Mars Radiation Environment Characterization
A GEANT4 based Model

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LIP & ESA
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Overview

- Radiation-induced failure of sensitive instrument, spacecraft/missions: (e.g. Marie instruments-Oct./Nov.03 and Nozomi-3 Dec. 03);
- ESA, NASA and others have flown or plan many missions to Mars
- Model features include:
  - Geant4 particle transport;
  - Time, position, solar longitude;
  - Solar cycle modulated cosmic ray and solar particle event spectra;
  - 4-D atmosphere and geology.
- Outputs: Energy and Species spectra, Fluence maps, Dose calculations
Atmospheric Database

- **European Martian Climate Database (EMCD)**
  - Temperature, density, pressure, etc
  - Stored on a $5^\circ$x$5^\circ$, longitude-latitude grid from the surface to 120km
  - Vertical coordinate for the 3D variables is defined as
    \[ \sigma = \frac{p}{p_0}, \]
    \[ p = \text{atmospheric pressure}, \quad p_0 = \text{surface pressure}. \]
  - 12 times a day Mars Universal Time at longitude $0^\circ$;
  - 12 Martian “seasons”
  - Each season covers $30^\circ$ in solar longitude ($L_s$)
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
Radiation inputs

- CREME96 for near-Earth interplanetary locations.
- Galactic cosmic rays (GCR)
  - Solar-quiet proton flux in the solar maximum
  - Simulated as isotropic momentum distribution: $10^5$ protons
- Particle events (SPE)
  - Energetic protons: “worst week” model
  - Simulated perpendicularly to the surface: $10^5$ protons
- Models are based on measurements at Earth (1AU)
- The phasing in the solar cycle: foreseen for ExoMars.
Olympus Mons Cliff (12h, Ls=180-210)
GCR: Radiation Environment at the Surface

At low energies:
- Neutrons
- Photons
- Electrons

At high energies (> $10^3$ MeV):
- Protons

The Ions are mainly:
- Deuteron, Triton
- Alpha

Backscattering
- 60% All particles
- 96% Neutrons
SEP: Radiation Environment at the Surface

At low energies:
- Neutrons
- Photons
- Electrons

At high energies ($10^2$-$10^3$ MeV):
- Protons
- No significant signature
- Ions
- Backscattering
  - 19% All particles
  - 51% Neutrons
Tyrrhena Patreana (12h, Ls=180-210)

1-2 Km Altitude
GCR : Fluence Maps at the Surface

- Neutrons E>30MeV
- Lower Altitude
- Higher Pressure
- Higher Fluences

- Fluences \( \sim 10^7 \text{n/cm}^2 \) per year
GCR: Low Energy Neutrons

- Neutrons E< 30MeV
- Mars Universal Time
  Martian Longitude 0°:
  - 22h : 191K
  - 02h : 208K
  - 12h : 248K
- Fluences Per year
  \( \sim 10^8 \text{n/cm}^2 \)
- Temperature changes
  \( \rightarrow 1\% \)
## Summary

<table>
<thead>
<tr>
<th>Input</th>
<th>Site</th>
<th>High Lights</th>
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| GCR   | Tyrrhena Patera (80E, 7.5S) | - Doses per year: <10 rad(SiO2)  
- Neutron (>30MeV) : $10^7$  
- Neutron (<30MeV) : $10^8$ |
| GCR   | Olympus Mons Cliff (140W, 22.5N) | - Tot.Fluences [x$10^8$ #/cm$^2$] per year :  
  p = 0.3, e- = 0.1, n = 1.5, i < 0.1, $\gamma$ = 1.5  
- Backsc: 96% neutrons, 60% all particles |
| SEP WW| Olympus Mons Cliff (140W, 22.5N) | - Tot.Fluences [x$10^8$ #/cm$^2$] per evt :  
  p = 7.4, e- = 0.7, n = 3.5, i << 0.1, $\gamma$ = 6.2  
- Backsc: 51% neutrons, 19% all particles |
Conclusions

- Results show:
  - Energy Spectra and Particle Species at any location $5^\circ \times 5^\circ$.
  - Backscattered component: Very Important.
  - TID on the surface will probably not concern electronics
  - Proton and Neutron environments -> result in NIEL effects and in SEE.

- Methodology easily adaptable:
  - To evaluate dose equivalents and induced degradation on components;
  - To future improved knowledge of geology and atmosphere, e.g. local water ice content in the soil;
  - Direct adaptable for other planets and Moons such as Mercury and Europa
Spenuis I n er f ace

- Methodology is intended to be:
  - Publicly available in the future
  - Interfaced with Spenuis.

- Discussion is needed