

Highlights from the
GEANT4 Space Users' Workshop
Leuven, 3-7 Oct 2005

Giovanni Santin*



*Rhea System SA
@ Space Environments and Effects Analysis
ESA / ESTEC

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Joint Workshop

- SPENVIS: Space Environment Information System
- Geant4 Space Users

3 - 7 October 2005

Faculty Club Leuven, Belgium



SPENVIS workshop

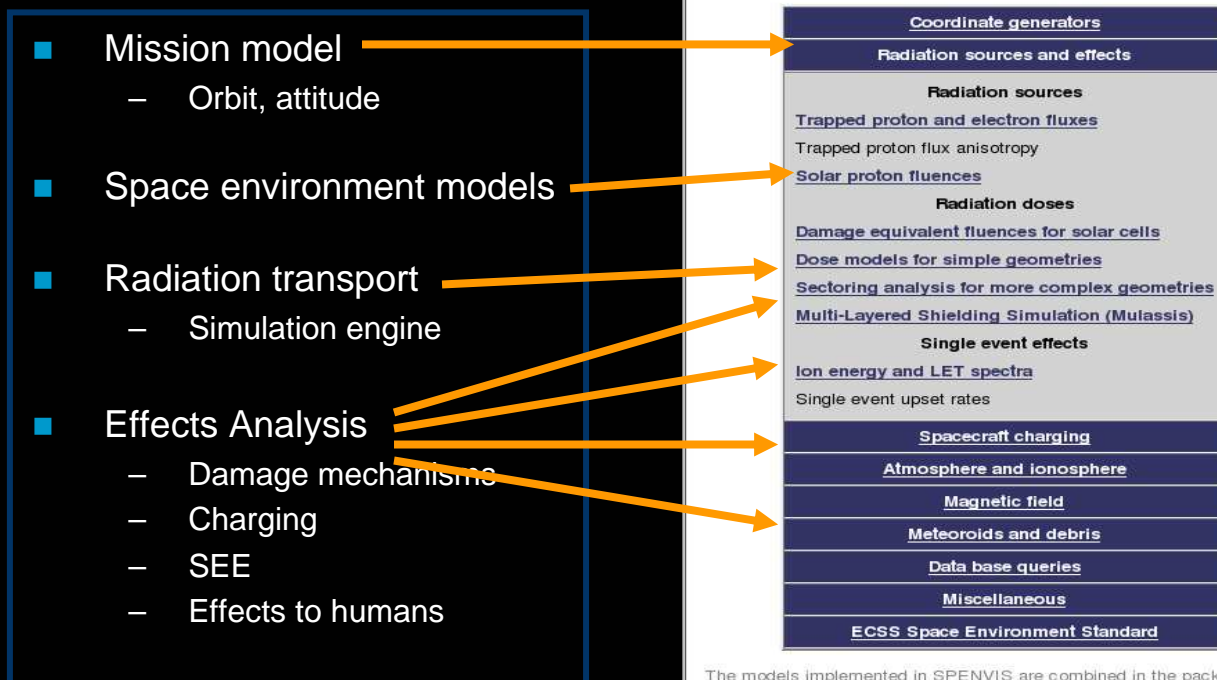
- SPENVIS
 - Space Environment Information System
 - Sample from sessions
- Joint
- Geant4 Space Users



SPENVIS

Space Environment Information System

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



Model packages - Konqueror

Location Edit View Go Bookmarks Tools Settings Window Help

Location: <http://miura.oma.be/spenvis/htbin/spenvis.exe?%23chi>

SPENVIS DEVELOPER Project: JWST Model packages

UP Output Help

Coordinate generators

Radiation sources and effects

Radiation sources

Trapped proton and electron fluxes

Trapped proton flux anisotropy

Solar proton fluences

Radiation doses

Damage equivalent fluences for solar cells

Dose models for simple geometries

Sectoring analysis for more complex geometries

Multi-Layered Shielding Simulation (Mulassis)

Single event effects

Ion energy and LET spectra

Single event upset rates

Spacecraft charging

Atmosphere and ionosphere

Magnetic field

Meteoroids and debris

Data base queries

Miscellaneous

ECSS Space Environment Standard

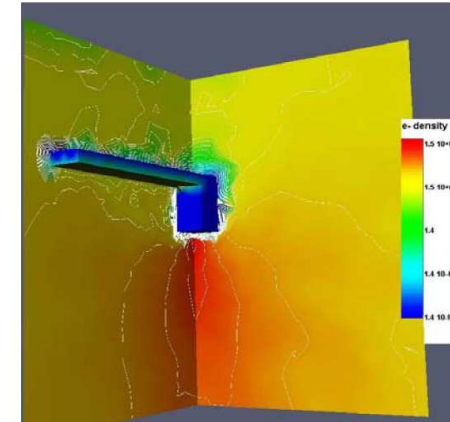
The models implemented in SPENVIS are combined in the packages listed above. Clicking on a package name will expand the table with a list of models. Some model suites have to be executed in a prescribed order. Model links will not be available when pre-required runs have not been

SPENVIS WS: highlights

- Plasma / Charging
- Solar Cell degradation:
GEANT4/MULASSIS :NIEL and
degr. models
- Radiation environment models:
solar protons, radiation belts
- Single Event Effects (SEE) models

SPIS simulation of SMART-1

- Array facing:
 - ~16 V
 - $\sim 10^7 \text{ cm}^{-3}$



SPENVIS WORKSHOP, 3 Oct 2005,
Leuven-Louvain, Belgium



Displacement Damage Dose Approach For Determining Solar Cell Degradation In Space With Spenvis Implementation

Dr. Scott R. Messenger
SFA, Inc.
(messenger@nrl.navy.mil)

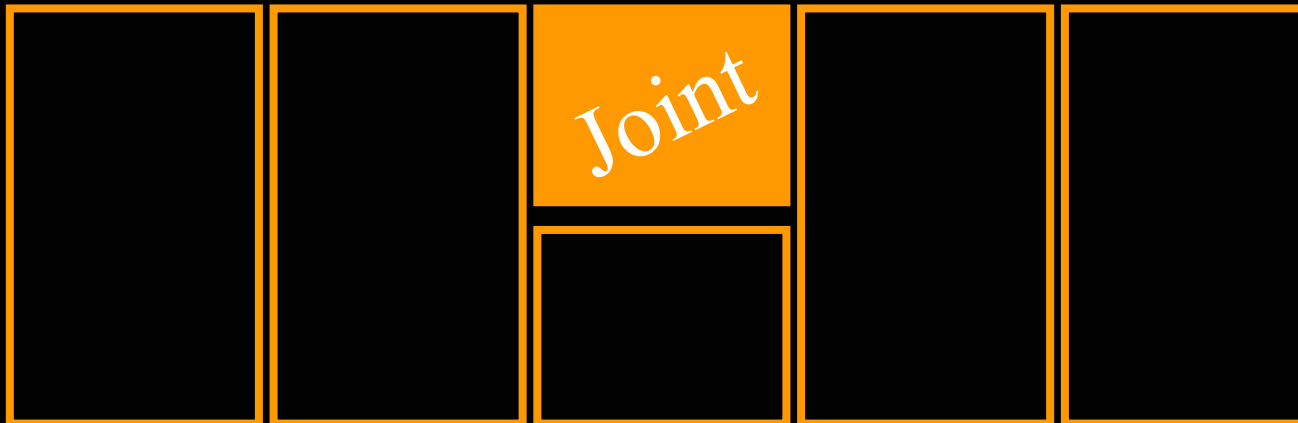
SPENVIS & GEANT4 workshop
Faculty Club
Leuven, Belgium
3 - 7 October 2005



Geant 4

Joint session SPENVIS / GEANT4 Space Users

- SPENVIS
- Joint
 - Introduction to GEANT4 and recent developments
 - GEANT4 tools available within SPENVIS
(now or in the near future)
 - MULASSIS , GEMAT, MAGNETOCOSMICS, GRAS
- Geant4 Space Users



GEANT4 tools in SPENVIS

QinetiQ | esa Space Environments and Effects Analysis Section

Dose Equivalent Analysis

- Not yet implemented in SPENVIS
- Uses ICRP-60 Q(L) function to calculate Dose Equivalent
- Deviates from standard for $H^*(d)$ due to geometry simplifications: $H(d)$ in Mulassis is calculated for the whole spherical shell, not just the solid angle along a particular direction.

Pelliccioni, M. "Overview of Fluence-to-Effective Dose and Fluence-to-Ambient Dose Equivalent Conversion Coefficients for High Energy Radiation Calculated Using the FLUKA Code", Radiat. Prot. Dosim. 88(4), 279-297 (2000)

5th October 2005 | SPENVIS Integration of Mulassis - SPENVIS Workshop | 28

Geometry Construction Commands

- A layered geometry structure
 - Arbitrary number of layers of different materials
- One layer is designated as the **Contact Layer**
 - Contact Volumes (CVs) can be added
- One layer is designated as the **Depleted Layer**
 - Sensitive Volumes (SVs) can be added

QinetiQ

MULASSIS

GEMAT

GRAS Analysis

Modular, extendable design

QinetiQ | esa

Giovanni Santin - GRAS - Leuven, 5 Oct 2005 | 17

Magnetic shielding on Earth

Cutoff Rigidities vs position

MAGNETOCOSMICS | SPENVIS and Geant4 Space User's Workshop 2005, Leuven

MAGNETO-COSMICS

GRAS

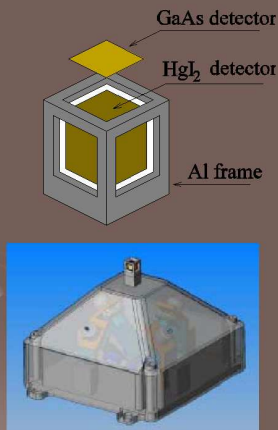
GEANT4 Space Users workshop

- SPENVIS
- Joint
- Geant4 Space Users
 - Radiation detectors / monitors
 - Effects to electronics
 - Model modeling
 - Exploration programme



Space radiation detectors / monitors

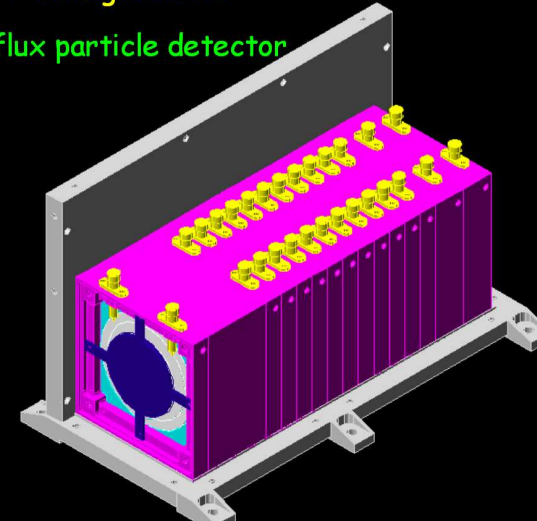
SIXS Particle Instrument



- SIXS Particle Instrument
 - 2π sr Field-of-View around anti-nadir with Geometric Factor of $\sim 0.1 \text{ cm}^2 \text{ sr}$
 - Five GaAs surface detectors around a HgI2 core detector
 - Measures
 - 0.1 - 3 MeV electrons
 - 1 - 30 MeV protons
 - $\Delta E/E \sim 50\%$ energy channel separation
 - coarse directional resolution
 - 64-s/1-s time resolution

3. The EPT configurations

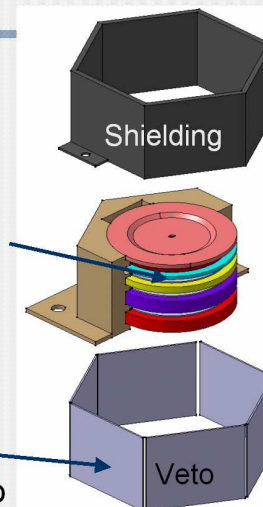
3.1. Low flux particle detector



The HEP Sensor System...

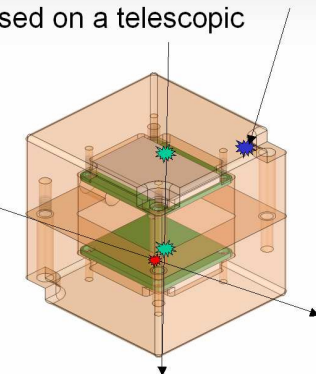
...Design Approach

- Range Telescope with:
 - Measured quantities:
 - Range
 - dE/dx in all layers
 - Stack of silicon PIN diodes and absorber layers
 - Size determined by rate about 2 cm diameter
 - Full digital readout
 - Active veto outside
 - Passive shield around Veto



LISA Pathfinder radiation monitor

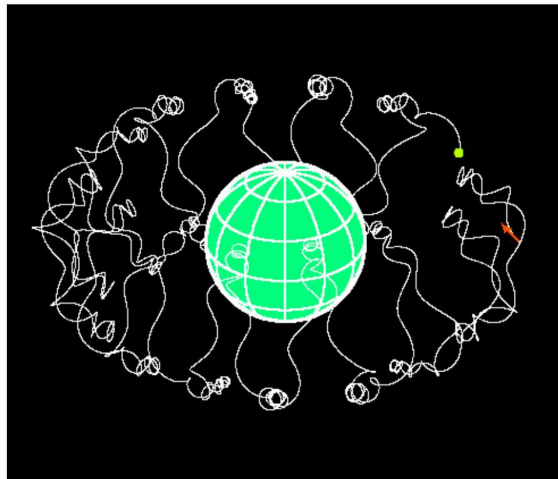
- Variations in charging can compromise science goals of the mission
- Want to measure the flux responsible for charging
- A particle monitor is proposed based on a telescopic arrangement of PIN diodes.
- 5-10 g/cm² of shielding stops particles $E < 70-90 \text{ MeV}$
- Count rates sufficient to detect small fluctuations in flux
- Energy resolution to distinguish GCR and SEP spectra.



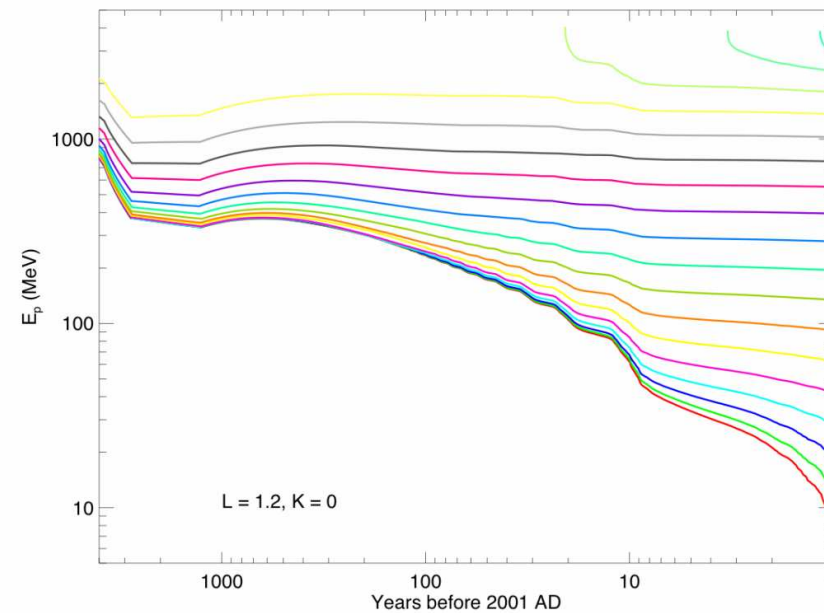
Theoretical Modeling of the Inner Zone Using GEANT4 Simulations as Inputs

R. S. Selesnick and M. D. Looper
The Aerospace Corp., Los Angeles, CA USA

R. A. Mewaldt
Caltech, Pasadena, CA USA



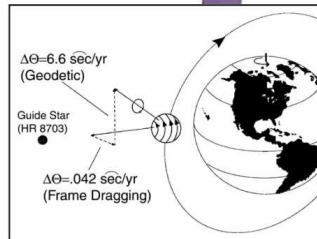
Model modeling...



S/C Internal charge deposit

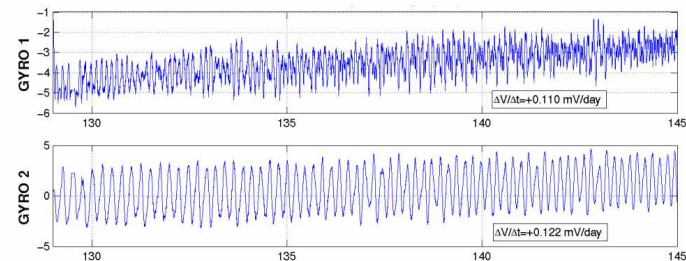
Gravity Probe B

- Aims to detect geodetic and frame-dragging effects on free-falling gyroscopes in low earth orbit
- 600km polar orbit
- Gyroscopes accumulate charge from SAA
- GP-B payload also includes a high energy proton monitor (30-500MeV)



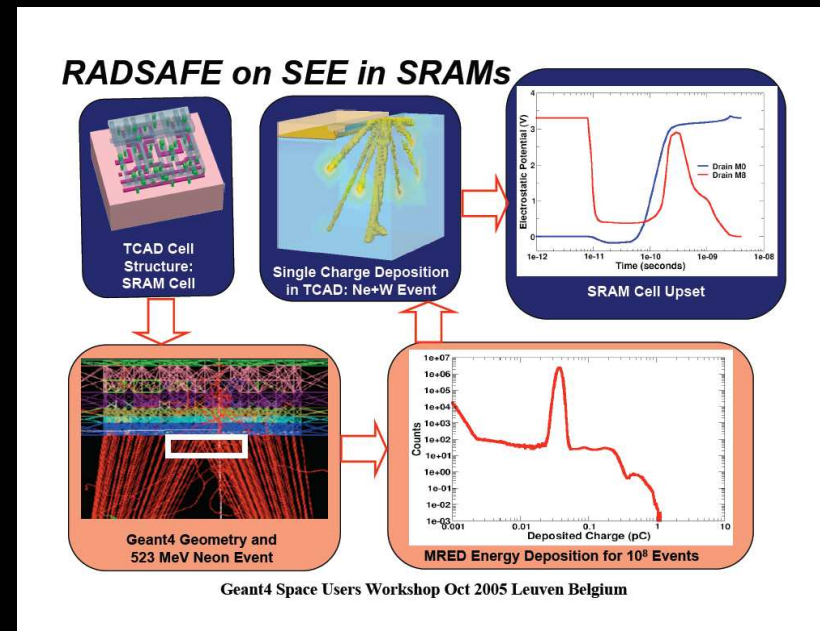
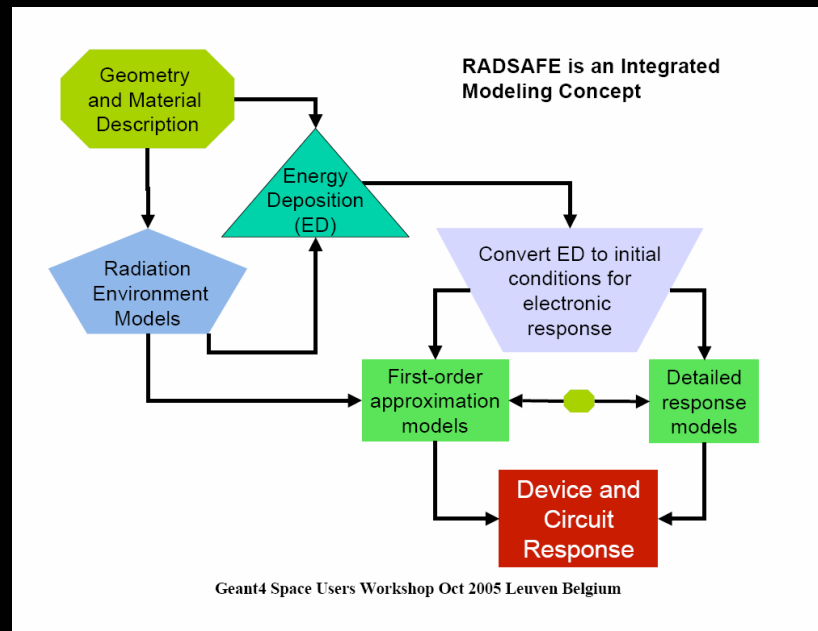
Results and data comparison

- The average charging rate, calculated from simulations is **+12.5e/s**
- Charging rate measured on orbit is +0.11mV/day or **+8.0e/s**

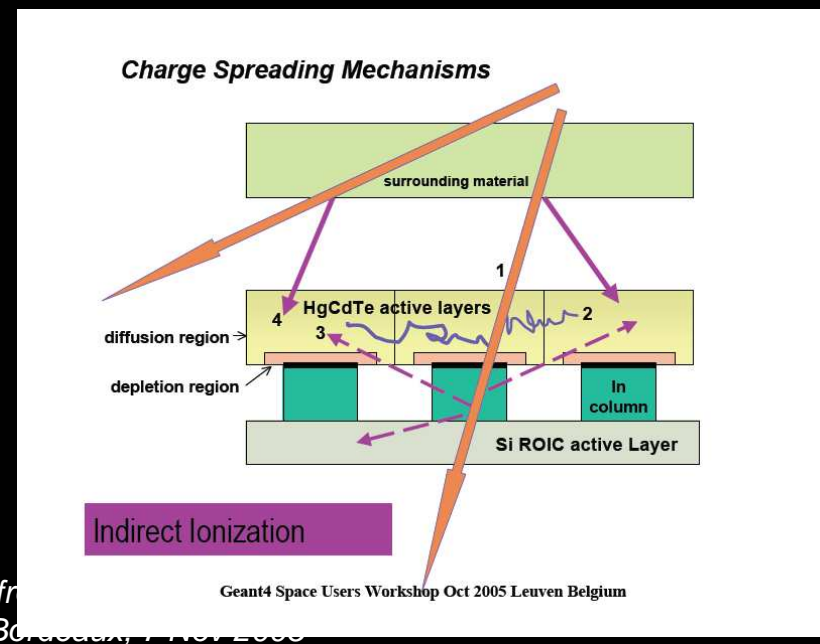


Peter Wass – Imperial College

RADSAFE

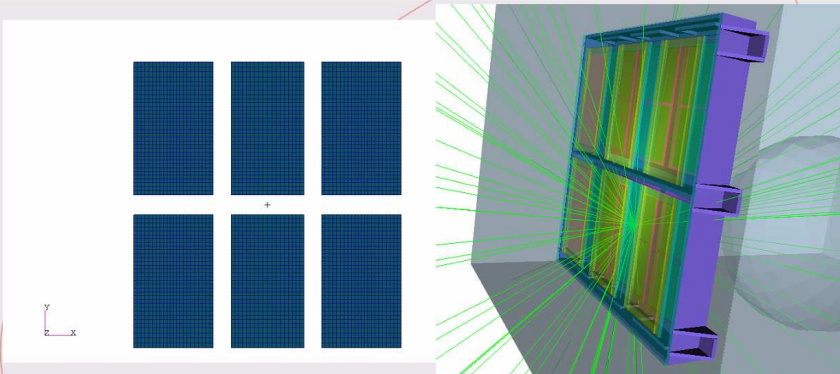


- SEE in microelectronics
- Detector response
- *R.Reed – Vanderbilt University*



Dose from ray tracing in CAD geometry models

Sectorial Analysis for the PCBs



- ◆ FEM Grids used as point target for the analysis
- ◆ Shielding and TID map for each PCB
- ◆ Very Fast and Efficient Method
 - From Geometry definition to post-process 3 days

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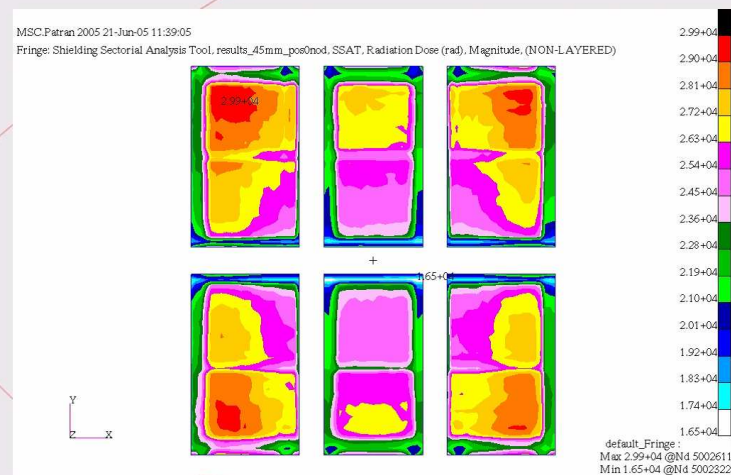
SPENVIS & GEANT4 WORKSHOP

Adolfo Aguilar - EFACEC

Post-Processed Results using PATRAN



- ◆ TID Maps obtained for each location of the PCB
- ◆ 3.5 mm (30krad) Al thickness reduced the mass



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12

NIEL tool



Uni Köln

Tool Module "NIEL"

Two options of running module NIEL

- (a) NIEL calculation by applying the Lindhard partition function to the initial energy of the recoils (not for high-energy projectiles, not for compounds with high ΔZ , no information about 3D defect distribution)
- (b) NIEL calculation by MC simulation of the damage cascade step by step in the vicinity of the active volume (validity of algorithms and models in Geant4 limited at low energy; e.g. binary collision model rather should be replaced by a molecular dynamics code)

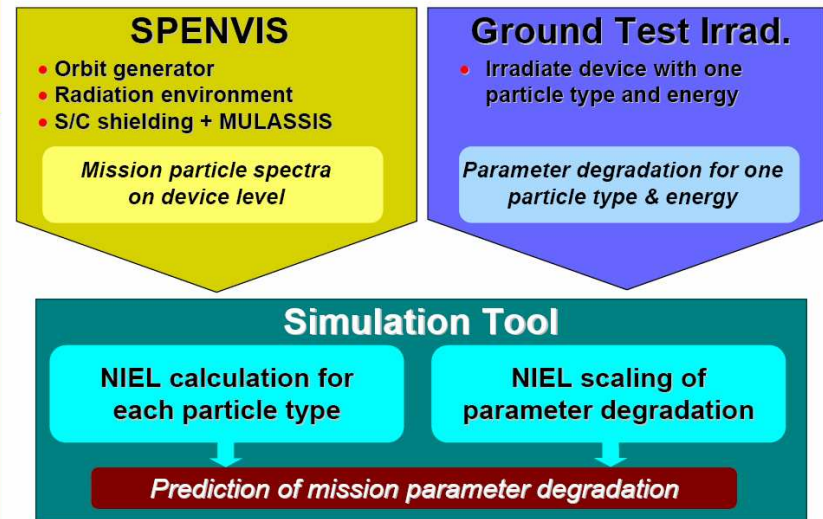
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- Uses Screened Coulomb scattering
 - Implementation by Vanderbilt University
 - Nucl Instr Meth B 227, Issue 3, 420-430 (2004)*

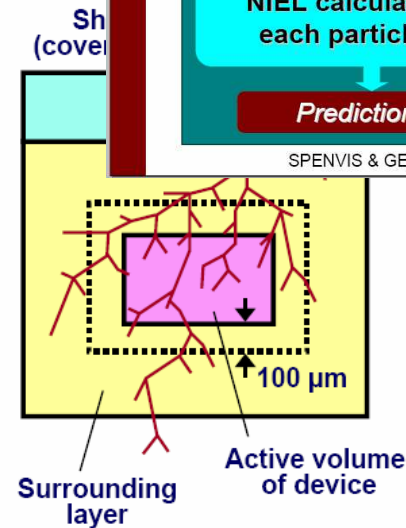


Uni Köln

ST under SPENVIS (1)



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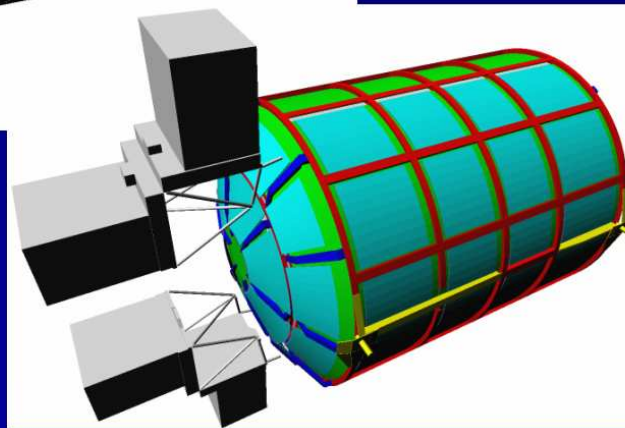
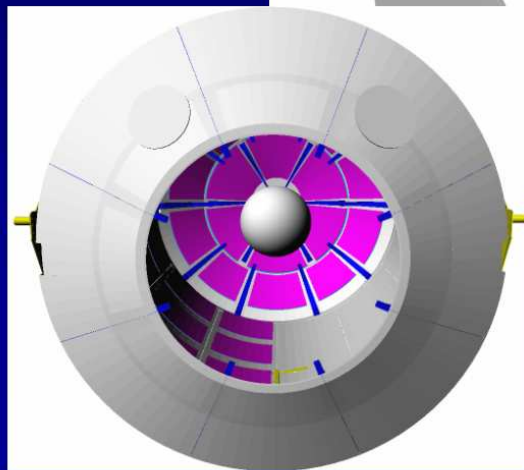
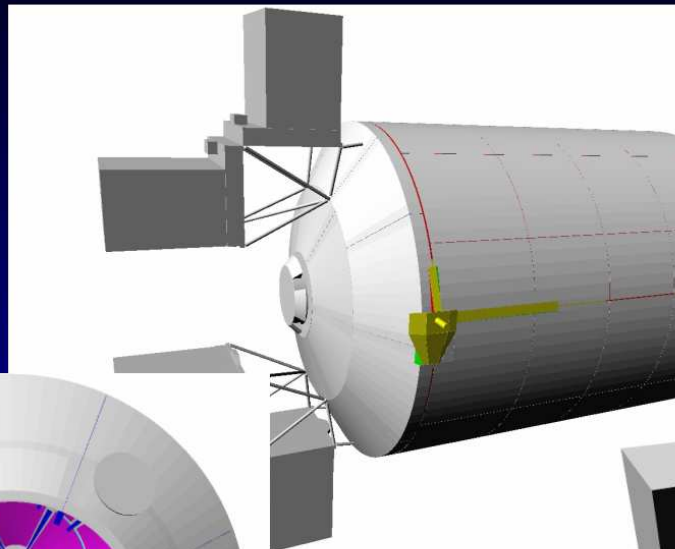


H.H.Fischer, K.Thiel
Cologne university

DESIRE

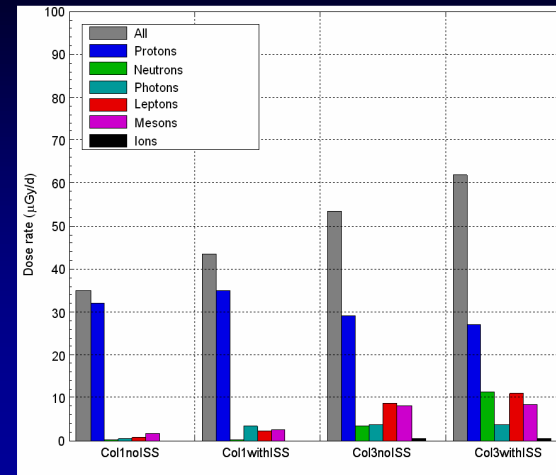
Doses in ESA ISS/Columbus

The "Columbus3" Geant4



SPENVIS and Geant4 Workshop, Leuven, 05/10/06, Tore Ersmark (KTH)

Cosmic ray proton doses



Dose rates in ICRU sphere due to incident cosmic ray protons; itemized by geometry model and particle type at surface of sphere

SPENVIS and Geant4 Workshop, Leuven, 05/10/06, Tore Ersmark (KTH)

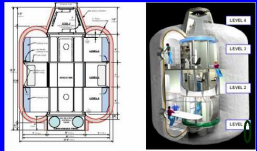
16/19

Tore Ersmark
KTH Stockholm

REMSIM

Radioprotection for interplanetary manned missions

SIH - Simplified Inflatable Habitat



Vehicle concepts

Two (simplified) options of vehicles studied

Simplified Rigid Habitat

A layer of Al (structure element of the ISS)

Simplified Inflatable Habitat

Modeled as a **multilayer structure**

- ML: external thermal protection blanket
 - *Betacloth and Mylar*
- Meteoroid and debris protection
 - *Nextel (bullet proof material) and open cell foam*
- Structural layer
 - *Kevlar*
- Redundant bladder
 - *Polyethylene, polyacrylate, EVOH, kevlar, nomex*

Materials and thicknesses by ALENIA SPAZIO

The Geant4 geometry model retains the essential characteristics of the vehicle concept relevant for a dosimetry study

S. Guatelli, M.G. Pia - INFN Sezione di Genova

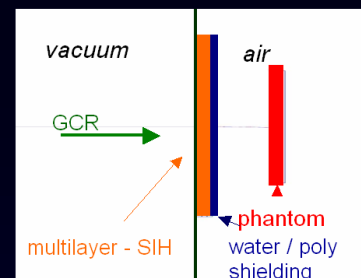
INFN Genova

Shielding materials

Comparison between

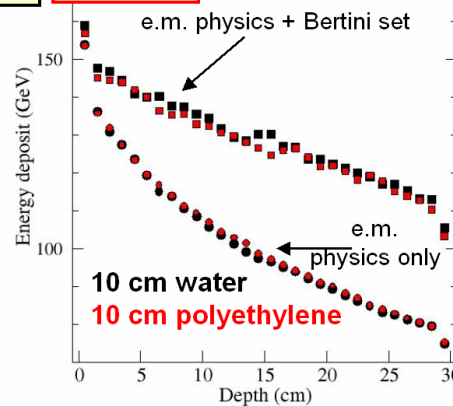
- Water
- Polyethylene

Equivalent shielding results



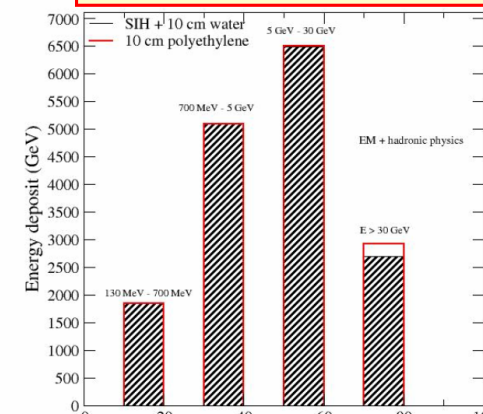
GCR p

100 k events



S. Guatelli

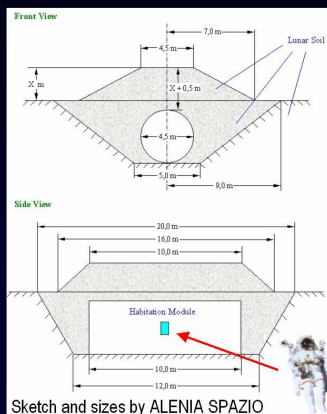
Energy deposit given by slices of the GCR p spectrum



Surface Habitats

- Use of local material
- Cavity in the moon soil + covering heap

The Geant4 model retains the essential characteristics of the surface habitat concept relevant to a dosimetric study



Sketch and sizes by ALENIA SPAZIO

S. Guatelli, M.G. Pia - INFN Sezione di Genova

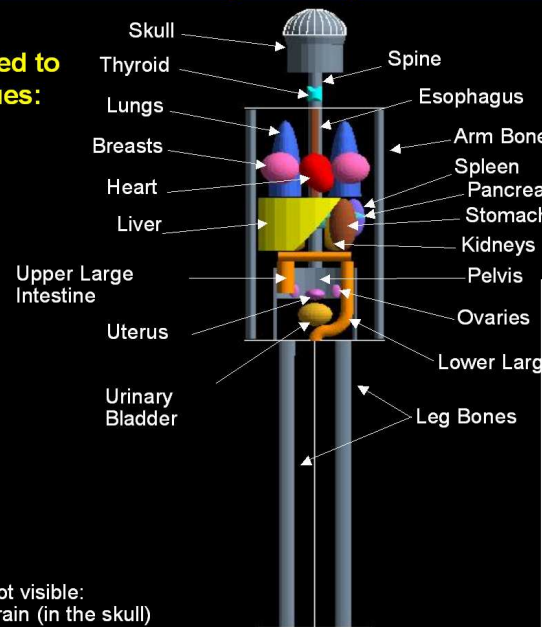


Anthropomorphic phantoms

Female ORNL Anthropomorphic Phantom

Three materials used to model human tissues:

- Skeleton,
- Lungs,
- Soft tissue



Not visible:
Brain (in the skull)

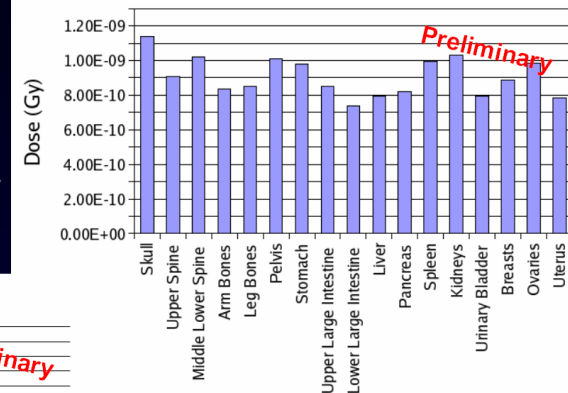
Susanna Guatelli

GEANT4 - DNA Collaboration

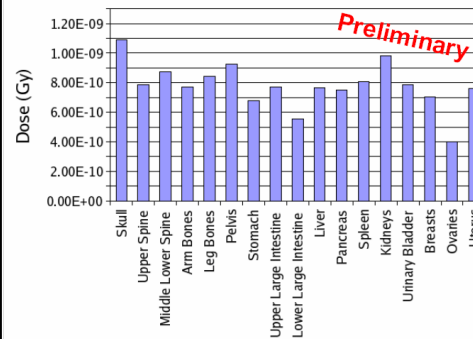
First results

- Calculation of the dose in the anthropomorphic phantom

Shielding: 5 cm of water



Shielding: 10 cm of water

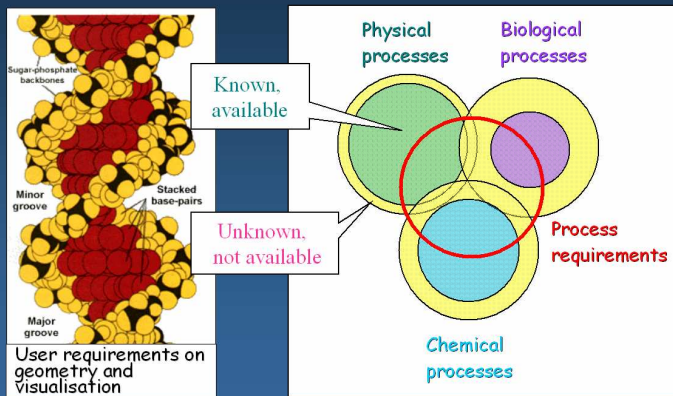


Preliminary

Geant4 Workshop

GEANT4 - DNA

Collection of User Requirements



Maria Grazia Pia, INFN Genova

- EM models in water down to ~7 eV
- Radiobiological models
- DNA models

GEANT4 – DNA Collaboration



Giovanni Santin - Rep
Geant4 Coll. W

TARGET THEORY	SINGLE-HIT	$S = e^{-D/D_0}$
TARGET THEORY	MULTI-TARGET SINGLE-HIT	$S = 1 - (1 - e^{-qD})^n$
MOLECULAR THEORY	RADIATION ACTION	$S = e^{-p(\alpha D + \beta D^2)}$
MOLECULAR THEORY	DUAL RADIATION ACTION	$S = S_0 e^{-k(\xi D + D^2)}$
MOLECULAR THEORY	REPAIR-MISREPAIR LIN REP / QUADMIS	$S = e^{-\alpha D} [1 + (\alpha D T / \epsilon)]^\epsilon$
MOLECULAR THEORY	REPAIR-MISREPAIR LIN REP / MIS	$S = e^{-\alpha D} [1 + (\alpha D / \epsilon)]^\epsilon \Phi$
MOLECULAR THEORY	LETHAL-POTENTIALLY LETHAL	$S = \exp[-N_{TOT} [1 + \frac{N_{PL}}{\epsilon(1 - e^{-\epsilon B A t r})}]]^\epsilon$
MOLECULAR THEORY	LETHAL-POTENTIALLY LETHAL - LOW DOSE	$S = e^{-\eta_{AC} D}$
MOLECULAR THEORY	LETHAL-POTENTIALLY LETHAL - HIGH DOSE	$-\ln[S(t)] = (\eta_{AC} + \eta_{AB}) D - \epsilon \ln[1 + (\eta_{AB} D / \epsilon)(1 - e^{-\epsilon B A t r})]$
MOLECULAR THEORY	LETHAL-POTENTIALLY LETHAL - LQ APPROX	$-\ln[S(t)] = (\eta_{AC} + \eta_{AB} e^{-\epsilon B A t r}) D + (\eta_{AB}^2 / 2\epsilon)(1 - e^{-\epsilon B A t r})^2 D^2$

Maria Grazia Pia, INFN Genova

$$S = e^{-D/D_0}$$

REVISED MODEL

$$S = 1 - (1 - e^{-qD})^n$$

$$S = e^{-q_1 D} [1 - (1 - e^{-q_2 D})^n]$$

$$S = e^{-p(\alpha D + \beta D^2)}$$

$$S = S_0 e^{-k(\xi D + D^2)}$$

$$S = e^{-\alpha D} [1 + (\alpha D T / \epsilon)]^\epsilon$$

$$S = e^{-\alpha D} [1 + (\alpha D / \epsilon)]^\epsilon \Phi$$

$$S = \exp[-N_{TOT} [1 + \frac{N_{PL}}{\epsilon(1 - e^{-\epsilon B A t r})}]]^\epsilon$$

$$S = e^{-\eta_{AC} D}$$

$$-\ln[S(t)] = (\eta_{AC} + \eta_{AB}) D - \epsilon \ln[1 + (\eta_{AB} D / \epsilon)(1 - e^{-\epsilon B A t r})]$$

$$-\ln[S(t)] = (\eta_{AC} + \eta_{AB} e^{-\epsilon B A t r}) D + (\eta_{AB}^2 / 2\epsilon)(1 - e^{-\epsilon B A t r})^2 D^2$$

In progress:
calculation of
model
parameters
from clinical
data

Review of the work in progress^{2/5}

Total cross sections

	Electrons	Protons (H+)	Hydrogen (H)	Alpha (He++)	He+	He
Elastic	Brenner (7.5 - 200 eV) Emfietzoglou (> 200 eV)	Neglected	Neglected	Neglected	Neglected	Neglected
Excitation	Emfietzoglou Bom (7 eV - 10 keV)	Miller and Green Bom (100 eV - 10 MeV)	Neglected	Miller and Green (1 keV - 15 MeV)	Miller and Green (1 keV - 15 MeV)	Miller and Green (1 keV - 15 MeV)
Charge decrease	Does not apply	Dingfelder (100 eV - 2 MeV)	Does not apply	To be done	To be done	Does not apply
Charge increase	Does not apply	Does not apply	Miller and Green Dingfelder (0.1 keV - 100 MeV)	Does not apply	To be done	To be done
Ionization	To be done	Rudd (0.1 - 500 keV) To be done (> 500 keV)	Rudd (0.1 - 100 MeV)	To be done	To be done	To be done

Final states

	Electrons	Protons (H+)	Hydrogen (H)	Alpha (He++)	He+	He
Elastic	Brenner (7.5 - 200 eV) Emfietzoglou (> 200 eV)	Neglected	Neglected	Neglected	Neglected	Neglected
Excitation	Emfietzoglou Bom (7 eV - 10 keV)	Miller and Green Bom (100 eV - 10 MeV)	Neglected	Miller and Green (1 keV - 15 MeV)	Miller and Green (1 keV - 15 MeV)	Miller and Green (1 keV - 15 MeV)
Charge decrease	Does not apply	Dingfelder (100 eV - 2 MeV)	Does not apply	To be done	To be done	Does not apply
Charge increase	Does not apply	Does not apply	Miller and Green Dingfelder (0.1 keV - 100 MeV)	Does not apply	To be done	To be done
Ionization	To be done	Rudd (0.1 - 500 keV) To be done (> 500 keV)	Rudd (0.1 - 100 MeV)	To be done	To be done	To be done

Spensvis & Geant4 Workshop - 3-7 October 2005 - R. Capra

RESTEC Fluxes and doses on Mars

■ Ana Keating
LIP Lisbon / ESA

Simulation Setup

The geometry implemented in Geant 4 program takes into account:

- 32 atmospheric layers
- Properties from EMCD
- Composition
 - 95% CO₂
 - 2.5% N₂
 - 1.25% Ar
 - 1.15% O₂
 - 0.07% CO
 - 0.03% H₂O
- Soil : Density of 3.75 g/cm³
- 30% Fe₂O₃ and 70% of SiO₂

07/10/05 SPENVIS-GEANT4 Workshop 4

Olympus Mons Cliff (12h, Ls=180-210)

Altitude [Km]

- 12.5-15
- 10-12.5
- 7.5-10
- 5-7.5
- 2.5-5
- 0-2.5
- 2.5-0
- 5--2.5
- 7.5--5

07/10/05 SPENVIS-GEANT4 Workshop 6

GCR: Radiation Environment at the Surface

At low energies:

- Neutrons
- Photons
- Electrons

At high energies (> 10³MeV):

- Protons

The Ions are mainly:

- Deuteron, Triton
- Alpha

Backscattering

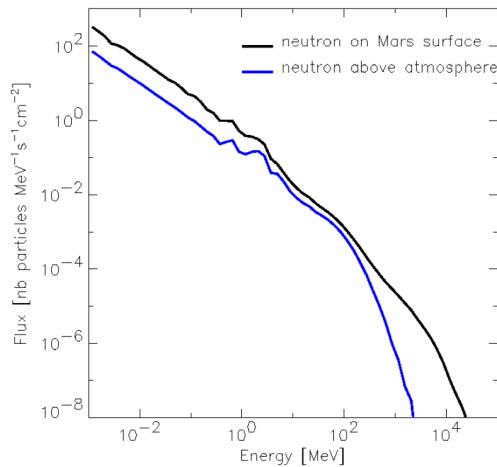
- 60% All particles
- 96% Neutrons

07/10/05 7

PLANETOCOSMICS

Earth, Mars, Mercury

Flux of neutrons on Mars induced by galactic cosmic ray protons at solar minimum

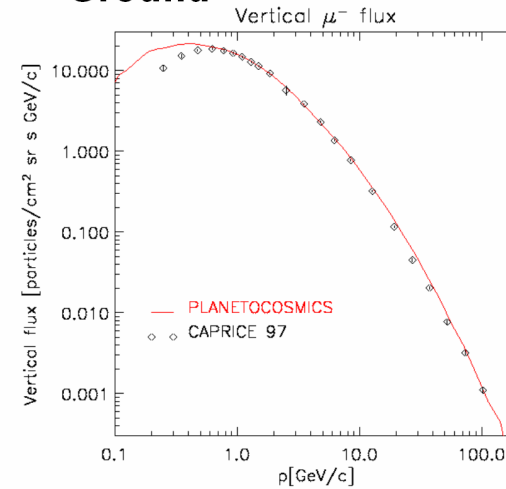


PLANETOCOSMICS

SPENVIS/GEANT4 workshop

*Laurent Desorgher
(Bern University)*

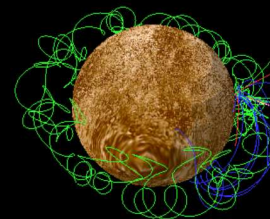
Muon Spectrum on Ground



PLANETOCOSMICS

SPENVIS/GEANT4 workshop

Mercury Soil + Dipole B0= 300 nT



e- > 1 MeV
e+ > 1 MeV
proton > 10 MeV

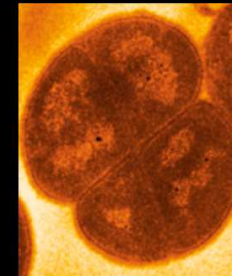
10 GeV protons from dayside

Lewis Dartnell

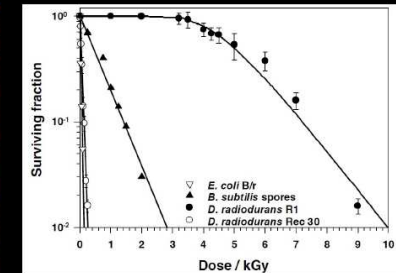
CoMPLEX (Centre for Mathematics and Physics in the
Life Sciences and Experimental Biology)

University College London, UK

Radioresistant bacteria



Deinococcus radiodurans



Survival curves of *D. radiodurans*, *B. subtilis*, and *E. coli*

Life on Mars?

Using Geant4 to model the subsurface radiation environment

Refugial Life

- Could extremophile life persist *beneath* the surface, within pockets of liquid water...?
- Deep hot Biosphere on Earth.
- Methane plumes detected seeping out of ground.



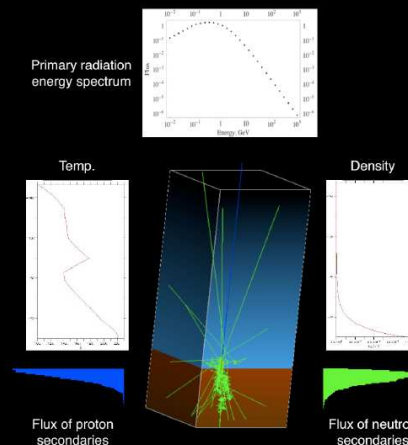
Geant4 workshop. Leuven,

Andrew Coates, MSSL

Contin - Report from the G

Geant4 Coll. WS, Bordeaux, 7 NOV 2005

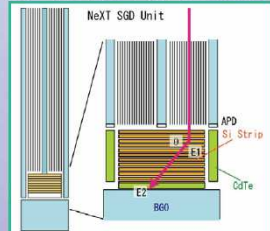
The Model



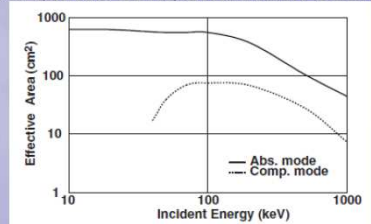
GEANT4 in Japan: NeXT and Suzaku

Concept study for NeXT Mission

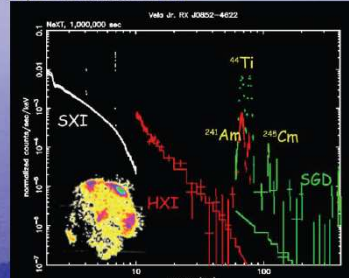
NeXT SGD
Narrow Field Compton Telescope
50-400 keV, $10^7 \text{cnt/s/cm}^2/\text{keV}$



Performance estimation with Geant4



Scientific simulation



H. Tajima et al. IEEE NSS-CR, vol.1, p314, 2004

S. Watanebe et al. IEEE TNS 49, p1292, 2002 T. Tanaka et al. SPIE 2004


Hard X-ray Detector, HXD

Cross Section: Optical Axis

Top View

- Photo-absorber: PIN Si diode, BGO scintillator
- Passive Collimator
- Anti coincidence shield BGO scintillator

16 Well-type Units and 20 Anti BGO Units



M. Kokubun et al., IEEE T.N.S.51,1991,2004
M. Tashiro et al., IEEE T.N.S.,49,1893,2002 and references therein.
Original concept in T. Kamae et al. Proc. SPIE, 2806, 314, 1996

General purpose GEANT4 web interface

Input G4Macro template	Dynamic web form																										
<pre># #Define the reference date # /MAGCOS/BFIELD/SetStartDate P_Year P_Month P_Day P_Hour P_Minute P_Second # #Define the magnetic field # /MAGCOS/BFIELD/SetGeomagneticFieldModel P_InternalField /MAGCOS/BFIELD/SetExternalFieldModel P_ExternalField /MAGCOS/SOURCE/SetPositionVector GEO P_Xpos P_Ypos P_Zpos P_LengthUnit</pre>	<table border="1"><thead><tr><th colspan="2">Bfield Definition</th></tr></thead><tbody><tr><td>Year</td><td>2005</td></tr><tr><td>Month</td><td>1</td></tr><tr><td>Day</td><td>1</td></tr><tr><td>Hour</td><td>0</td></tr><tr><td>Minute</td><td>0</td></tr><tr><td>Second</td><td>0</td></tr><tr><td>InternalField</td><td>IGRF</td></tr><tr><td>ExternalField</td><td>NOFIELD</td></tr><tr><td>Xpos</td><td>2.3</td></tr><tr><td>Ypos</td><td>1</td></tr><tr><td>Zpos</td><td>0</td></tr><tr><td>LengthUnit</td><td>Re</td></tr></tbody></table> <p>Submit Query</p>	Bfield Definition		Year	2005	Month	1	Day	1	Hour	0	Minute	0	Second	0	InternalField	IGRF	ExternalField	NOFIELD	Xpos	2.3	Ypos	1	Zpos	0	LengthUnit	Re
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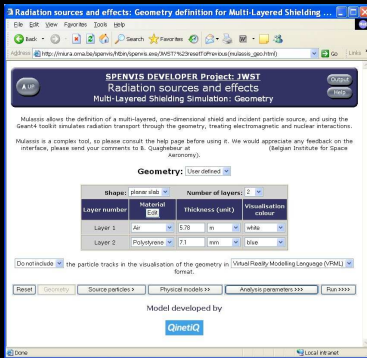
Set of PHP functions

■ Laurent Desorgher (Bern University)

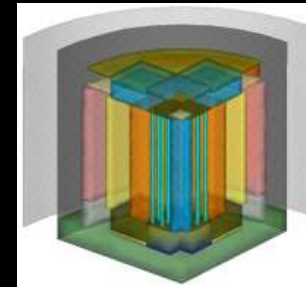
Geant4 Web Interface Prototype

- G4 coding needed only in the main file:
G4UIsession* session
= new G4UIGainPHPServer();

Interface GEANT4 to CAD GUI (or CAD GUI to GEANT\$)



GUI tool



Geometry modeling

Script instructions:

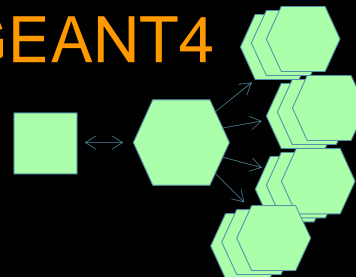
- Physics
- Radiation Environment
- Analysis type



Geometry exchange format

- GDML
- CAD / STEP
- ...

GEANT4



Conclusions

- Fruitful meeting of 2 communities (SPENVIS / GEANT4)
- Increasing use of GEANT4
- Usability
Ready-to-use tools and interfaces
- Physics
Improved EM models
Need for further upgrade in hadronics

<http://geant4.esa.int>

<http://www.spennis.oma.be>

Announcement: GDML session

- J.McCormick is trying to organize a parallel informal discussion session to discuss present use, trends, future developments related to GDML
- Please join if interested