The GATE platform dedicated to hadrontherapy

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On behalf of the OpenGATE collaboration

Start in 2002 with 2 laboratories: EPFL & LPC

The collaboration & Partners

25 members: laboratories, clinics, and companies developing an open source platform

Spokesperson: Lydia Maigne

Technical coordinator: David Sarrut + Technical board

France

- U1101 Inserm, Brest
- IJCLab, Paris-Orsay
- **LPC –CNRS-IN2P3, Clermont-Ferrand**
- IPHC –CNRS-IN2P3, Strasbourg
- CPPM –CNRS-IN2P3, Marseille
- UMR5515 CNRS, CREATIS, Lyon
- **IP2I, CNRS-IN2P3, Lyon**
- BioMaps, CEA Paris-Saclay
- CRCT - U1037 Inserm, Toulouse
- LPSC – CNRS-IN2P3, Grenoble

Europe

- University of Julich, Germany
- University of applied Sciences, Aachen, Germany
- Medisip, Ghent University, Belgium
- Technological Educational Institute of Athens, Greece
- BioemTech, Athens, Greece
- **Medical University of Vienna, Wiener Neustadt, Austria**
- **MedAustron, Wiener Neustadt, Austria**
- **ACMIT, Wiener Neustadt, Austria**
- **Christie Medical Physics & Engineering, Manchester, UK**
- JPET collaboration, Jagiellonian University, Krakow, Poland
- Univ. of Patras, Dept of Med.Phys., Greece

Cross validation with the Geant4 collaboration
Susanna Guatelli & Sébastien Incerti

Elsewhere

- Memorial Sloan-Kettering Cancer Center, New York, USA
- UC Davis, Davis, USA
- Sogang University, Seoul, South Korea
- **NIRS, Chiba, Japan**

GATE-RTion

- **Goals**
  - Foster collaboration between clinical partners and laboratories to improve treatment delivery
  - Passive and PBS proton and carbon beams quality assurance
  - Clinical applications
  - Cross validation with TPS
- **« Frozen » version of GATE (v8.1 using Geant4.10.03.p03, QGSP_BIC_EMZ and SHIELDING_EMZ physics builder) and common tools for analysis**
- **3 clinical partners involved**
  - **The Centre Antoine Lacassagne** (Nice, France): IBA PT (Louvain-la-Neuve, Belgium) Synchro-Cyclotron (S2C2) machine with proton energy range 70-230 MeV
  - **The Christie NHS Foundation Trust** (Manchester, UK) has a Varian (Palo Alto, California, US) ProBeam (Cyclotron) machine with proton energy range 70-245 MeV
  - **MedAustron** (Wiener Neustadt, Austria) has a MAPTA (Synchrotron) machine with proton and carbon ion energy ranges of 60-250 MeV and 120-400 MeV/n, respectively

GATE-RTion – Project Paper (1)

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Technical Note

Technical Note: GATE-RTion: a GATE/Geant4 release for clinical applications in scanned ion beam therapy

L. Grevillot, D. J. Boersma, H Fuchs, A. Aitkenhead, A. Elia, M. Bolsa, C. Winterhalter, M. Vidal, S. Jan, U. Pietrzyk, L. Maigne, D. Sarrut

First published: 18 May 2020 | https://doi.org/10.1002/mp.14242 | Citations: 1

- **The Centre Antoine Lacassagne (Nice, France): Proton radiography images**
- Proton radiography images of the anthropomorphic human head phantom were compared
  - RayStation 6.0 TPS,
  - GATE-RT-ion
  - Lynx 2D scintillator (IBA Dosimetry, Schwarzenbrück, Germany)
  - Results compared with MyQA software (IBA Dosimetry, Schwarzenbrück, Germany) for comparisons
  - γ-index analysis (2%, 2mm) between GATE-RTion simulations and TPS, more than 95% of the pixels passed the test. This study demonstrates the feasibility of using GATE-RTion to predict proton radiography images

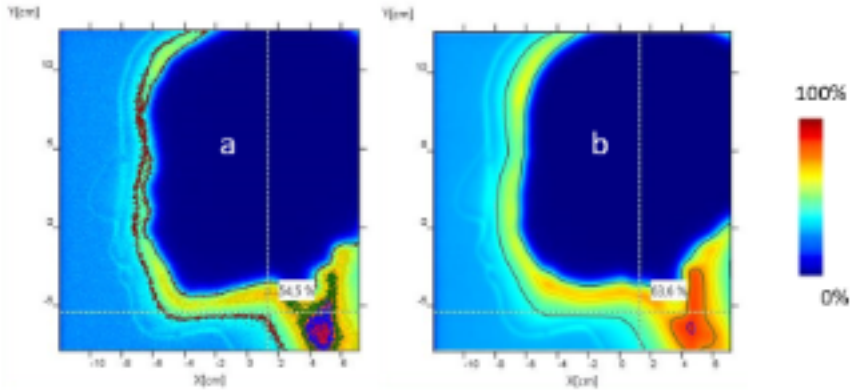

Figure 1: Relative comparison of a GATE dose simulation (a) and a 2D Lynx measurement (b) acquired at the same downstream position for an anthropomorphic phantom. An arbitrary dose scale is used between 100% (red) and 0% (dark blue) - same for both relative dose distributions.

GATE-RTion – Project Paper (2)

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Technical Note

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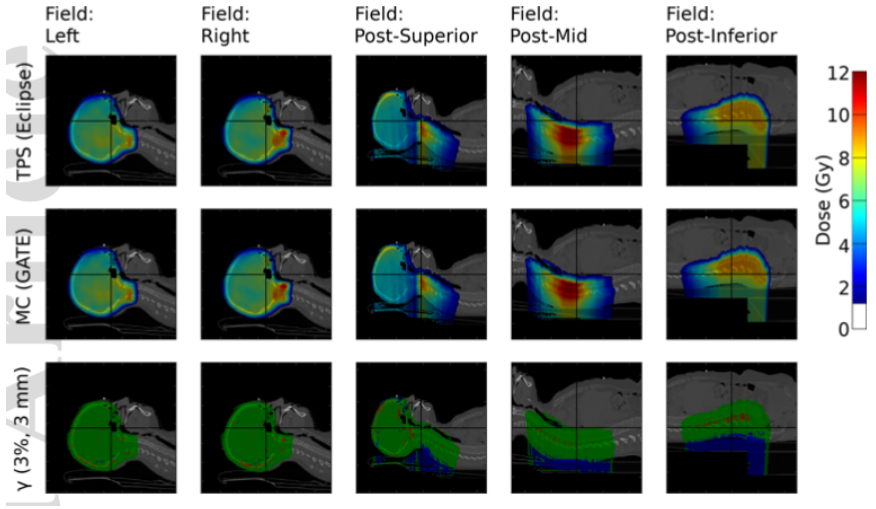
First published: 18 May 2020 | https://doi.org/10.1002/mp.14242 | Citations: 1

- **Independent Dose Calculation of proton beam therapy plans at The Christie**
- Treatment planning for proton pencil beam scanning
  - Varian Eclipse (version 13.7) TPS, proton- convolution-superposition (version 13.7.16) analytical dose calculation algorithm.
  - GATE-Rtion (**AUTOMC,** Aitkenhead, Br J Radiol 2020)
- 23.4 Gy in 13 fractions, delivered using 5 fields: a pair of left/right fields to the brain, and 3 fields to the spine (superior, mid and inferior
- a 3D gamma analysis at 3%, 3mm, the percentage of voxels in the patient having γ ≤ 1 was between 92.4% and 95.8% for all fields, and the GATE-RTion simulation was between 1.6% and 2.4% hotter than the TPS in terms of the median dose to the patient.



Comparison of TPS (Varian Eclipse) and MC (AutoMC / GATE-RTionV1.0) calculations of a 5-field craniospinal axis proton treatment plan, planned at the Christie for delivery on a Varian ProBeam system. Top row: TPS; Middle row: GATE- RTion;Bottom row:Gamma 3%(local),3mm using a 10% lower dose threshold. Voxels in green have γ≤1,while voxels in (red/blue) have γ > 1 and are (hotter/colder) than the TPS respectively.

GATE-RTion – Project Paper (3)

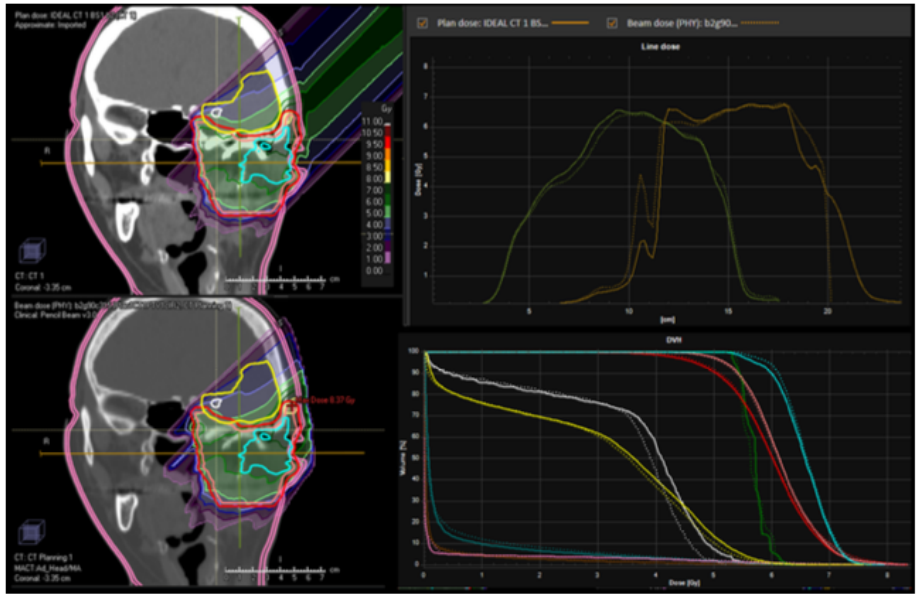
MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Technical Note

Technical Note: GATE-RTion: a GATE/Geant4 release for clinical applications in scanned ion beam therapy

L. Grevillot, D. J. Boersma, H Fuchs, A. Aitkenhead, A. Elia, M. Bolsa, C. Winterhalter, M. Vidal, S. Jan, U. Pietrzyk, L. Maigne, D. Sarrut

- **Independent Dose Calculation with Scanned Ion Beams at MedAustron**
- Treatment planning for carbon pencil beam scanning
  - RayStation version 8B from RaySearch Laboratories (Stockholm, Sweden) with MC 4.2
  - GATE-RTion **(IDEAL: Independent DosE cAlculation for Light ion beam therapy)**
  - 3D-block/24 PinPoint ionization chambers type 31015, PTW, Freiburg
- Curative carbon ion treatment up to 65.6 Gy RBE in 16 fractions of 4.1 Gy RBE (4 fractions per week). The PTV1 is treated with 9 fractions up to 36.9 Gy RBE, using 4 beams with a horizontal beam line and table rotations of 315°, 355°, 320° and 360°



Comparison of the physical dose distribution for a carbon ion beam having an oblique incidence in the head region of a patient. IDEAL/GATE-RTion dose distribution (Top left) is compared to the TPS (bottom left) in terms of Dose Volume Histogram (DVH, bottom right) and dose profiles (top right). For DVH and dose profiles, solid lines correspond to IDEAL/GATE-RTion and dotted lines to the TPS. The positions of the two orthogonal dose profiles in the patient are visible in the patient images on the left side (orange and green lines).

GATE-RTion – Validation paper for PBS

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Research Article | Open Access

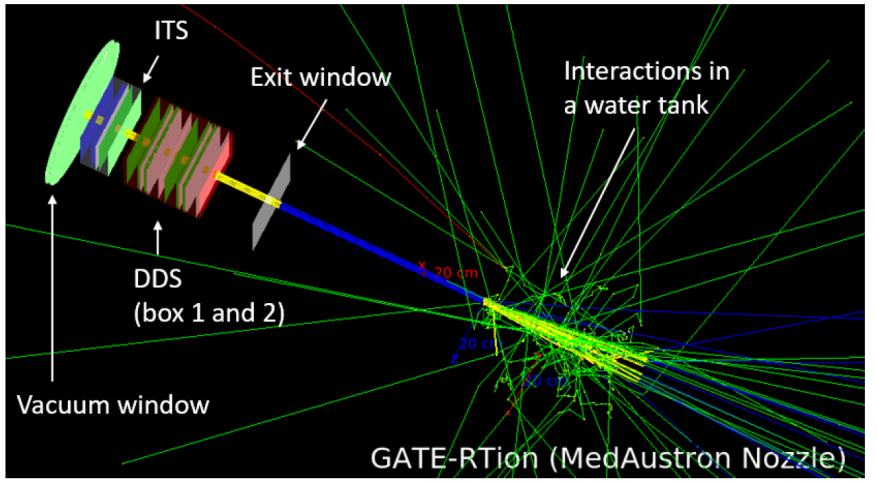
Evaluation of GATE-RTion (GATE/Geant4) Monte Carlo simulation settings for proton pencil beam scanning quality assurance

Carla Winterhalter, Michael Taylor, David Boersma, Alessio Elia, Susanna Guatelli, Ranald Mackay, Karen Kirkby, Lydia Maigne, Vladimir Ivanchenko, Andreas F. Resch ... See all authors

First published: 23 September 2020 | https://doi.org/10.1002/mp.14481

- **Comparisons of physics lists in proton PBS treatments**
  - QGSP_BIC, QGSP_BIC_EMY, QGSP_BIC_EMZ, QGSP_BIC_HP_EMZ
  - Cuts varying form 0.1 to 1 mm
  - Maximum step size: 0.1 mm, 1 mm, none
- **Recommendations**
  - Patient specific quality assurance measurements:
    - No step limiter on proton tracks; production cuts of 1 mm for electrons, photons and positrons (in the phantom and range-shifter) and 10 mm (world); best agreement to measurement data was found for QGSP_BIC_EMZ
  - Considering the patient CT model,
    - No step limiter on proton tracks; production cuts of 1 mm for electrons, photons and positrons (phantom/range-shifter) and 10 mm (world) if the goal is to achieve sufficient dosimetric accuracy to ensure that a plan is clinically safe; or 0.1 mm (phant om/range-shifter) and 1 mm (world) if higher dosimetric accuracy is needed (increasing execution times by a factor of 2); most accurate results expected for QGSP_BIC_EMZ

GATE-RTion – Other activities



Main Applications at MedAustron

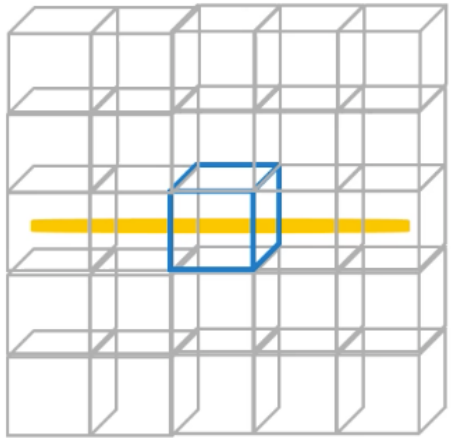
- **Proton and carbon ion beamlines modeling**
  - Passive elements design (Grevillot, PMB 2015)
  - Proton gantry nozzle design optimization (Fuchs, PTCOG 2016)
  - Non-isocentric scanned proton treatments (Elia, Physica Medica 2020)
  - Automated beam line modeling tools (Fuchs, Med Phys 2020)
- **Dosimetry activities**
  - Stopping power prediction for beam monitor calibration in number of ions
  - 3D distributions of Stopping power ratio (Bolsa, MedPhys 2020, accepted)
  - Prediction of alanine response for end-to-end testing (Carlino PMB2018)
- **Independent Dose calculation**
  - **IDEAL: Independent DosE cAlculation for Light ion beam therapy**
  - Proton and carbon ion beams (Grevillot, ESTRO 2020)
  - Collaboration with IBA -> CE MyQAiON/IDEAL (2021+)

GATE-RTion – Other activities

Calculation of the biological dose (NanOx and MKM models) – BioDose actor implementation – PhD thesis Yasmine Ali

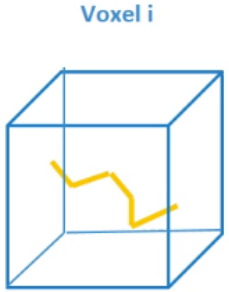
The actor methodology

VOXELIZED TARGET VOLUME



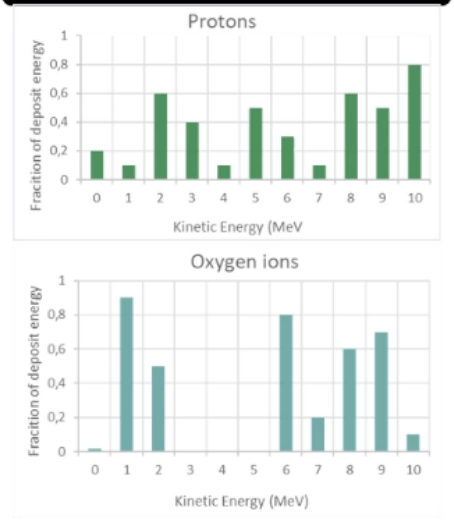
The resolution of the matrix, the size of the voxels, the position of the matrix are initialized via the messenger thanks to the parameters the user set in the macro.

ENERGY DEPOSITION BY STEPS



Is retrieved from each step :
- The particle type
- The kinetic energy (pre step point)
- The energy deposition

PER PARTICLE & PER KINETIC ENERGY



An histogram of the cumulative deposited energy is created for each type of particle as a function of the kinetic energy.

ALPHA BETA MIX CALCULATION

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

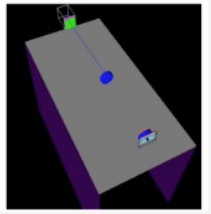
$$\beta_{mix} = \sum_{k=1}^{N} f_k \sqrt{\beta_k}$$

We weight each alpha/beta values with the deposit energy fraction according to obtain the alpha and beta mix values.

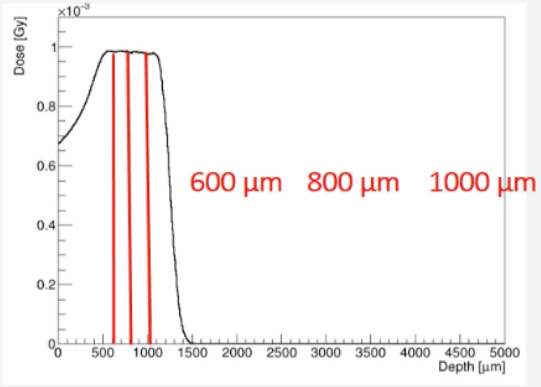
GATE-RTion – Other activities

Calculation of the biological dose – BioDose actor implementation – PhD thesis Yasmine Ali

ARRONAX BEAM LINE

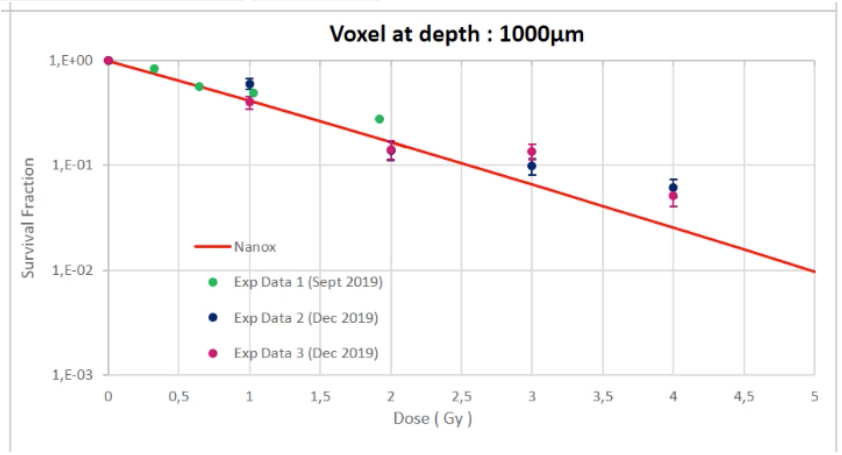


Helium
Energy: 67.4 MeV
Irradiation mode: passive



SQ20B cells irradiated at 3 positions of the SOBP, in September and December 2019.

	NanOx				MMKM
IONS	HSG	CHO-K1	V79	SQ20B	HSG
PROTONS	✓	✓	✓	✓	✓
HELIUM	✓	✓	✓	✓	✓
CARBON	✓	✓	✓		✓
OXYGEN	✓	✓	✓		✓
NEON	✓	✓	✓		✓



GATE-RTion – Other activities

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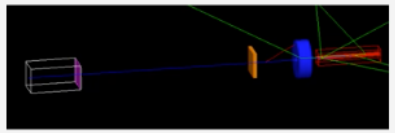
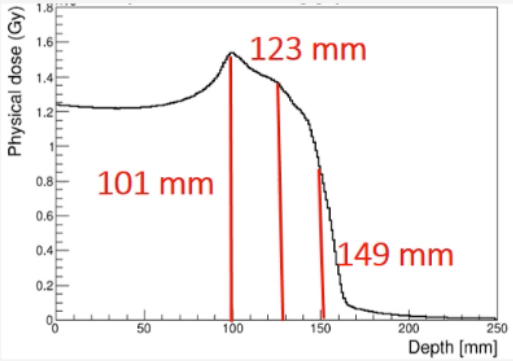
HIMAC LINE



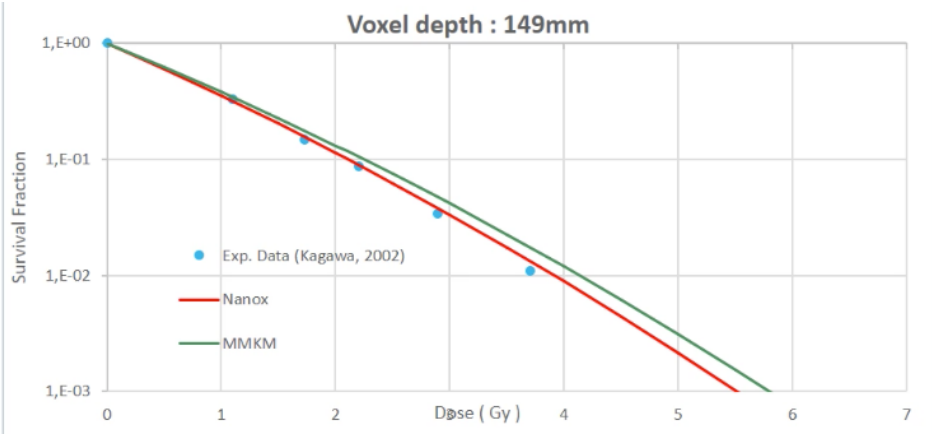
Carbon
Energy: 320 MeV/n
Irradiation mode: passive



HSG cells irradiated at 3 positions of the SOBP, in 2002.

Kagawa et al. (2002)

	NanOx				MMKM
IONS	HSG	CHO-K1	V79	SQ20B	HSG
PROTONS	✓	✓	✓	✓	✓
HELIUM	✓	✓	✓	✓	✓
CARBON	✓	✓	✓		✓
OXYGEN	✓	✓	✓		✓
NEON	✓	✓	✓		✓



Conclusion

- GATE ready for QC in hadrontherapy
- Federation of clinical partners
- Hot topics
  - G4 Physics settings
  - RBE evaluation (BioDose actor available for 2021)
  - on-line MR-guidance for particle therapy (integration of magnetic and electric field maps)
  - Neutron dosimetry
  - Biophysical models for the prediction of RBE ->G4DNA
  - Carbon ion dosimetry and ICRU90 recommendations
  - Range monitoring
  - BNCT & PBCT
- GATE-RTion2 coming soon with recommendations for carbon ion therapy