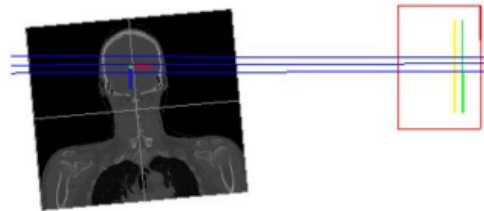
Dosimetry

Isodoses
DVH
Comparisons with RayStation

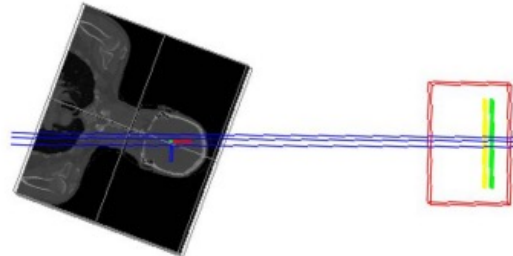


p & C-ion clinical PBS beams in patient

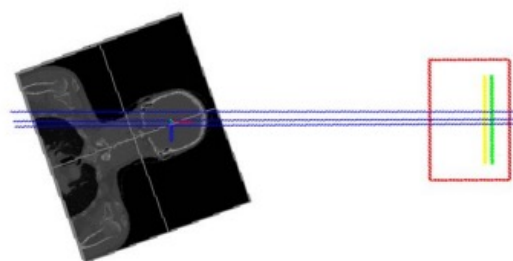
5°



250°



290°



CT : 50 x 50 x 44 cm³

Voxel size: 0.97 0.97 2 mm³

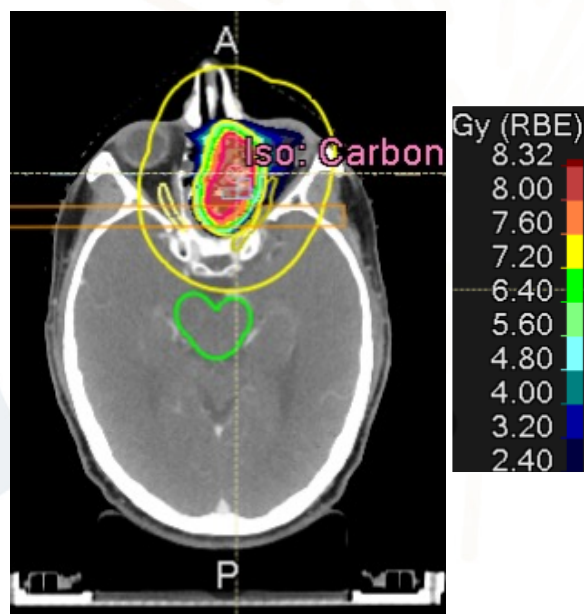
3 beams

8 Gy(RBE)

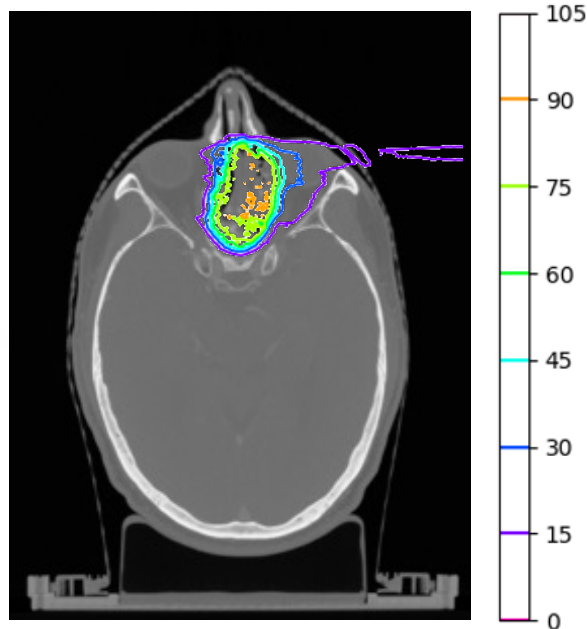
Human Salivary Gland (HSG)

Treatment plan : isodoses

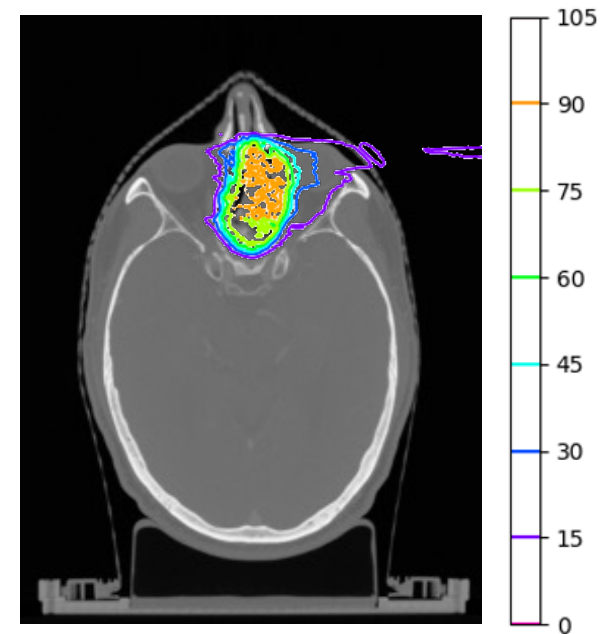
Raysearch



DoseActor



BioDoseActor
(mMKM)



Conclusion & perspectives

Results

- ✓ Promising BioDose actor version 2
- ✓ 2 biophysical models: mMKM and NanOx
- ✓ Validated for passive and active beams
- ✓ Voxel images
- ✓ Computing time equivalent to DoseActor

TO DO (short term)

- ✓ To be submitted to Med. Phys. Journal by Dec. 2022
- ✓ Available on Github after publication
 - ✓ GATE 9.2
 - ✓ GATE 10
- ✓ Extended comparisons with Raysearch outputs (LEMI):
 - ✓ Isodoses
 - ✓ DVH

Perspectives

Extended validation with:

- ✓ other models
- ✓ other GATE actors

