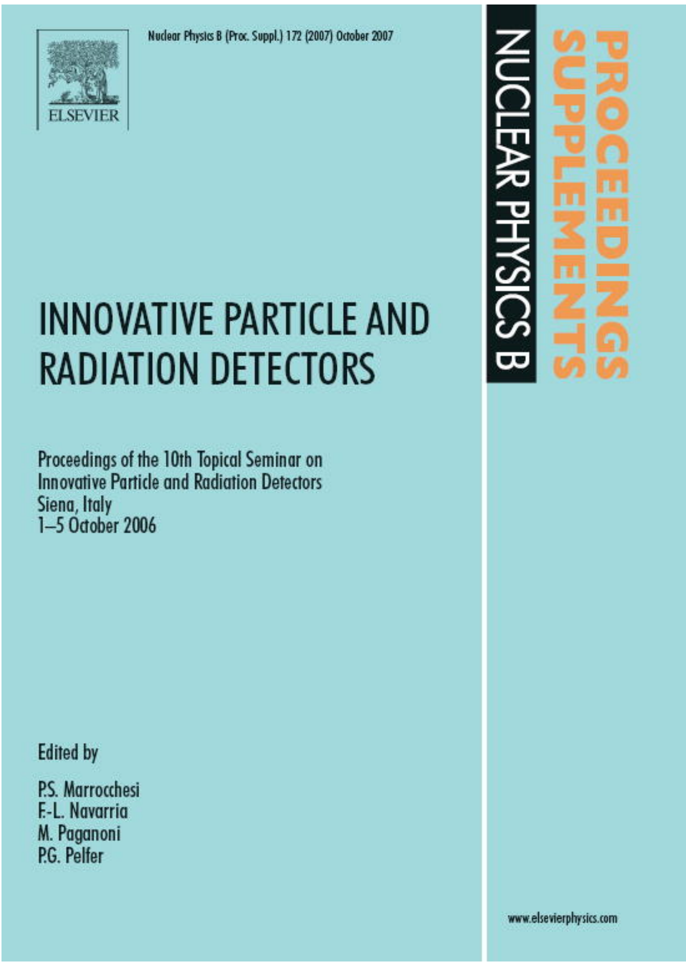
Nuclear Physics B (Proc. Suppl.) 172 (2007) October 2007
ELSEVIER
NUCLEAR PHYSICS B
PROCEEDINGS SUPPLEMENTS
INNOVATIVE PARTICLE AND RADIATION DETECTORS
Proceedings of the 10th Topical Seminar on
Innovative Particle and Radiation Detectors
Siena, Italy
1–5 October 2006
Edited by
P.S. Marrocchesi
F.-L. Navarria
M. Paganoni
P.G. Pelfer
www.elsevierphysics.com

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B (Proc. Suppl.) 172 (2007) 101–103
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
www.elsevierphysics.com

Evolution of the GATE project: new results and developments

G. Santin[a], S. Staelens[b], R.Taschereau[c], P.Descourt[d], C.R. Schmidtlein[e], L.Simon[f], D. Visvikis[d], S. Jan[g], I. Buvat[h]

[a]ESA-ESTEC,
Keplerlaan 1, 2200 AG Noordwijk, The Netherlands

[b]ELIS Department, Ghent University,
B-9000 Ghent, Belgium

[c]CRUMP Institute for Molecular Imaging, University of California Los Angeles,
700 Westwood Plaza A438, Los Angeles, CA 90095-1770

[d]U650 INSERM, LaTIM,
Brest, France

[e]Memorial Sloan-Kettering Cancer Center,
New York, New York, US

[f]Department of Radiation Oncology, Institut Curie,
Paris, France

[g]Service Hospitalier Frédéric Joliot (SHFJ), CEA-Orsay,
Orsay, France

[h]U678 INSERM, CHU Pitié-Salpêtrière,
Paris, France

We present the status of the Geant4 Application for Emission Tomography (GATE) project, a Monte Carlo simulator for Single Photon Emission Computed Tomography (SPECT) and Positron annihilation Emission Tomography (PET). Its main features are reminded, including modelling of time dependent phenomena and versatile, user-friendly scripting interface. The focus of this manuscript will be on new developments introduced in the past 4 years. New results have been achieved in the fields of validation on real medical and research PET and SPECT systems, voxel geometries, digitisation, distributed computing and dosimetry.

1. INTRODUCTION

Simulations play a key role in functional imaging, with applications ranging from scanner design, to image reconstruction, scatter correction, protocol optimisation [1]. Analytical models provide rapid response and are often preferred to more complex simulation approaches when speed is required, but at the cost of approximations in the description of physics processes, geometry or system response. Monte Carlo (MC) is now widely used in parallel to analytical computations or experimental studies. Previous dedicated tools offered fast development cycle, and optimisations (with remarkable impact on computing speed) were possible by limiting the application range, or reducing the level of detail on physics and geometry models.

Research groups and clinical users share the need for new generation simulation tools offering ease of use, precision and speed, together with flexibility and support of the software implementation. GATE [2] intended to answer to the requirements from these two communities.

2. STATUS AND EVOLUTION OF THE GATE PROJECT

A number of simulators for PET and/or SPECT were developed in the nineties and early 2000's [3], suggesting that until recently no code was considered as a standard for MC simulations in emission tomography. A new code, GATE, has recently been designed as upper layer of the GEANT4 toolkit [4] with the ambition to become the gold standard in nuclear medicine simulations.

doi:10.1016/j.nuclphysbps.2007.07.008

GEANT4, an open source project with collaborative development and long-term support, was chosen as core element for the good description of physics and geometry models, and the modern software technology. Ease of use and tailoring for use in PET and SPECT are covered by GATE specific developments. The usability of GATE is greatly improved by a scripting mechanism by which users can design and control complete simulations (from geometry model to activity and detector response) using macros, without any C++ coding [5]. A number of PET and SPECT commercial and research tomographs, together with commonly used phantoms, have been modelled in GATE via the scripting mechanism [6][7][8][9].

Explicit modelling of time includes detector motion, patient motion, radioactive decay, dead time, time of flight, tracer kinetics [10]. Interfaces to voxellised models and image reconstruction packages improve the integration of GATE in the global modelling cycle.

The OpenGATE collaboration [11], counting at present 22 laboratories, shares long-term development, validation, documentation, and support of the tool. Access to the GATE software is open, offering to registered users (more than 1000, world wide, at the time of writing) source code and support tools (e.g. documentation, mailing lists).

2.1. Recent developments

The possibility to load voxel geometry (and source) models was added to GATE. The interface includes generic internal treatment of voxel elements and dedicated developments for input of various formats [12], also with variable voxel size [13]. Besides the traditional use as input for the material description, the voxel model can also be used as a map of source activities, overlaid onto the geometry.

The relevance of the correction of movement artefacts is increasing with the improvement of the scanner resolution, and the availability of description of these movements in realistic phantoms a key feature in modern simulation tools. On top of the generic voxel models, dedicated interfaces to specific widely used phantoms were recently added to GATE: the 4D NURBS-based Cardiac-Torso (NCAT) and the 4D Digital Mouse Whole Body (MOBY) phantoms [14][15] are available (as geometry and activity maps), fully integrating the model respiratory and cardiac motions and time-dependent activities within each organ with the GATE time management [16].

Significant improvements were made to the detector response simulation (“digitizer”): new processing types are available for the assembly of the linear signal processing chain, including configurable dead time [17][7].

Other recent developments include the extension of GATE to the dosimetry application domain [18], user-friendly interfaces to the GEANT4 optical photon tracking, and a new Graphical User Interface.

A major collaboration effort aims at performance improvement through efficiency optimisation (variance reduction techniques include importance sampling and forced detection) [19] and distributed computing (with openMosix, Condor, and so on) [20]. A truly parallel version with MPI is also under construction and first results are demonstrated on worldwide computer grids.

Developments are ongoing for the integration of modelling tools for hybrid scanners (including SPECT/CT, PET/CT, OPET) [21][22][23][24][25].

Recent clinical applications of GATE include a study on contamination effects in Tl-201 myocardial perfusion imaging [26].

3. CONCLUSIONS AND OUTLOOK

Simulations will be more and more present in (nuclear) medical imaging in the future: for designing imaging protocols and interpreting SPECT and PET scans, in the very imaging process of a patient. GATE has become a popular tool for Monte Carlo simulations in emission tomography, with collaborative effort in development, validation and support by the OpenGATE collaboration. Thanks to the significant results obtained by the wide user community, it is hoped by the authors that GATE, nowadays considered as tool of excellence in the domain, will become the gold standard simulator in nuclear medicine.

REFERENCES

1. I. Buvat and I. Castiglioni, “Monte Carlo methods in PET and SPECT”. Quarterly J. Nucl. Med., 46: 48-59, 2002
2. S. Jan, G. Santin, D. Strul, S. Staelens *et al.* (OpenGATE collaboration), “GATE: a

simulation toolkit for PET and SPECT", Phys. Med. Biol. 49 (2004) 4543-4561

3. I. Buvat, D. Lazaro, Monte Carlo simulations in emission tomography and GATE: an overview, in Nucl. Instr. and Meth. A 569 (2006), p. 323-329.
4. S. Agostinelli *et al.* [GEANT4 Collaboration], "Geant4: a simulation toolkit", Nucl.Instr.Meth A506, 250 (2003).
5. D. Strul, G. Santin, D. Lazaro, V. Breton, C. Morel. "GATE (Geant4 Application for Tomographic Emission): a PET/SPECT general-purpose simulation platform". Nucl. Phys. B (Proc. Suppl.) 125 (2003) 75-79
6. C.R. Schmidtlein, S.A. Nehmeh *et al.*, "Validation of GATE Monte Carlo simulations for the GE Advance PET scanner" J. Nucl. Med. 45 (2004) 409P-410P
7. C.R. Schmidtlein, A.S. Kirov *et al.*, "Validation of GATE Monte Carlo simulations of the GE Advance/Discovery LS PET scanner", Med. Phys. 33 (2006) 198-208
8. R. Van Holen, S. Vandenberghe, S. Staelens, Y. D'Asseler, I. Lemahieu, "Contrast noise behaviour for a rotating slat collimated gamma camera". EUROMEDIM 2006 proc., 2006
9. F. Bataille *et al.*, "Monte Carlo simulation for the ECAT HRRT using GATE". IEEE MIC Conf Records 4 (2004) 2570-2574
10. G. Santin, D. Strul, D. Lazaro, L. Simon, M. Krieguer, M. Vieira, V. Breton, C. Morel. "GATE: A Geant4-based simulation platform for PET, SPECT integrating movement and time management". IEEE Trans. Nucl. Sci. 50 (2003) 1516-1521
11. OpenGATE Collaboration web-site: http://www.opengatecollaboration.org
12. S. Staelens, G. Santin, D. Strul *et al.*, "Monte Carlo simulations of Interfile based emission and attenuation maps for clinical applications". J. Nucl. Med. 44 (2003) 048
13. R. Taschereau, P.L. Chow, A.F. Chatziioannou, "Monte Carlo simulations of dose from microCT imaging procedures in a realistic mouse phantom", Med. Phys. 33 (2006) 216-224
14. W.P. Segars, B.M. Tsui, D.S. Lalush *et al.*, "Development and application of the new dynamic NURBS-based Cardiac-Torso (NCAT) phantom" J Nucl Med 42 (5), 2001.
15. W.Segars *et al*, "Development of a 4D Digital Mouse Phantom for Molecular Imaging Research", Mol. Imaging Biol 6 (2004) 149
16. P. Descourt, W. P. Segars, F. Lamare *et al.* "RTNCAT (Real Time NCAT): Implementing Real Time Physiological Movement of Voxellized Phantoms in GATE", IEEE MIC Conf Proc, 2006
17. L. Simon *et al.*, "Simulation of time curves in small animal PET using GATE", Nucl. Instr. Meth.A527 (2004)
18. D. Visvikis *et al.*, "Use of the GATE Monte Carlo package for dosimetry applications". Nucl Instr Meth A569. 2006. pp. 335-340
19. S. Staelens *et al.,* "GATE: Improving the computational efficiency". Nucl. Instr. and Meth. A 569 (2006), p. 341.
20. De Beenhouwer J, Kruecker D, Staelens S, Ferrer L, Chatziioannou A, Rannou F. "Distributed computing platform for PET and SPECT simulations with GATE". IEEE NSS Conf. Record 4, (2005) p2437 - 2440
21. P. Gonias *et al.*, "Validation of a GATE model for the simulation of the Siemens biograph™ 6 PET scanner", Nucl Instr Meth A 571 (2007) 263.
22. D. Lazaro *et al*, Monte Carlo simulation of the Hi-Rez using GATE. J. Nucl. Med. 46 (2005) 487P
23. D. Brasse *et al.*, "Development of a High Resolution SPECT System Dedicated to Small Animal Imaging". IEEE MIC Conf Rec, 2004
24. F.R. Rannou *et al.*, "Investigation of OPET performance using GATE, a Geant4-based simulation software". IEEE Trans Nucl Sci. 2004;51:2713–7
25. G. Alexandrakis et al, "Tomographic bioluminescence imaging by use of a combined optical-PET (OPET) system: a computer simulation feasibility study". Phys Med Biol 2005;50:4225-41
26. S. Staelens, T. De Wit, I. Lemahieu, F. Beekman, "Significant septal penetration effects caused by impurities in cyclotron-produced Thallium-201", Abstract book suppl. to J Nucl Med. 47 (5), 2006.