

# Geant4 Package in SPENVIS

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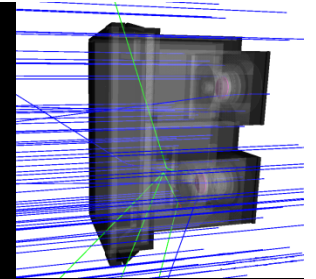
**Tutorial**



**Geant4 Package in SPENVIS**

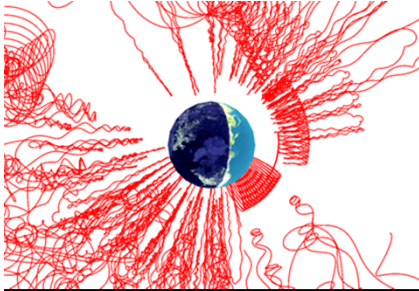
SPENVIS User Workshop  
Brussels 2013

# Outline



- Introduction
- Overview of the Geant4 models in SPENVIS
- Material definition
- GDML geometry definition
- Particle source
- GDML source geometry for GRAS
- Physics scenario & cuts-in-range
- Selecting analysis parameters
- Future ... Next Generation SPENVIS

**Tutorial**

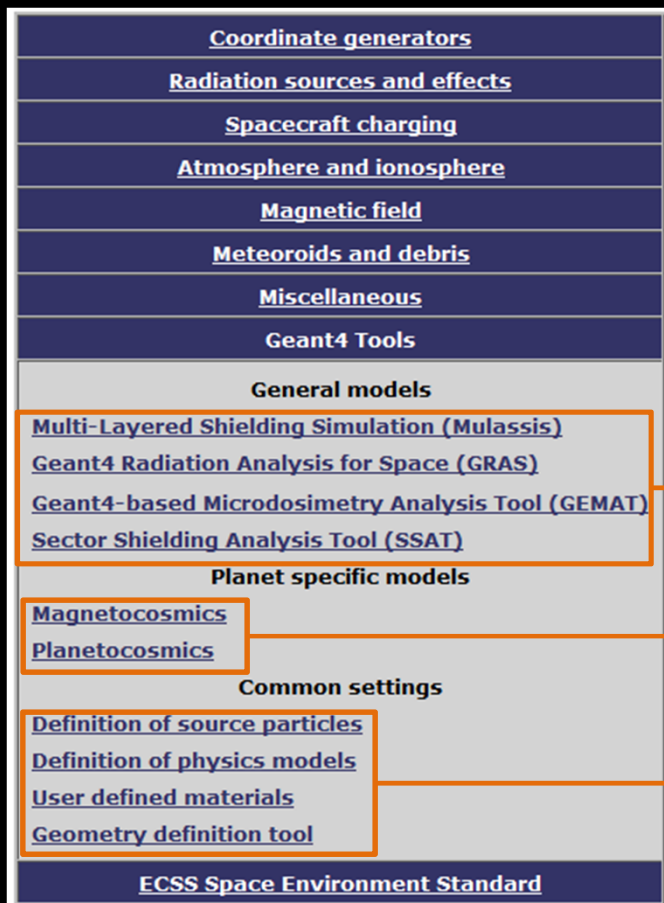


# Introduction

- User friendly interface
- No prior knowledge of Geant4
- Generated macro file can be used directly by local Geant4 application
- Interaction with other SPENVIS models & tools

**Tutorial**

# Introduction



Models available for all planets

Model availability depends on planet selection

Tools providing inputs for multiple models

Tutorial

# Introduction

<a href="#">Coordinate generators</a>
<a href="#">Radiation sources and effects</a>
<a href="#">Spacecraft charging</a>
<a href="#">Atmosphere and ionosphere</a>
<a href="#">Magnetic field</a>
<a href="#">Meteoroids and debris</a>
<a href="#">Miscellaneous</a>
<a href="#">Geant4 Tools</a>
<b>General models</b>
<b><a href="#">Multi-Layered Shielding Simulation (Mulassis)</a></b>
<a href="#">Geant4 Radiation Analysis for Space (GRAS)</a>
<a href="#">Geant4-based Microdosimetry Analysis Tool (GEMAT)</a>
<a href="#">Sector Shielding Analysis Tool (SSAT)</a>
<b>Planet specific models</b>
<a href="#">Magnetocosmics</a>
<a href="#">Planetocosmics</a>
<b>Common settings</b>
<a href="#">Definition of source particles</a>
<a href="#">Definition of physics models</a>
<a href="#">User defined materials</a>
<a href="#">Geometry definition tool</a>
<a href="#">ECSS Space Environment Standard</a>

Status	Settings	Remarks
default	<a href="#">Source particles</a>	---
default	<a href="#">Geometry</a>	---
missing	<a href="#">Analysis parameters</a>	Need user selection
<b>Advanced settings</b>		
default	<a href="#">Material definition</a>	---
default	<a href="#">Region cut-in-range</a>	---
default	<a href="#">Physics models</a>	---

Create macro

**Geometry:** User defined

Shape: planar slab    Number of layers: 2

Layer number	Material	Thickness (unit)	Visualisation colour
Layer 1	G4_Al	11.0 mm	grey
Layer 2	G4_Si	2.0 mm	yellow

**Visualisation**

Format: Virtual Reality Modelling Language (VRML)

Particle tracks: Display

Reset    Save >>

Status	Settings	Remarks
defined	<a href="#">Source particles</a>	mono-energetic, e-
defined	<a href="#">Geometry</a>	Planar slab, 2 layers
defined	<a href="#">Analysis parameters</a>	Fluence
<b>Advanced settings</b>		
defined	<a href="#">Material definition</a>	2 material defined
default	<a href="#">Region cut-in-range</a>	---
defined	<a href="#">Physics models</a>	Standard EM, Hadron

Create macro

Tutorial

# Introduction

<a href="#">Coordinate generators</a>
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<b>ECSS Space Environment Standard</b>

Status	Settings	Remarks
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default	<a href="#">Geometry</a>	---
missing	<a href="#">Analysis parameters</a>	Need user selection
<b>Advanced settings</b>		
default	<a href="#">Material definition</a>	---
default	<a href="#">Region cut-in-range</a>	---
default	<a href="#">Physics models</a>	---

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Format: Virtual Reality Modelling Language (VRML)

Particle tracks: Display

Reset    Save >>

Status	Settings	Remarks
defined	<a href="#">Source particles</a>	mono-energetic, e-
defined	<a href="#">Geometry</a>	Planar slab, 2 layers
defined	<a href="#">Analysis parameters</a>	Fluence
<b>Advanced settings</b>		
defined	<a href="#">Material definition</a>	2 material defined
default	<a href="#">Region cut-in-range</a>	---
defined	<a href="#">Physics models</a>	Standard EM, Hadron

Create macro

Use macro for a local run  
OR  
Run model on SPENVIS

Tutorial

# Overview of the Geant4 models in SPENVIS

- **Geant4 Radiation Analysis for Space (GRAS v2.3, v3.1)**
  - General space radiation analysis for 3D geometry models
- **Multi-Layered Shielding Simulation (MULASSIS v1.19, v1.23)**
  - Radiation analysis for a multi-layered, one-dimensional shield
- **Geant4-based Microdosimetry Analysis Tool (GEMAT v2.4, v2.8)**
  - Microdosimetry effects of space radiation on micro-electronics and micro-sensors
- **Sector Shielding Analysis Tool (SSAT v2.1)**
  - Performs ray tracing from a user defined point within the geometry to determine shielding levels and shielding distributions

Tutorial

# Overview of the Geant4 models in SPENVIS

- **MAGNETOCOSMICS (v2.0)**
  - Charged particle trajectories & magnetic field lines
  - Cut-off rigidities as a function of position
- **PLANETOCOSMICS (v2.0)**
  - Definition of a planetary magnetic field, atmosphere & soil
  - Interactions of cosmic rays with planetary environment
- **Supporting Tools**
  - Geometry definition tools
  - GDML analysis tool
  - Material definition tool



# Overview of the Geant4 models in SPENVIS

## Other:

- Mars Energetic Radiation Environment Models (MEREM)
- Jupiter Radiation Environment and Effects Models and Mitigation (JOREM)
  - PLANETOCOSMICS-J
  - Genetic Algorithm Radiation Shield Optimiser (GARSO) for MULASSIS
- MC-SCREAM
  - NIEL based damage equivalent fluences for solar cells

# Material definition

Used by:  
MULASSIS, GRAS, GEMAT &  
PLANETOCOSMICS

User defined materials (4)

G4_AI (Al)	Del
G4_GLASS_PLATE (*N.A.*)	Del
G4_ALUMINUM_OXIDE (Al <sub>2</sub> O <sub>3</sub> )	Del
gallium_arsenide (Ga-As)	Del

Adding new material

Source: NIST compounds

Material: Calcium Tungstate

Chemical formula: Ca-W-O<sub>4</sub>

Density [g cm<sup>-3</sup>]: 6.062

Add

Reset Save >>

User defined  
SPENVIS list  
NIST pure elements  
NIST compounds

Blood ICRP  
Bone Compact ICRU  
Bone Cortical ICRP  
Boron Carbide  
Boron Oxide  
Brain ICRP  
Butane  
n-Butanol  
C-552  
Cadmium Telluride  
Cadmium Tungstate  
Calcium Carbonate  
Calcium Fluoride  
Calcium Oxide  
Calcium Sulfate  
Calcium Tungstate  
Carbon Dioxide  
Carbon Tetrachloride  
Cellulose Cellophane  
Cellulose Butyrate

# Material definition: User defined

Used by:  
MULASSIS, GRAS, GEMAT &  
PLANETOCOSMICS

Unique name  
chosen by user

No user materials have been defined

**Adding new material**

Source: User defined

Name<sup>(\*)</sup>:

Chemical formula:

Density [g cm<sup>-3</sup>]: 1

(\*) should include only letters, digits or underscores and start with a letter

Special syntax required:

- chemical symbol & stoichiometric proportion
- hyphen to separate elements
- isotope and stoichiometry defined by integers

[www.spennis.oma.be/help/models/g4\\_material.html](http://www.spennis.oma.be/help/models/g4_material.html)

<http://www.spennis.oma.be/forum/viewtopic.php?f=5&t=116>

# GDML geometry definition

Available for  
GRAS & SSAT

GRAS execution mode: GDML		
Status	Settings	Remarks
default	<a href="#">Source particles</a>	---
default	Source geometry	no visualisation
error	Analysis parameters	Load GDML first
Advanced settings		
missing	<b>GDML definition</b>	Need user selection
default	Region cuts-in-range	---
default	<a href="#">Physics models</a>	---

Create macro

Status	Settings	Remarks
default	<a href="#">Shielding distribution</a>	---
default	<a href="#">Ray tracing</a>	---
missing	<b>GDML definition</b>	Need user selection

Source: **new file upload**

Title: simple geometry

File: D:\Users\neophytos\Documents\SPENVIS-4\SPENV

last geometry definition  
uploaded GDML file  
new file upload

Tutorial

# GDMML geometry definition

Source:

Title:

File:

Status	Settings	Remarks
default	<a href="#">Shielding distribution</a>	---
default	<a href="#">Ray tracing</a>	---
defined	<a href="#">GDMML definition</a>	upl, <a href="#">GDMML file analysis</a>

**GDMML NAMELIST used by GRAS templates**

**GDMML file**

File: spenvis\_gdm.gdm (1381)

**Content summary**

Surroundings: volume 'World'  
                   material 'Vacuum'

Statistics: 2 material(s)  
                   1 solid volume(s)  
                   0 empty volume(s)

**Structure overview**

Structure:     • World (Vacuum)

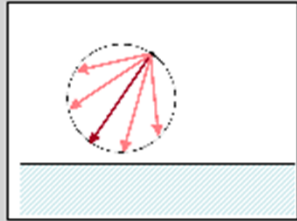
```

+1.00 +0.00 +0.00 +0.00
+0.00 +1.00 +0.00 +0.00
+0.00 +0.00 +1.00 +0.00
+0.00 +0.00 +0.00 +1.00

   o v01 (G4_A1)
      +1.00 +0.00 +0.00 +0.00
      +0.00 +1.00 +0.00 +0.00
      +0.00 +0.00 +1.00 +0.00
      +0.00 +0.00 +0.00 +1.00
    
```

# Incident particle source: User defined

Used by:  
MULASSIS, GRAS,  
GEMAT &  
PLANETOCOSMICS

Source particle type and spectrum		
Environment:	User defined	mono-energetic
Number of primary particles to simulate:	100,000	
Warning: Particle track visualisation will be disabled!		
Incident particle type:	proton	
Incident energy spectrum		
Mono-energetic energy:	35.0	[MeV]
Fluence/(Flux) intensity:	1.0	[cm <sup>-2</sup> (s <sup>-1</sup> )]
Angular distribution:		
Angular distribution:	cosine-law	
Minimum angle:	0.0	[degrees]
Maximum angle:	90.0	[degrees]
		
Reset Save >> Create GPS macro		

mono-energetic  
linear  
power law  
exponential  
tabulated

electron  
positron  
proton  
neutron  
alpha  
ion  
gamma  
neutrino

cosine-law  
isotropic  
parallel beam  
none

# Incident particle source: Mission based

## energy biasing:

- electron results can be misleading due to Bremsstrahlung
- improve simulation efficiency
- increases probability of low flux particles being generated
- useful when spectrum is soft or thick shielding

linear  
power-law  
exponential  
cubic spline

**Source particle type and spectrum**

Environment: Mission based

Number of primary particles to simulate:

Incident particle type:

**Incident energy spectrum**

Mission average spectrum

energy biasing

Interpolation type:

**Angular distribution**

The angular distribution follows a cosine-law.

trapped particles  
long-term solar particles

1  
10  
100  
1,000  
10,000  
100,000  
1,000,000  
10,000,000

electron  
proton

**NEW!!**

# Incident particle source: Mission based

```
#
#Source definition
#
# =====
# SPENVIS particle source
# Project: SPENVIS_USER_WORKSHOP_2013
# title:
# Particle: proton
# Mission Segment: 1 365.0 Days
# =====
/gps/particle proton
/gps/ene/type Arb
/gps/hist/type arb
/gps/hist/point 1.000000E-01 3.050200E+08
/gps/hist/point 1.500000E-01 2.332000E+08
/gps/hist/point 2.000000E-01 1.721000E+08
/gps/hist/point 3.000000E-01 1.010300E+08
/gps/hist/point 4.000000E-01 6.609200E+07
/gps/hist/point 5.000000E-01 4.435900E+07
/gps/hist/point 6.000000E-01 3.142400E+07
/gps/hist/point 7.000000E-01 2.321700E+07
/gps/hist/point 1.000000E+00 1.149900E+07
/gps/hist/point 1.500000E+00 3.794100E+06
/gps/hist/point 2.000000E+00 1.468200E+06
/gps/hist/point 3.000000E+00 3.320500E+05
/gps/hist/point 4.000000E+00 1.170500E+05
/gps/hist/point 5.000000E+00 5.038100E+04
/gps/hist/point 6.000000E+00 2.845300E+04
/gps/hist/point 7.000000E+00 1.763900E+04
/gps/hist/point 1.000000E+01 6.878600E+03
/gps/hist/point 1.500000E+01 1.599500E+03
/gps/hist/point 2.000000E+01 4.542900E+02
/gps/hist/point 3.000000E+01 9.340400E+01
/gps/hist/point 4.000000E+01 3.077900E+01
/gps/hist/point 5.000000E+01 1.892200E+01
/gps/hist/point 6.000000E+01 1.089000E+01
/gps/hist/point 7.000000E+01 8.466200E+00
/gps/hist/point 1.000000E+02 5.486300E+00
/gps/hist/point 1.500000E+02 2.841100E+00
/gps/hist/point 2.000000E+02 1.604200E+00
/gps/hist/point 3.000000E+02 5.475100E-01
/gps/hist/point 4.000000E+02 3.646600E-02
/gps/hist/inter Lin
/gps/ang/type cos
#
#Normalisation
#
/control/alias NORM_FACTOR_ENERGY " 2.022277E+15 "
```

```
'Trapped proton model: AP-8 MAX'
0.05, 2.00, 0.00
'Energy','MeV', 1,'Energy'
'IFlux','cm^-2!n s!u-1!n', 1,'Integral Flux'
'DFlux','cm!u-2!n s!u-1!n MeV!u-1!n', 1,'Differential Flux'
1.0000E-01, 6.4126E+07, 3.0502E+08
1.5000E-01, 5.0671E+07, 2.3320E+08
2.0000E-01, 4.0806E+07, 1.7210E+08
3.0000E-01, 2.8636E+07, 1.0103E+08
4.0000E-01, 2.0599E+07, 6.6092E+07
5.0000E-01, 1.5417E+07, 4.4359E+07
6.0000E-01, 1.1727E+07, 3.1424E+07
7.0000E-01, 9.1324E+06, 2.3217E+07
1.0000E+00, 4.6266E+06, 1.1499E+07
1.5000E+00, 1.8101E+06, 3.7941E+06
2.0000E+00, 8.3252E+05, 1.4682E+06
3.0000E+00, 3.3829E+05, 3.3205E+05
4.0000E+00, 1.6842E+05, 1.1705E+05
5.0000E+00, 1.0420E+05, 5.0381E+04
6.0000E+00, 6.7660E+04, 2.8453E+04
7.0000E+00, 4.7290E+04, 1.7639E+04
1.0000E+01, 1.8940E+04, 6.8786E+03
1.5000E+01, 5.9764E+03, 1.5995E+03
2.0000E+01, 2.9453E+03, 4.5429E+02
3.0000E+01, 1.4412E+03, 9.3404E+01
4.0000E+01, 1.0772E+03, 3.0779E+01
5.0000E+01, 8.2559E+02, 1.8922E+01
6.0000E+01, 6.9876E+02, 1.0890E+01
7.0000E+01, 6.0778E+02, 8.4662E+00
1.0000E+02, 4.1063E+02, 5.4863E+00
1.5000E+02, 2.2676E+02, 2.8411E+00
2.0000E+02, 1.2652E+02, 1.6042E+00
3.0000E+02, 4.6217E+01, 5.4751E-01
4.0000E+02, 1.7018E+01, 3.6466E-02
'End of Block'
```

SPENVIS mission average spectrum e.g. from AP-8

Calculated by integrating the differential particle spectrum over the energy limits of the simulation

$$\int_{T_1}^{T_0} f(T)dT = F(T_0) - F(T_1)$$



# GDML source geometry for GRAS

Source geometry			
Length units:	[ mm] ▾		
Centered at:	world ▾		
	x: 0	y: 0	z: 2000
Type:	disk ▾	radius: 20	
Pointing to:	Target_001:Target_001 (mat_Silicon) ▾		
	x: 0	y: 0	z: 0
Visualisation			
Format:	Virtual Reality Modelling Language (VRML) ▾		
	Particle tracks:	Display ▾	
Reset Save >>			

point  
disk  
sphere

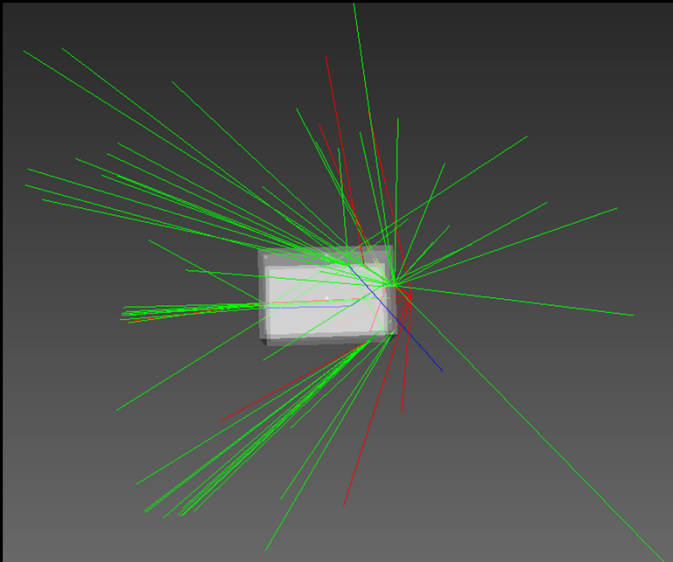
Position of the source

Direction of the gun

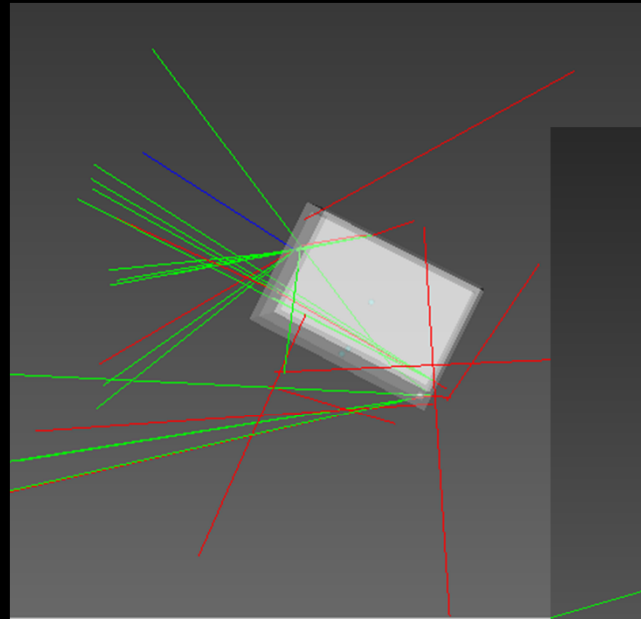
Encapsulated PostScript (EPS)  
Virtual Reality Modelling Language (VRML)

Tutorial

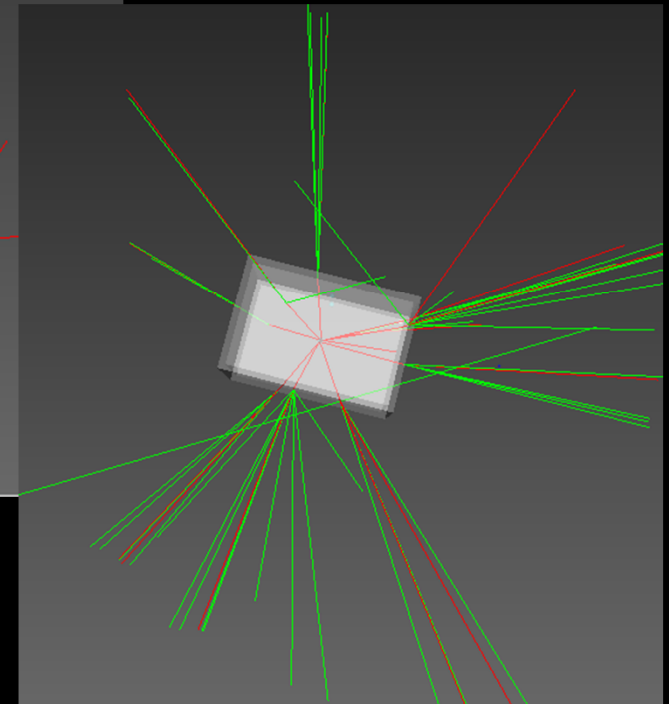
# GDML source geometry for GRAS



Disk source of 20 mm radius



Spherical source of 2 m radius

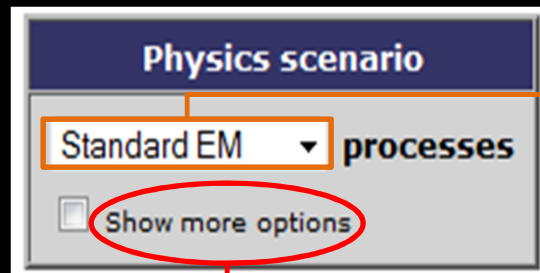


Spherical source of 20 mm radius

All positioned w.r.t world

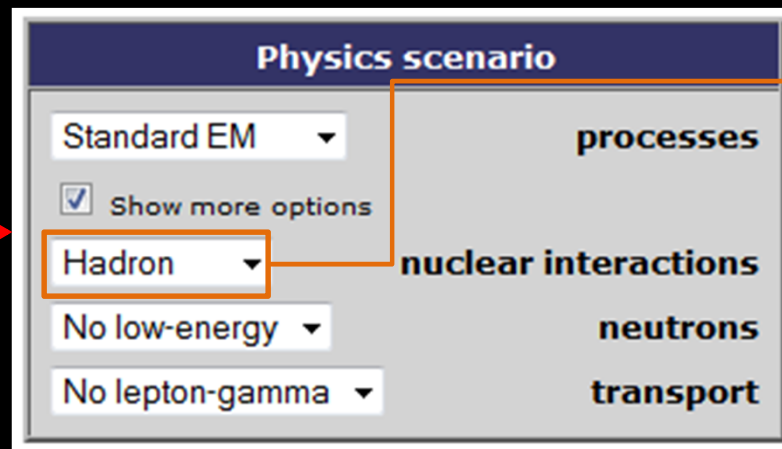
Tutorial

# Physics scenario



Standard EM  
Low-energy EM

Are very low energy EM interactions important to the simulation or not?



No hadron  
Hadron

- No low energy neutrons if only interested in attenuation of incident protons by shielding layers
- Often, for high energy proton interactions it is unnecessary to treat the detailed electron-positron-gamma transport

# Cut-in-range

- General principles in Geant4 regarding secondary particle production cuts:
  1. Each process has its intrinsic limit(s) to produce secondary particles
  2. All particles produced (and accepted) will be tracked up to zero range
  3. Production cuts-in-range are assigned to regions
- A region is a collection of geometry volumes.
- Default region covering the whole geometry with global cut-in-range for gamma, electron and positron productions.
- User can change the global production cuts-in-range. The default values for the global cuts-in-range length is 1  $\mu\text{m}$ .
- A cut of for example 1. mm for photons means that no photon will be produced if the expected range in the current material is less than 1. mm.

# Selecting analysis parameters

GRAS

Analysis type: Total ionizing dose

Energy deposition / TID

Output units: rad

Select 2 volumes for analysis:

Volume 1: Target\_001:Target\_001 (mat\_Silicon)

Volume 2: Target\_111:Target\_111 (mat\_Silicon)

Reset Save >>

- Fluence
- Total ionizing dose
- Mulassis only*
- Non ionizing dose
- Pulse height spectrum
- GRAS only*
- Non ionizing energy loss
- Dose equivalent analysis
- Equivalent dose

MULASSIS

Analysis type: Total ionizing dose

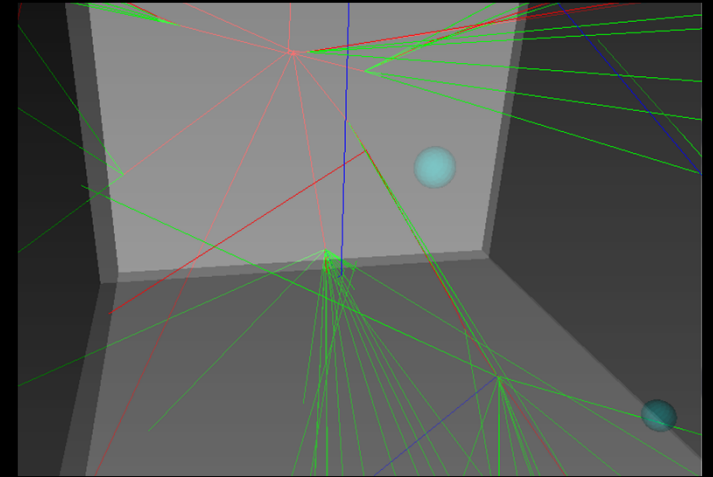
Energy deposition / TID

Output units: rad

Select layers for energy deposition/total ionising dose analysis:

1  2

Reset Save >>



Tutorial

# GRAS fluence analysis: GDML mode

Analysis type:

Fluence analysis

Select particle type(s):   
electron  
gamma  
proton  
neutron  
pion  
muon

Select  interface(s) for analysis:

1.

2.

3.   and

Energy binning mode:

Number of bins:

Lower edge of lowest energy bin:

Upper edge of highest energy bin:

## Note that:

- The order of the volume names is important!!
- Volumes must share a boundary otherwise output fluence is zero

# GRAS fluence analysis: GDML mode

Analysis type: **Fluence**

**Fluence analysis**

Select particle type(s): **incident particle**  
electron  
gamma  
proton  
neutron  
pion  
muon

Select **3** interface(s) for analysis:

1. **from** **Spacecraft2:Spacecraft2 (mat\_Aluminium)**

2. **to** **Target\_000:Target\_000 (mat\_Silicon)**

3. **between** **Spacecraft2:Spacecraft2 (mat\_Aluminium)** and **Target\_001:Target\_001 (mat\_Silicon)**

Energy binning mode: **linear**

Number of bins: **10**

Lower edge of lowest energy bin: **0.0** MeV

Upper edge of highest energy bin: **100.0**

**Reset** **Save >>**

```
#  
#Analysis definition  
#  
/gras/analysis/fluence/addModule fluence1  
/gras/analysis/fluence/fluence1/addVolumeInterface {Spacecraft2} *
```

```
/gras/histo/setHistoByName fluence1_fluence_e- 10 0.000E+00 0.100E+03 MeV lin  
/gras/histo/setHistoByName fluence1_fluence_proton 10 0.000E+00 0.100E+03 MeV lin  
/gras/histo/setHistoByName fluence1_fluence_neutron 10 0.000E+00 0.100E+03 MeV lin
```

# Future work

- Separate macro file for the source + GCRs as source
- Revisit physics scenario definition
- New functionalities in GRAS v3.1. e.g. reverse MC, normalisation, new analysis types (LET analysis, charging etc.)
- Geant4 models will continue being an important element in the new SPENVIS-NG
- New models will be more easily integrated (plug-in models, machine-machine interface etc.)



# Bibliography

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- Santin G. et al, *Particle radiation transport and effects models from research to space weather operations*, 38th COSPAR Scientific Assembly, Bremen 18-15 July, p.11, 2010
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- Truscott P. et al, *Simulation of the Radiation Environment Near Europa Using the Geant4-Based PLANETOCOSMICS-J Model*, IEEE Trans. Nucl. Sc, vol. 58, 6, 2776-2784, 2011
- ECSS-E-HB-10-12A, Calculation of radiation and its effects and margin policy handbook

# Useful links

- **Geant4 General Particle Source Users Manual:**  
[http://reat.space.qinetiq.com/gps/new\\_gps\\_sum\\_files/gps\\_sum.htm](http://reat.space.qinetiq.com/gps/new_gps_sum_files/gps_sum.htm)
- **Geant4 home:** <http://geant4.web.cern.ch/geant4/>
- **Geant4 Space Users:** <http://geant4.esa.int/index.php/home.html>
- **GEMAT home:** <http://reat.space.qinetiq.com/gemat/>
- **GRAS home:** <http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html>
- **MAGNETOCOSMICS home:** <http://cosray.unibe.ch/~laurent/magnetocosmics/>
- **MULASSIS home:** <http://reat.space.qinetiq.com/mulassis/>
- **PLANETOCOSMICS home:** <http://cosray.unibe.ch/~laurent/planetocosmics/>
- **SSAT home:** <http://reat.space.qinetiq.com/ssat/>