

# Monte-Carlo Simulation of PET with GEANT

T.Hasegawa<sup>1)</sup> and H.Murayama<sup>2)</sup>

1)Kitasato Univ., Allied Health Sciences, Kitasato 1-15-1, Sagamihara, Kanagawa, Japan

2)NIRS, Anagawa 4-9-1, Inage, Chiba, Japan

## INTRODUCTION

In Monte-Carlo simulation, physics phenomena of gamma rays generated by positron decays are simulated in a computer event by event. The scattering and absorption of gamma rays are subjected to appropriate physics probability distributions, which are incorporated into the computer algorithm with a help of random numbers. Although the Monte-Carlo method is time consuming in general, the simulation can be as close as possible to the real phenomena in a complex PET scanner if required with a sufficient computation time. In addition, the simulation gives us valuable information such as trajectories and interaction positions, which are not measured. Therefore, the Monte-Carlo simulation is an important technique to understand the characteristics of PET scanners.

There have been several Monte-Carlo studies for PET as summarized in the table. Some groups made their own simulation programs by themselves. Among these, SIMSET has an important advantage in its variance reduction algorithm, which reduces computation time efficiently. However, the present SIMSET code approximates the detectors part by ignoring scattering in the detectors and assuming the perfect detection at the detector surface although the detector depth must be considered to reproduce the spatial resolution of a PET scanner [13].

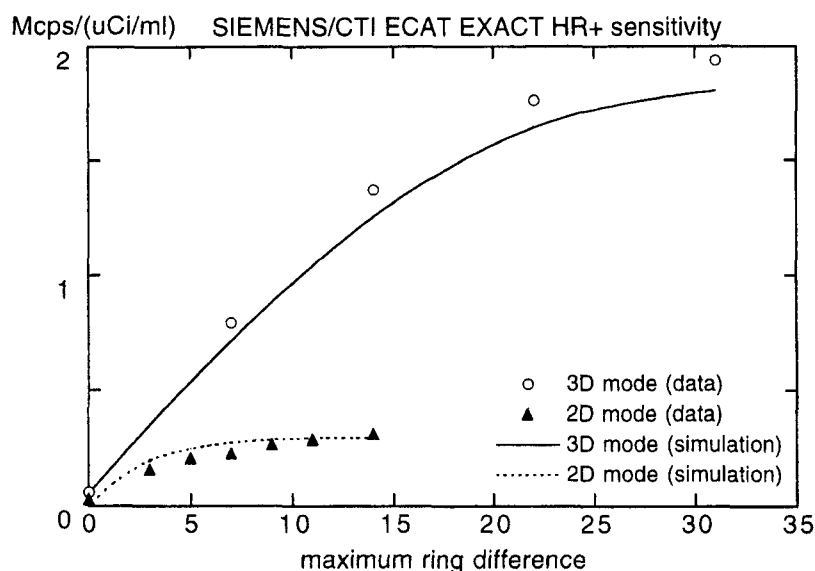
| code name | affiliation of the 1st author | references   | commercial PET scanners studied              |
|-----------|-------------------------------|--|--|
|           | BNL                           | [1] J.Logan et al.   | -  |
|           | TRIUMF                        | [2] J.G.Rogers et al., [3] L.R.Lupton et al.                             | -  |
|           | MGH                           | [4] C.W.Stearns et al.   | -  |
| PETSIM    | McGill Univ.                  | [5-8] C.J.Thompson et al., [9] Y.Picard et al.                           | -  |
| SIMSET    | Univ. of Washington           | [10] T.K.Lewellen et al., [11] D.R.Haynor et al., [12] D.R.Haynor et al. | -  |
| SIMSET    | Kitasato Univ.                | [13] T.Hasegawa et al.   | SIEMENS/CTI EXACT47                          |
|           | Karolinska                    | [14] M.Dahlborn et al.   | -  |
|           | TRIUMF                        | [15] J.S.Barney et al.   | SIEMENS/CTI 953B and Scanditronix PC2048-7WB |
| GEANT     | Louvain Univ.                 | [16] C.Michel et al.   | SIEMENS/CTI 931/08-12 and 953B               |
| GEANT     | TRIUMF                        | [17] G.Tsang et al., [18-19] C.Moisan et al.                             | SIEMENS/CTI HR+                              |
| EGS4      | Heidelberg Univ.              | [20] L.Adam et al.   | Scanditronix PC2048-7WB                      |
| EGS4      | Akita-nouken                  | [21] Y.Narita et al.   | Shimadzu SET2400W                            |
|           | GSI                           | [22] J.Pawelke et al., [23] R.Hinz et al.                                | SIEMENS/CTI HR+(modified)                    |
| EGS4      | Milano Univ.                  | [24] I.Castiglioni et al.  | GE Advance                                   |

Some groups have been using general-purpose simulation codes, EGS4 [25] and GEANT [26], which have been developed for high energy physics experiments originally. They have an advantage in flexibility to simulate arbitrary detector and material configuration. EGS4 is preferably used to simulate low energy photon and electron phenomena. GEANT has a good user interface to define complex geometry such as a huge detector system with million channels.

#### OUR SIMULATION CODE WITH GEANT

Our Monte-Carlo simulation code is based on the latest version of GEANT. The complex segmented detector crystals of one of the latest PET scanner, SIEMENS/CTI ECAT EXACT HR+, were precisely incorporated into the simulation. Various data-acquisition parameters such as maximum-ring-difference, which defines the maximum ring number difference allowed in the coincidence detection, are taken into account.

The following figure compares measured sensitivity with simulation results for various maximum-ring-difference values in 2D and 3D modes. Simulated scatter fraction and random coincidence rate for a standard uniform cylindrical phantom in 3D mode are 35 % (maximum-ring-difference = 0) and 10.9 kcps (253 uCi in total) in good agreements with experimental data of 33% and 10.94 kcps, respectively.



We have been using the Monte-Carlo simulation code for the purpose of understanding the characteristics of the basic performance of PET scanners, analyzing the effects of external end-shield to cope with activity out-of the field-of-view in 3D mode, simulating ideal or extreme condition which could not be realized in experiments, and designing a new PET scanner.

#### ACKNOWLEDGEMENT

We thank C.Michel for simulation programs, H.Matsuura, T.Nakajima and Y.Wada for phantom experiments. This study was supported in part by grants from the Ministry of Education Science and Culture of Japan (Grant-in-Aid No. 10770453) and from Kitasato University (Grant-in-Aid No. SAHS-B033-1997 and SAHS-B065-1998).

## REFERENCES

- [1] J.Logan and H.J.Bernstein, "A Monte Carlo simulation of Compton scattering in positron emission tomography", *J. Comput. Assist. Tomog.* 7(2), 1983, 316-320.
- [2] J.G.Rogers, R.Harrop, P.E.Kinahan, N.A.Wilkinson, and G.H.Coombes, "Conceptual design of a whole body PET machine", *IEEE Trans. Nucl. Sci.* 35(1), 1988, 680-684.
- [3] L.R.Lupton and N.A.Keller, "Performance Study of Single-Slice Positron Emission Tomography Scanners by Monte Carlo Techniques", *IEEE Trans. Med. Imag.*, MI-2(4), 1983, 154-168.
- [4] C.W.Stearns, C.A.Burnham, D.A.Chesler and G.L.Brownell, "Simulation studies for cylindrical positron tomography", *IEEE Trans. Nucl. Sci.* 35(1), 1988, 708-711.
- [5] C.J.Thompson, "The effects of collimation on scatter fraction in multi-slice PET", *IEEE Trans. Nucl. Sci.* 35(1), 1988, 598-602.
- [6] C.J.Thompson, "The effects of collimation on singles rates in multi-slice PET", *IEEE Trans. Nucl. Sci.* 36(1), 1989, 1072-1077.
- [7] C.J.Thompson, "The effects of detector material and structure on PET spatial resolution and efficiency", *IEEE Trans. Nucl. Sci.* 37(2), 1990, 718-724.
- [8] C.J.Thompson, J.Moreno-Cantu and Y. Picard, "PETSIM: Monte Carlo simulation of all sensitivity and resolution parameters of cylindrical positron imaging systems", *Phys. Med. Biol.*, 37(3), 1992, 731-749.
- [8] Y.Picard, C.J.Thompson and S.Marrett, "Improving the Precision and Accuracy of Monte Carlo Simulation in Positron Emission Tomography", *IEEE Trans. Nucl. Sci.* 39(4), 1992, 1111-1116.
- [10] T.K.Lewellen, C.P.Anson, D.R.Haynor, R.L.Harrison, A.N.Bice, S.F.Schubert, R.S.Miyaoka, S.B.Gillespie and J.Zhu, "Design of a simulation system for emission tomographs", *J. Nucl. Med.* 29, 1988, 29 (abstract).
- [11] D.R.Haynor, R.L.Harrison, T.K.Lewellen and A.N.Bice, "Improving the efficiency of emission tomography simulations using variance reduction techniques", *IEEE Trans. Nucl. Sci.* 37(2), 1990, 749-753.
- [12] D.R.Haynor, R.L.Harrison and T.K.Lewellen, "The use of importance sampling techniques to improve the efficiency of photon tracking in emission tomography simulations", *Med. Phys.* 18(5), 1991, 990-1001.
- [13] T.Hasegawa, H.Murayama and Y.Wada, "Monte Carlo simulation of PET performance measurement for EXACT47 at NIRS", *Jpn. J. Med. Phys.* 17(2), 1998, 83-93.
- [14] M.Dahlborn, L.Eriksson, G.Rosenqvist and C.Bohm, "A study of the possibility of using multi-slice PET systems for 3D imaging", *IEEE Trans. Nucl. Sci.* 36, 1989, 1066-1071.
- [15] J.S.Barney, J.G.Rogers, R.Harrop and H.Hoverath, "Object shape dependent scatter simulations for PET", *IEEE Trans. Nucl. Sci.*, 38, 1991, 719-725.
- [16] C.Michel, A.Bol, T.Spinks, D.Townsend, D.Bailey, S.Grootenboer and T.Jones, "Assessment of response function in two PET scanners with and without interplane septa", *IEEE Trans. Med. Imag.*, 10, 1991, 240-248.
- [17] G.Tsang, C.Moisan and J.G.Rogers, "A Simulation to Model Position Encoding Multicrystal PET Detectors", *IEEE Trans. Nucl. Sci.* 42(6), 1995, 2236-2243.
- [18] C.Moisan, P.Tupper, J.G.Rogers and J.K.de Jong, "A Monte Carlo study of the acceptance to scattered events in a Depth Encoding PET camera", *IEEE Trans. Nucl. Sci.*, 43, 1996, 1974-1980.
- [19] C.Moisan, D.Vozza and M.Loope, "Simulating the Performances of an LSO Based Position Encoding Detector for PET", *Conference Record of 1996 IEEE NS Symposium and MI Conference*, 1997.
- [20] L.Adam, M.E.Bellemann, G.Brix and W.J.Lorenz, "Monte Carlo-Based Analysis of PET

- Scatter Components", J. Nucl. Med. 37(12), 1996, 2024-2029.
- [21] Y.Narita and M.Shidahara, private communication, 1997.
- [22] J.Pawelke, W.Enghardt, T.Habere, B.G.Hasch, R.Hinz, M.Kraemer, K.Lauckner and M.Sobiella, "In-beam PET-imaging for the control of heavy ion tumour therapy", IEEE Trans. Nucl. Sci. 44, 1997, 1492-1498.
- [23] R. Hinz, J. Debus, W. Enghardt, T. Haberer, B.G. Hasch, O. Jaekel, K. Lauckner, M. Kraemer, J. Pawelke and M. Sobiella, "Simultaneous control of the radiation therapy with heavy ions by positron emission tomography", Conference Record of 1998 IEEE NS Symposium and MI Conference, 8-14 Nov, 1999.
- [24] I. Castiglioni, O.Cremonesi, M.C.Gilardi, V.Bettinardi, G.Rizzo, A.Savi, E.Bellotti and F.Fazio, "Scatter Correction Techniques in 3D PET : A Monte Carlo Evaluation", Conference Record of 1998 IEEE NS Symposium and MI Conference, 8-14 Nov, 1999.
- [25] W.R.Nelson, H.Hirayama and D.W.O.Rogers, "The EGS4 code system", SLAC-256, 1985.
- [26] European Laboratory for Particle Physics (CERN, Conseil European pour la Recherche Nuclearire), Information Technology Division, CH-1211 Geneva 23, Switzerland.