Australian Institute of Physics NSW Branch (June News)

The June meeting of the NSW AIP branch was held at the University of Sydney on Tuesday the 29th of June 2010. The invited speaker for the meeting was Dr Susanna Guatelli, with research activities in Medical Radiation Physics. Dr Guatelli has completed her PhD in physics at University of Genova, Italy. Her main research activities are in the field of Monte Carlo simulations in radiation physics with application of the GEANT radiation transport code. She has completed research at CERN in the simulation of monitoring radiation detectors for HEP and radiation shielding of spacecraft for space exploration missions as well as in dosimetry for IMRT, brachytherapy and Proton Therapy. Dr Guatelli first came to Australia as a postdoctoral fellow with the Detector Group at ANSTO, led by Dr. Mark Reinhard. Since March 2009, Dr Guatelli has been a lecturer within the School of Engineering Physics at the University of Wollongong, performing research at the Centre of Medical Radiation Physics (CMRP), led by Prof. Anatoly Rosenfeld.

Dr Guatelli's talk was entitled "Angels and Demons: the real CERN" and started with an overview of the story and research of CERN, then focussed on the CERN technology transfer program, and in particular, to the CERN technology transfer to CMRP.

From left to right, Dr Frederick Osman, Dr Susanna Guatelli, Dr Michael Lerch and Chen-Yu Huang

CERN (www.cern.ch) is the biggest nuclear physics laboratory in the world, had its beginnings in 1954, with the mission of performing fundamental research in physics, developing advanced technology, enhancing collaborations among scientists of different nationalities, and training the scientists of the future. Nowadays CERN research is mainly devoted to High Energy Physics (HEP), with the Large Hadron Collider (LHC) experiment, involving research institutes from 85 different countries. The main goal of LHC is to answer the unresolved questions of the Standard Model: investigate high energy collisions, detect the Higgs boson, investigate dark energy and dark matter, understand the asymmetry between matter and antimatter.

While the attention of the media is focused on the CERN fundamental physics research, much less attention is dedicated to other CERN domains of activity such as the CERN Knowledge and Technology Transfer program that covers a crucial role in CERN policy (http://technologytransfer.web.cern.ch/technologytransfer). This program includes the transfer of technologies developed at CERN to other domains of research, such as medical physics, space science, information technology, and industry.

Geant4 (www.cern.ch/geant4) is a Monte Carlo Simulation Toolkit, modelling the interactions of particles with matter. Geant4 was originally born for High Energy Physics, with functionality adequate to LHC experiment studies. Thanks to the advanced software technology solutions adopted, Geant4 was easily extended to other domains, as space science and medical physics, by including physics models devoted to low energy domain [1, 2]. Nowadays Geant4 is widely used in Medical Physics studies, from proton therapy to brachytherapy, IMRT, to optimise the radiotherapy treatments and to verify the accuracy of the treatment planning systems, adopted in hospitals. Geant4 is widely used also in the characterisation and optimisation of novel detectors, and in radiation protection for shielding simulations.

Geant4 is widely used at CMRP, as a Monte Carlo simulation code in dosimetry, microdosimetry and nanodosimetry, to enhance and characterise radiotherapy treatments, and to study novel detectors, developed at CMRP. Dr Guatelli's talk then focused on the description of some Geant4-based research activities, performed at CMRP, managed by Dr Guatelli.

Dr Guatelli presented CMRP research on the development of a fast neutron, energy-independent tissue equivalent dosimeter under development for radiation protection and space missions particularly, described in detail in [3]. The neutron dosimeter consists of a pixellated silicon detector, Medipix2 [4] complemented by a special design structured polyethylene converter, as shown in Figure 1.

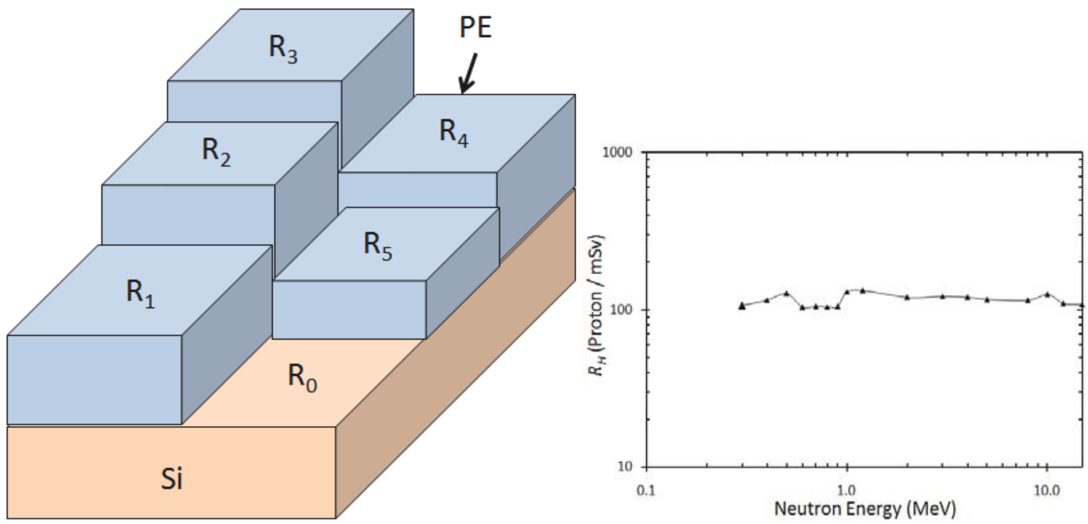


Figure1: a) Sketch of the fast neutron, energy independent, dosimeter, consisting of Medipix2 pixelated detector, complemented by structured polyethylene converter with 3D shape optimized by GEANT 4 b) Simulated by GEANT 4 dose equivalent response of finally designed neutron dosimeter [3].

The modelling of the response of the MEDIPIX 2 covered with structured polyethylene converter with GEANT 4 allowed adjustment of the 3D shape of the converter to make response of the dosimeter, in terms of tissue equivalent neutron dose, energy independent and gamma photon insensitive. Such dosimeter is portable and designed for space missions for astronauts to monitor the biologically relevant neutron dose.

Geant4 is widely used at CMRP to study other novel detectors, as Silicon-On-Insulator (SOI) microdosimeters [5] first solid state microdosimeter able to measure the radiation dose deposited at the cellular level, in any mixed radiation field, and derive the dose equivalent based on microdosimetric spectra. The development of this detector started more than 10 years ago at CMRP, and it was optimised using Geant4 simulations.

Geant4 was used at CMRP to simulation in proton therapy, fast neutron therapy, and radiation protection in earth labs, in aviation and space (some of them can be found in [6-10]). Fundamental characteristics of SOI microdosimeters, such as tissue equivalence, was characterised by means of Geant4 ([11]). Silicon is not tissue equivalent and a methodology was developed to convert microdosimetric spectra in silicon to water, in proton radiation fields of interest for proton therapy and radiation protection in Low Earth Orbit (LEO) studies. In this study it was found that a simple geometrical factor scale (approx 0.56) is adequate to convert microdosimetric energy deposition spectra in silicon to equivalent energy deposition spectra in water, along the Bragg curve, when the proton field has an energy range between a few MeV and 250 MeV. It was in a good agreement with CMRP earlier works for alpha particles and heavy ions [12]. At present at CMRP we are developing a generic algorithm for conversion of microdosimetric spectra in silicon to water, for any mixed radiation field, consisting of protons, alpha particles and energetic ions typical of the deep space radiation environment.

A very interesting study are performed at CMRP, by means of Geant4, is to investigate possible magnetic field enchanced radiobiological effects in radiation therapy, in order to improve the effectiveness of the radiotherapy treatment. The hypothesis of this study relies on the fact that:
(1) early damage to cells by radiation starts with the early damage in the DNA helixes, determined by the microscopic pattern of energy deposition (number of ionizations) on DNA level; the number of Double Strand Breaks in DNA helix is correlated to this pattern;
(2). For any kind of ionising radiation, about 80% of the deposited energy to tissue is due to low energy (delta) electrons ($E < 10$ keV);.
(3) Changing spatial distribution of low energy electrons in a magnetic field can change clustered damage of DNA without changes the absorbed dose.

Towards this aim, the CMRP MC Group is investigating the application of Geant 4 for simulation of clusters of ionizations in the nuclesome and DNA modelled in water as presented in Fig 2a. For benchmarking Geant 4 with such low energy electrons, transport in water in comparison with the Physikalisch-Technische Bundesanstalt (PTB) established low electron energy Monte Carlo code has been done. Mean ionization cluster size with respect to the initial electron energy for the DNA segment and the nucleosome, calculated by means of the Geant4 and PTB codes presented in a Fig. 2b suggested good agreement of the two codes. The advantage of Geant 4 in comparison with the PTB code is in the possibility of performing simulations in the presence of magnetic field. The effect of a magnetic field on direct ionization in the DNA and nuclesome has not shown essential RBE enhancement and other mechanisms are under investigation. This work is continuing in collaboration with PTB, Germany, LLUMC USA and ANSTO. More details of this preliminary simulation work can be found in [13].

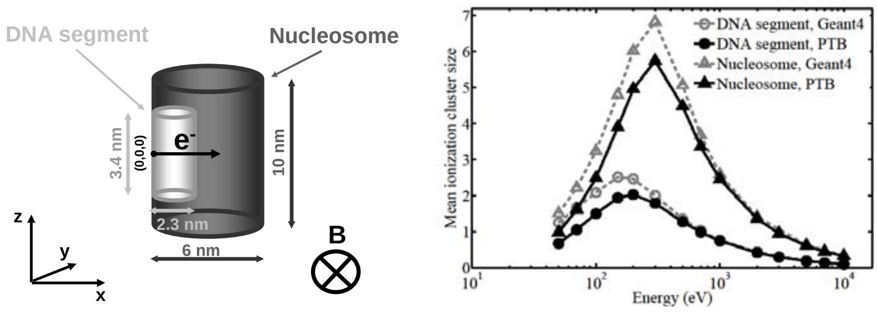
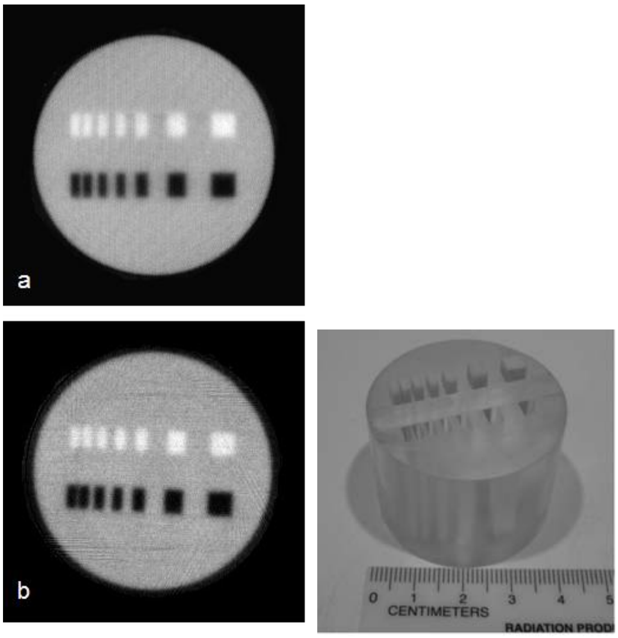


Fig. 2a) Geometrical set-up of the Monte Carlo simulations including the direction of the magnetic field in the Geant4 simulation. The nucleosome and DNA segment models were embedded in water; b) Mean ionization cluster size with respect to the initial electron energy for the DNA segment and the nucleosome, calculated by means of the Geant4 and PTB codes without magnetic field. [13]

Another example of the application of Geant 4 at CMRP in the simulations of radiation therapy in the present of magnetic field can be found in [14] where modification of the skin doses was predicted in conditions on MRI guide radiotherapy on medical LINAC. Geant 4 was also applied at CMRP for simulations of the response of edge on MOSFET dosimeters in Microbeam Radiation Therapy (MRT) [15] where dose pattern on micron scale level is of interest. This direction of research is important for Australian synchrotron medical beamline where MRT facility is being built.

Recently essential progress have been achieved at CMRP jointly with LLUMC and University of Haifa in proton computer tomography (pCT) where new algorithm for image reconstruction was developed utilizing GEANT 4 simulations and the “Most Likely proton Path” (MLP) formalism for protons coming through the tissue [16,17]. The recorded experimental data, and similar data set generated by GEANT4 based MC code simulating the experimental set-up for pCT in LLUMC, were treated by 3D image reconstruction software exploiting algebraic reconstruction technique (ART) combined with the MLP concept given in the Appendix of [16]. Reconstruction results presented as the transversal cuts of the 3D image of the phantom are shown in Fig. 3. This work was fulfilled mostly by Scott Penfold and was possible originally due to strong Geant 4 training at CMRP with active participation of Dr Guatelli.



c)

Fig. 3. Transversal cuts of the 3D phantom image reconstructed from (a) simulated with help of Geant 4 and (b) experimental data c) Acrylic phantom. The upper row is filled with bone-equivalent plastic, the lower row is empty.

In her talk, Dr Guatelli dedicated few words also to her experience in teaching Geant4 to undergraduate and postgraduate students, at the School of Engineering Physics of University of Wollongong, in a laboratory hands-on course, documented in [18]. Students were engaged in the work and understood the importance of the adoption of Monte Carlo method in physics, however they were frustrated by the computing difficulties encountered, given the absence of a significant computing background. Strategies have been identified to improve the course, as i.e. providing a web page, with pre-lab documentation, re-structure of the course, with higher number of laboratory hours, to teach basic computing programming to students.

In conclusion Geant4 was born at CERN for HEP experiments, and then was extended to other domain of research, as medical physics and space science. In particular at CMRP, Geant4 is widely used for dosimetry in conventional and proton therapy, microdosimetry, nanodosimetry, different detector response and proton imaging counting on a large research group within the Centre for Medical Radiation Physics at the University of Wollongong, consisting of three staff members and about 10 Master/PhD students.

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