Recent developments in GEANT4-related activities at ESA: physics, tools, interfaces

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**Geant4 Simulations in the Space domain**

- Simulations in Space domain are just one element in a big picture going from
  - Design, to Construction, Integration, Testing, Launch, Operation
  - In an environment in which commercial companies and not academia are the main players

- Geant4 has been a strategic choice for ESA
  - Advanced physics
  - Extendibility (OO design)
  - Interfaces (Geometry/CAD, visualization, post-processing, analysis)
  - Open source approach (plus code transparency)
  - Long term support in a collaborative world wide effort

- ESA is member of the Geant4 Collaboration since 1997

- Two communities of Geant4 Space Users
  - Science
  - Industry

Areas of attention
- Physics
- Interfaces
- Usability
Outline

1. Physics models
2. Interfaces
3. (Engineering) Tools
1. Physics models

- Scientific Exploration:
  Low En EM
- Manned space flight:
  Even Lower En EM and physics for hadrons

2. Interfaces

3. (Engineering) Tools
Simulations of the Space Radiation Environment

Sources

(Extra) Galactic and anomalous Cosmic Rays
- Protons and Ions
- $E_\text{avg} \sim 1 \text{ GeV}$, $E_{\text{max}} > 10^{21} \text{ eV}$
- Continuous low intensity

Solar radiation
- Protons, some ions, electrons, neutrons, gamma rays, X-rays...
- Softer spectrum
- Event driven – occasional high fluxes over short periods

Trapped radiation
- Electrons $\sim 10 \text{ MeV}$
- Protons $\sim 10^2 \text{ MeV}$

Goals

Mission design
- Ground tests
- Extrapolation to real life in space
- Cheaper than accelerator tests

Science analyses
- Particle signal extraction
- Background
- Degradation

Environment models
- Simulation of the emission and the propagation of radiation in space

Effects

Effects in components
- Single Event Effects
  - (SE Upset, SE Latchup, …)
- Degradation
  - (Ionisation, displacement, …)

Effects to science detectors
- Background
  - (Spurious signals, Detector overload, …)
- Charging
  - (internal, interferences, …)

Threats to life
- Dose (dose equivalent) and dose rate in manned space flights
- Radiobiological effects
Space environment and Physics models

Geant4 models

- Optical
- EM Standard
- EM Low Energy
- HAD protons
- HAD ions

Space environment

- Plasma
- Tr. Electrons
- Tr. Protons
- Solar protons
- Cosmic rays: p, α, ions
- Extreme Energy Cosmic Rays

Energies:
- 100 eV
- 1 keV
- 10 MeV
- 100 MeV
- 100 GeV
- 100 TeV
- 100 PeV
Mercury BepiColombo X-ray spectrometer

- Rock samples irradiation and fluorescence emission measurement
  - Geant4 atomic deexcitation
  - Physics validation
  - Creation of a reference database

- The simulation reproduces:
  - Complex geological materials
  - Experimental Geometry
  - Response and efficiency of the detector
Geant4 DNA

- Damage mechanisms
- Interactions of Radiation with Biological Systems at the Cellular and DNA Level

**Geant4-DNA collaboration (ESA funding)**

- Electromagnetic interactions in liquid water down to ~7.5 eV
  - $e^-, p, H, He$
- Validation: two independent computations by LPC Clermont & CENBG from literature

<table>
<thead>
<tr>
<th>$e^-$ Total cross section</th>
<th>Energy deposit</th>
<th>Rutherford + screening factor</th>
<th>Emfietzoglou</th>
<th>No models</th>
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<td>$e^-, H, He, He^+, He^{++}$ energy distribution</td>
<td>Tabulated</td>
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</table>

Human phantom library
Applications in radiation protection, therapy protocol studies

Analytical model
G. Guerrieri
INFN Genova

See related talks in this session
DESIRE Physics validation


DESIRE Physics validation

DESIRE web page:
http://gluon.particle.kth.se/desire
Physics for hadrons (ions) in GEANT4

http://reat.space.qinetiq.com/ionmarse/ionmarse.htm

- ESA – IONMARSE (P. Truscott, Qinetiq)
  - New nuclear-nuclear cross sections
  - Abrasion/Ablation (Wilson) in Geant4

- HADI (V. Ivantchenko)
  - Hadron and Ion models

- Also important for SEE studies
2. Interfaces

1. Physics models

2. Interfaces
   - Materials
   - CAD geometries
   - SPENVIS

3. (Engineering) tools
### NIST materials in Geant4

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<th>Z Name</th>
<th>ChFormula</th>
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<th>I(eV)</th>
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</table>

### NIST Elementary Materials

- NIST Elementary Materials
- NIST Compounds
- Nuclear Materials
- Space Materials

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V. Ivantchenko  
(ESA contract)
CAD Interface

Several examples of existing interfaces
- ESA ongoing contract (QinetiQ+sub.) to develop public prototype
- Future contract (2006) to integrate GEANT4 interface with GUI

Vanderbilt University (2005)

EFACEC (2005)

QinetiQ (2005)
SPENVIS
Space Environment Information System

- Space Environment Information System
  - Models and tools for the space environments effects analysis
  - Also GEANT4-based models

- Web Interface
  - Mission model
    - Orbit, attitude
  - Space environment models
  - Radiation transport
    - Simulation engine
  - Effects Analysis
    - Damage mechanisms
    - Charging
    - SEE
    - Effects to humans
SPENVIS / GEANT4 Space Users Workshop
3-7 Oct 2005

- Joint session: GEANT4 tools in SPENVIS
  (now or in the near future)
  - MULASSIS
  - MAGNETOCOSMICS
  - GRAS
  - GEMAT
Geant4 Space Users

- Gather and help the GEANT4 space user community

- New web page
  - User list
  - Related publications
  - Resources (codes...)
  - Related events
  - ...

- Events
  - Tutorials
  - Space User Workshops
  - ...

http://geant4.esa.int
GEANT4 Tutorial for Space Industry

3 March 2005
ESA / ESTEC

Organisation:
Giovanni Santin
Petteri Nieminen
Ali Mohammadzadeh

Space Environments and Effects Analysis
Radiation Effects and Component Analysis Techniques

- GEANT4-based tools for Space: **SSAT, QARM, MULASSIS, GRAS**
- ~30 people (despite heavy snowfall, block of Amsterdam airport, …)
- Attendees from industry (not only space) and research institutes
3. (Engineering) tools

1. Physics models

2. Interfaces

3. (Engineering) tools
   - PlanetoCosmics
   - SSAT
   - MULASSIS
   - GEMAT
   - NIEL
   - GRAS
PlanetoCosmics
Cosmic Rays in planetary Atmo- / Magneto- spheres

- Laurent Desorgher, University of Bern

http://reat.space.qinetiq.com/septimess/magcos/
PlanetoCosmics
Mars field and atmosphere

NASA Mars-GRAM2001 model

Geant4 implementation courtesy L. Desorgher,
University of Bern
SSAT
Sector Shielding Analysis Tool

- Ray tracing: from a user-defined point within a Geant4 geometry

SHIELDING

- shielding levels
  fraction of solid angle for which the shielding is within a defined interval
  global and from single materials

- shielding distribution
  the mean shielding level as a function of look direction

- It utilizes geantinos

DOSE

- Estimate of the dose at a point
  - Based on external Dose-Depth curve
    - E.g. SHIELDOSE-2 curve [rad VS g/cm²]
  - Ray-by-ray dose calculation

Results:
- Total dose
- Dose-Depth profile
- Dose directionality

ConeXpress model: R. Lindberg, ESA
MULASSIS
Multi Layered Shielding Simulation

- Layer Geometry
- Physics list choice
- Analysis capabilities
  - Dose
  - Pulse Height Spectrum
  - Ion. dose
  - NIEL
  - Dose equivalent calculation

- Web interface
- Primary particle spectrum and fluences from SPENVIS
  - Trapped protons
  - Solar protons
  - Trapped electrons
  - ...

Giovanni Santin - Recent developments at ESA - Geant4. Bordeaux, 4 Nov 2005
GEMAT
Geant4 Microdosimetry Analysis Tool

AIM
- Single Event Effects in microelectronics

- Dedicated geometry builder UI
- Dedicated physics list
- Built-in analysis modes
  - PHS: SEU rates
  - Path-length

- Analogy with medical microdosimetry for physics models
**NIEL**

Non Ionizing Dose and Damage

**AIM**
- Facilitate qualification procedure for new electronic devices used in space missions

- Displacement Damage (DD) in semiconductors induced by NIEL

- Performance degradation of electronics components

- Uses Screened Coulomb scattering
  - Implementation by Vanderbilt University

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**Graphs**

**NIEL due to elastic Coulomb scattering of p, α and Si in silicon**

Dependency on projectile properties as expected

**Coulomb and Total Proton NIEL for Silicon**

(Lindhard-Approximation, $E_d = 21$ eV)

**References**

GRAS
GEANT4 Radiation Analysis for Space

- Detector / Component effects
  - Dose, Fluence, NIEL, charging… for support to engineering and scientific design

- Human dosimetry
  - Dose Equivalent, Equivalent Dose for ESA exploration initiative

- 3D geometry
  - GDML format, or existing C++ class

- Ready-To-Use tool
  - Different analyses set without re-compilation

- Modular / extendable design

- Integration with GATE under investigation
  - Many commonalities

- Is being integrated into SPENVIS

GRAS open distribution

- [http://geant4.esa.int](http://geant4.esa.int)

- Working on Windows distribution
  - InstallShield
  - AIDA/OpenScientist (Win) included


Giovanni Santin - Recent developments at ESA - Geant4, Bordeaux, 4 Nov 2005
GRAS use cases

- JWST background
- TOF for neutron production exp.
- Total Dose in ConeXpress
Interface GEANT4 to CAD GUI (or CAD GUI to GEANT$)

GUI tool

Geometry modeling

Script instructions:
- Physics
- Radiation Environment
- Analysis type

GEANT4

Geometry exchange format
- GDML
- CAD / STEP
- …
Planned developments

- Radiation Effects on Advanced Technologies – Models and Software (Part II)
- Martian Radiation Environment Models; AO published in Oct 2005
  Extension of the developments presented in this Workshop + Geant4 heavy ion hadronic physics work + “active shield” concept analysis. Focus on ESA ExoMars mission.
- Preparatory Study of Investigations into Biological Effects on Radiation (AO now closed)
- Long-term R&D roadmap for the Exploration programme existing
Conclusions

- GEANT4 studies essential part of human space mission design and optimization
- Increased use of Geant4 in space thanks to tools and applications
- Extensions of present physics and interfaces required for manned and unmanned space missions
- Synergies with medical activities to address critical areas of improvement
  - Interfaces
  - Physics model extensions
- Fruitful collaboration in the past among ESA, GEANT4 collaboration, academia and external institutes

http://geant4.esa.int
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