

# MGGPOD: A MONTE CARLO SUITE FOR GAMMA RAY ASTRONOMY – VERSION 1.1

G. Weidenspointner<sup>1</sup>, S.J. Sturmer<sup>2</sup>, E.I. Novikova<sup>3</sup>, M.J. Harris<sup>4</sup>, A. Zoglauer<sup>5</sup>, C.B. Wunderer<sup>5</sup>, R.M. Kippen<sup>6</sup>, P. Bloser<sup>7</sup>, and Ch. Zeitnitz<sup>8</sup>

<sup>1</sup>Centre d'Etude Spatiale des Rayonnements, BP 4346, 31028 Toulouse Cedex 4, France

<sup>2</sup>NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, USA

<sup>3</sup>Navy Research Laboratory, Washington, DC, USA

<sup>4</sup>CSNSM, IN2P3, Orsay Paris, France

<sup>5</sup>Space Sciences Laboratory, University of California Berkeley, CA 94720, USA

<sup>6</sup>Los Alamos National Laboratory, NM, USA

<sup>7</sup>University of New Hampshire, Durham, NH, USA

<sup>8</sup>Universität Mainz, Mainz, Germany

## ABSTRACT

We announce the forthcoming public release of Version 1.1 of MGGPOD, a user-friendly suite of Monte Carlo codes built around the widely used GEANT (Version 3.21) package. MGGPOD is capable of simulating *ab initio* the physical processes relevant for the production of instrumental backgrounds. These processes include the build-up and delayed decay of radioactive isotopes as well as the prompt de-excitation of excited nuclei, both of which give rise to a plethora of instrumental gamma-ray background lines in addition to continuum backgrounds. A detailed qualitative and quantitative understanding of instrumental backgrounds is crucial for most stages of high-energy astronomy missions.

Improvements implemented in Version 1.1 of the proven MGGPOD Monte Carlo suite include: additional beam geometry options, the capability of modelling polarized photons, additional output formats suitable e.g. for event reconstruction algorithms, improved neutron interaction cross sections, and improved treatment of the radioactive decay of isomeric nuclear states.

The MGGPOD package and documentation are publicly available for download from <http://sigma-2.cesr.fr/spi/MGGPOD/>.

Key words: gamma-ray astronomy; hard X-ray astronomy; instrumentation; Monte Carlo simulation.

## 1. INTRODUCTION

Intense and complex instrumental backgrounds, against which the much smaller signals from celestial sources must be discerned, are a notorious problem for low energy gamma-ray and hard X-ray astronomy. Therefore a

detailed qualitative and quantitative understanding of instrumental line and continuum backgrounds is crucial for most stages of gamma-ray astronomy missions, ranging from the design, development, and performance prediction phases through calibration and response generation to data reduction. A promising approach for obtaining quantitative estimates of instrumental backgrounds is *ab initio* Monte Carlo simulation [see e.g. 3].

We have developed a suite of Monte Carlo packages, named MGGPOD [13], that supports this type of simulation. The original MGGPOD Monte Carlo suite (Version 1.0) and documentation have been publicly available for download from <http://sigma-2.cesr.fr/spi/MGGPOD/> since 2004. First applications include the successful modelling of the instrumental backgrounds of the TGRS Ge spectrometer onboard Wind [13], the SPI Ge spectrometer onboard the INTEGRAL observatory [10, 11], and of the Reuven Ramaty High-Energy Solar Spectroscopic Imager [15].

Since then MGGPOD has found an increasing number of applications including studies of the various instrument concepts for an Advanced Compton Telescope (ACT) [see e.g. 1, 2, 17], for focal plane detectors of Laue lens gamma-ray telescopes such as MAX or the Gamma-Ray Imager (GRI) [14, 16, 7], and for coded mask hard X-ray telescopes such as EXIST [4, 5]. These studies required additions to and improvements of the original MGGPOD Version 1.0, which will be made available to the general community in the forthcoming public release of Version 1.1 of MGGPOD after completing rigorous testing by the ACT and GRI collaborations.

In this paper we provide an overview of the capabilities, usage, and structure of the MGGPOD package, as well as a description of the additions and improvements implemented in Version 1.1.

## 2. THE MGGPOD MONTE CARLO SIMULATION SUITE

High-energy astronomy instruments are operated in an intense and complex radiation environment [see e.g. 13]. The MGGPOD Monte Carlo suite allows *ab initio* simulations of instrumental backgrounds – including the many gamma-ray lines – arising from interactions of the various ambient particle and photon radiation fields within the instrument and spacecraft materials. It is possible to simulate both prompt instrumental backgrounds, such as energy losses of cosmic-ray particles and their secondaries, as well as delayed instrumental backgrounds, which are due to the decay of radioactive isotopes produced in nuclear interactions. Of course, MGGPOD can also be used to study the response of gamma-ray instruments to astrophysical and calibration sources. The MGGPOD suite is therefore an ideal Monte Carlo tool for high-energy astronomy. A detailed description of the physics implemented in the original MGGPOD Monte Carlo suite (Version 1.0) can be found in Weidenspointner et al. [13]. The documentation available from the MGGPOD web site provides comprehensive practical advice for users.

### 2.1. Capabilities and Functionalities

MGGPOD is a suite of five closely integrated Monte Carlo packages, namely **MGEANT**, **GALOR**, **PROMPT**, **ORIHET**, and **DECAY**. The MGGPOD suite resulted from a combination of the NASA/GSFC MGEANT [9] and the University of Southampton GGOD [3] Monte Carlo codes, which were supplemented with the newly developed PROMPT package. All these packages are based on the widely used GEANT Detector Description and Simulation Tool (Version 3.21) created and supported at CERN<sup>1</sup>, which is designed to simulate the passage of elementary particles through an experimental setup.

In the following, we provide a synopsis of the capabilities and functions of the five packages that constitute the MGGPOD suite:

- MGEANT [9] is a multi-purpose simulation package that was created to increase the versatility of the GEANT simulation tool. A modular, “object oriented” approach was pursued, allowing for rapid prototyping of detector systems and easy generation of most of the radiation fields relevant to high-energy astronomy. Within the MGGPOD suite, MGEANT (i.e. GEANT) stores and transports all particles, and treats electromagnetic interactions from about 1 keV to a few TeV<sup>2</sup>. MGEANT pro-

<sup>1</sup>see <http://wwwinfo.cern.ch/asd/geant/>

<sup>2</sup>By default, the low-energy cutoff in GEANT is 10 keV. This cutoff energy can, however, be lowered, as e.g. described in the MGGPOD documentation. We have successfully lowered the cutoff energy down to 1 keV.

vides the option to use the GLECS and GLEPS packages to take into account the energy of bound electrons and photon polarization in Rayleigh and Compton scatterings (see Sec. 3). The MGEANT simulation package and a user manual are available at a NASA/GSFC web site<sup>3</sup>.

- GALOR [18] simulates hadronic interactions down to 1 MeV for nucleons and charged pions and down to thermal energies ( $10^{-5}$  eV) for neutrons. Equally important, this package<sup>4</sup> provides access to the energy deposits from all hadronic interactions as well as to isotope production anywhere in the simulated setup.
- PROMPT simulates prompt photon emission associated with the de-excitation of excited nuclei produced by neutron capture, inelastic neutron scattering, and spallation.
- ORIHET, originally developed for the GGOD suite [3] and improved for MGGPOD, calculates the build-up and decay of activity in any system for which the nuclide production rates are known. Hence ORIHET can be used to convert nuclide production rates, determined from simulations of cosmic-ray irradiation, to decay rates. These are required input for simulating the radioactive decays giving rise to delayed background.
- DECAY, again originally developed for GGOD and improved for our purposes, enables MGGPOD to simulate radioactive decays.

### 2.2. Structure

The overall structure of the MGGPOD package is illustrated in Fig. 1. Depending on the simulated radiation field or high-energy photon source distribution one or three steps, requiring two or three input files, are needed to obtain the resulting energy deposits in the detector system under study. In general, it is advisable to simulate each component of the radiation environment separately. MGGPOD distinguishes two classes of radiation fields.

- Class I comprises radiation fields for which only prompt energy deposits are of interest, such as celestial or laboratory gamma-ray sources or cosmic-ray electrons.
- Class II comprises radiation fields for which in addition delayed energy deposits resulting from the activation of radioactive isotopes need to be considered. Examples for Class II fields are cosmic-ray protons, geomagnetically trapped protons, or neutrons leaking from the Earth’s atmosphere.

<sup>3</sup>see <http://hea-www.gsfc.nasa.gov/docs/gamcosray/legr/mgeant/mgeant.html>

<sup>4</sup>see <http://www.staff.uni-mainz.de/zeitnitz/Gcalor/gcalor.html>

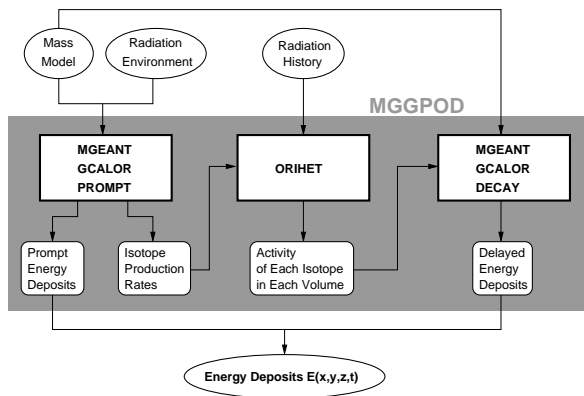


Figure 1. A flow chart illustrating the overall structure of the MGGPOD Monte Carlo simulation suite. The various simulation packages (shown in boxes) and input and output files (shown in ellipses and round-edged boxes) are explained in the text

For both of these classes, the simulation of the prompt energy deposits requires two inputs: a mass model, and a model of the simulated radiation field. The mass model is a detailed computer description of the experimental setup under study. It specifies the geometrical structure of instrument and spacecraft, the atomic and/or isotopic composition of materials, and sets parameters that influence the transport of particles in different materials. Each component of the radiation environment (and analogously for gamma-ray sources) to which the instrument is exposed is characterized by three quantities: the type of the incident particles, and their spectral and angular distributions. The prompt energy deposits are written to an output event file; in case of a Class II radiation field there is an additional output file in which all the nuclei produced in hadronic interactions are recorded.

To simulate delayed energy deposits (Class II radiation field only) two additional steps need to be taken. These require as input the time history of the radiation field which is responsible for the activation, and the isotope production rates obtained previously during the simulation of prompt background. Based on this information, first the activity of each isotope produced in each structural element of the mass model is determined. Then these activities are used to simulate the delayed energy deposits in the instrument due to radioactive decays in each volume of the mass model.

Combining prompt and delayed energy deposits from each component of the radiation environment and gamma-ray sources, it is possible to obtain the energy deposited in the system as a function of position and time. In particular, it is e.g. possible to obtain background energy spectra and rates for each detector element, and to assess the individual contributions of the various background components and mass model volumes, which is highly valuable when designing new instruments.

### 3. ADDITIONS AND IMPROVEMENTS FOR MGGPOD VERSION 1.1

The additions to and improvements of the original MGGPOD Version 1.0 were driven by the requirements for studying various instrument concepts for an Advanced Compton Telescope (ACT), Laue lens gamma-ray telescope focal plane detectors, and coded mask hard X-ray telescopes. The original version of MGGPOD was mainly tested by modelling gamma-ray instruments that employ monolithic Ge detectors, such as the TGRS Ge spectrometer onboard Wind [13], the SPI Ge spectrometer onboard the INTEGRAL observatory [10, 11], and of the Reuven Ramaty High-Energy Solar Spectroscopic Imager [15]. Future high-energy instruments will use highly segmented or pixellated detectors. In particular detectors for Compton telescopes aim not only at recording the energy of each incoming photon, but rather at recording the complete interaction sequence. Furthermore, a large number of different detector materials is being considered for future instrumentation (e.g. Si, Xe, CZT, CdTe); hadronic interactions and nuclear de-excitations for these were not well treated in Version 1.0 of MGGPOD.

All recent upgrades of the original MGGPOD suite will soon be publicly released in Version 1.1, after completing rigorous testing by the ACT and GRI collaborations. The additions and improvements for MGGPOD Version 1.1 are as follows.

- We introduced new beam geometries. It is now possible to model radiation fields whose intensity varies with zenith angle – a requirement for simulating e.g. Earth leakage radiations in low-Earth orbit (gamma-rays, neutrons, ...), or atmospheric background at balloon altitudes. Models can e.g. be generated with the ACTtools software available at <http://public.lanl.gov/mkippen/actsim/glecs/>. Also, new beam options were introduced to enable the simulation of photon beams from Laue diffraction lenses or hard X-ray mirrors.
- Additional output formats optimized for use with event reconstruction algorithms have been implemented. Among other information, it is possible to record the complete interaction information for all involved particles in passive as well as active (i.e. detector or veto shield) instrument materials. This is necessary e.g. for the creation of (probability based) response files for event reconstruction algorithms for Compton telescopes [e.g. MEGALib, see 19]. It is also possible to record vertex (i.e. initial position) and momentum vector for each simulated particle. This capability to retrace the origin of each event has also been helpful for optimizing e.g. the design of active and passive shielding for high-energy instrumentation.
- One of the many exciting science goals of the next generation of high-energy instruments is to measure

polarization. To include the effects of polarized incident photons in the Compton and Rayleigh scattering processes, the GLEPS package<sup>5</sup> is now available in MGGPOD. GLEPS [8] is an extension of the GLECS GEANT3 Low-Energy Compton Scattering Package [6], which takes into account the energy of bound electrons in photon scattering processes.

- The standard set of neutron cross sections available for GCALOR does not cover all elements/isotopes relevant for studying gamma-ray instrumentation. For selected elements/isotopes, we converted into GCALOR format the respective evaluated ENDF/B and JENDL neutron cross sections (complemented by other databases for isotopes of Zn missing in ENDF/B and JENDL). A slight modification of GCALOR was necessary to make sure that all these new cross section files can be read in properly.
- For selected elements/isotopes relevant for high-energy instrumentation (including Ge, Si, Xe, Cd, Zn, Te, Cs, I) we generated the PROMPT data files required to model de-excitations after neutron capture and inelastic neutron scattering. (De-excitations after spallations have already been modelled in Version 1.0 based on statistical considerations as described in [13].)
- In Version 1.0 of MGGPOD it was assumed that nuclei in isomeric states decay exclusively through internal transition. However, this is not always true – some isomeric states can also beta-decay. The beta decay channel of isomeric states has now been implemented, improving the simulation of delayed background due to radioactive decays in common detector materials such as CZT.
- Last but not least, we introduced many checks to avoid improper input by the user or in data files (e.g. DECAY or PROMPT), which if not recognized may lead to run-time errors that are hard to diagnose. In case improper input is identified, error or warning messages are written to the log file, and the run is terminated if necessary.

#### 4. SUMMARY

The MGGPOD Monte Carlo suite is an ideal tool for supporting the various stages of high-energy astronomy missions, ranging from the design, development, and performance prediction through calibration and response generation to data reduction. Version 1.0 of the MGGPOD software and documentation are publicly available for download at CESR. The package has been, and is being, successfully applied to an increasing number of past and present gamma-ray and hard X-ray missions. New applications often entail requirements for new functionalities, hence the MGGPOD suite is evolving continuously. The

additions and improvements required for studying various instrument concepts for an Advanced Compton Telescope, Laue lens gamma-ray telescope focal plane detectors, and coded mask hard X-ray telescopes will be made available to the community in the forthcoming release of Version 1.1 of MGGPOD.

#### REFERENCES

- [1] Boggs, S.E., et al., 2006a, Proc. of SPIE, 6266, 626624-1
- [2] Boggs, S.E., et al., 2006b, ACT Study Report, see *astro-ph/0608532*
- [3] Dean, A. J., et al. 2003, Space Sci. Rev. 105, 285
- [4] Garson, A. et al., 2005, AAS meeting #207
- [5] Garson, A. et al., 2006, Proc. of SPIE 6319, 63190D
- [6] Kippen, M., 2004, New Astr. Rev., 48, 221
- [7] Knödlseeder, J., 2006, Proc. of SPIE 6266, 626623
- [8] McConnell, M., & Kippen, M., 2004, HEAD meeting #8
- [9] Sturmer, S., et al. 2003, A&A, 411, L81
- [10] Weidenspointner, G., et al. 2003a, A&A, 411, L113
- [11] Weidenspointner, G., et al. 2003b, New Astr. Rev. 48, 227
- [12] Weidenspointner, G., et al. 2004, in *Proceedings of 5<sup>th</sup> INTEGRAL Workshop*, ESA SP-552, 905
- [13] Weidenspointner, G., et al. 2005, ApJS, 156, 69
- [14] Weidenspointner, G., et al. 2006, Exp. Ast., 20, 377
- [15] Wunderer, C.B., et al., 2004, *Proceedings of 5<sup>th</sup> INTEGRAL Workshop*, ESA SP-552, 913
- [16] Wunderer, C.B., et al., 2006a, Exp. Ast., 20, 367
- [17] Wunderer, C.B., et al., 2006b, these proceedings
- [18] Zeitnitz, C., & Gabriel, T. A., 1994, NIM A, 349, 106
- [19] Zoglauer, A., et al., 2006, New Astr. Rev., 50, 629

<sup>5</sup>see <http://public.lanl.gov/mkippen/actsim/glecs/>