The GATE platform dedicated to hadrontherapy

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On behalf of the OpenGATE collaboration
The collaboration & Partners

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

Spokesperson: Lydia Maigne
Technical coordinator: David Sarrut + Technical board

Start in 2002 with 2 laboratories: EPFL & LPC

Cross validation with the Geant4 collaboration
Susanna Guatelli & Sébastien Incerti

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

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
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
- $\gamma$-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.
• 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-supersosition (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 \( \gamma \leq 1 \) 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 \( \gamma \leq 1 \), while voxels in (red/blue) have \( \gamma > 1 \) and are (hotter/colder) than the TPS respectively.
• 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°
• **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 (phantom/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
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+)
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**: We weight each alpha/beta values with the deposit energy fraction according to obtain the alpha and beta mix values.

\[
\alpha_{mix} = \sum_{k=1}^{N} f_k \alpha_k \\
\beta_{mix} = \sum_{k=1}^{N} f_k \sqrt{\beta_k}
\]
Calculation of the biological dose – BioDose actor implementation – PhD thesis Yasmine Ali
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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)

IONS

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Voxel depth : 149mm

Survival Fraction

Exp. Data (Kagawa, 2002)
NanoX
MMXM

Lydia Maigne - Journée ARCHADE - 09/11/20
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