Assessment of Radiation Exposure in Manned Missions to Mars for Three Profiles

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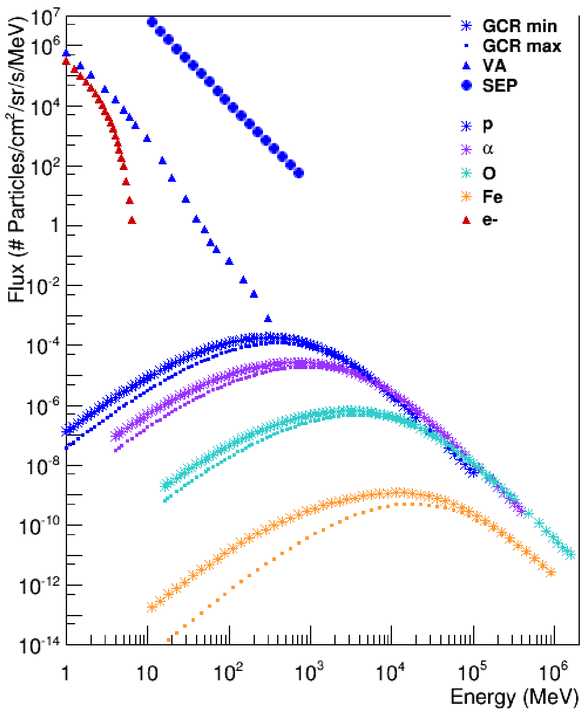
Introduction

Manned missions to Mars are the next step to human expansion in the Solar System.

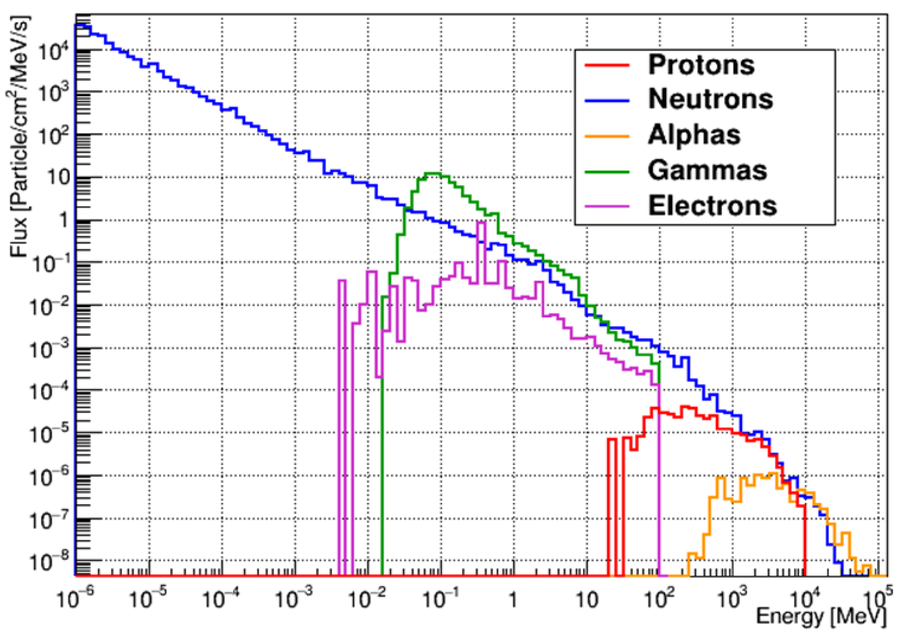
Radiation hazards are considerable and quantification and mitigation of these risks are essential.

In a Mars mission, the radiation fields present are:

- **Van Allen Belts (VA): protons and electrons**
- **Galactic Cosmic Radiation (GCR): protons and heavy ions**
- **Solar Energetic Particle (SEP) events: protons and electrons**
- **Mars radiation environment – weak magnetic field and only atmospheric shielding present.**

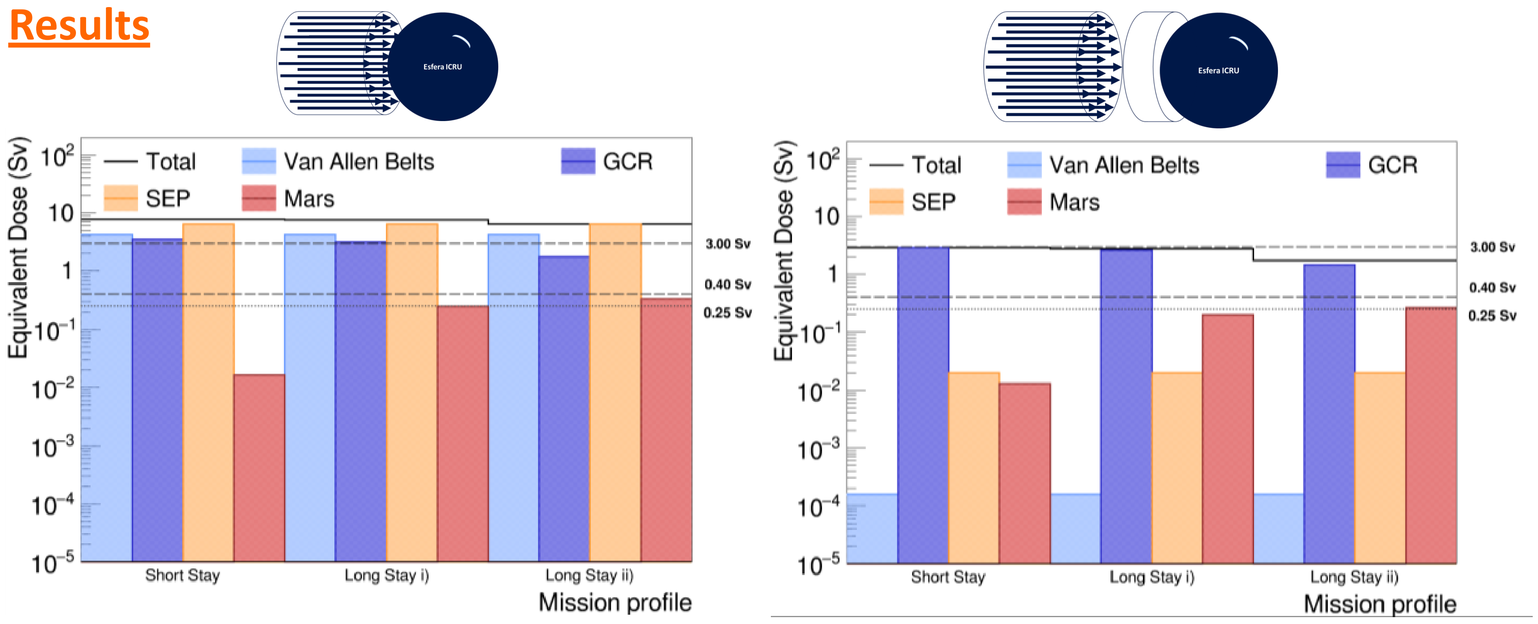


Radiation in free-space (GCR), around Earth (VA) and worst-case SEP event



Radiation arriving Mars surface after GCR interaction with Martian atmosphere and soil surface

Results



Without Shielding

With 27.8 g/cm² Al Shielding

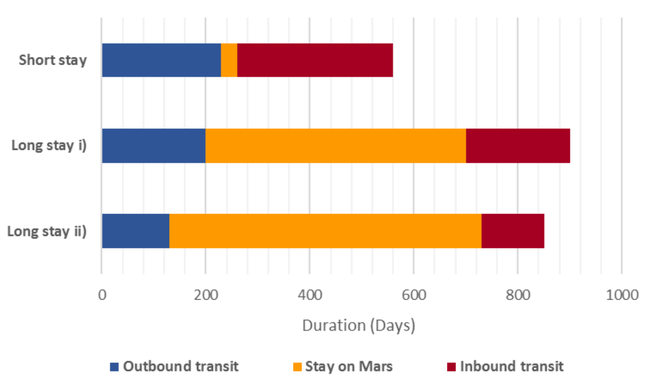
Stochastic - 3% REID

Age (yrs)	Career dose limits (Sv)	
	Male	Female
25	0.7	0.4
35	1.0	0.6
45	1.5	0.9
55	3.0	1.7

Simulation with the ICRU sphere (76,2% O; 11,1% C; 10,1% H; 2,6% N) to determine Equivalent Dose for NASA three mission profiles:

- **Total dose for the mission**
- **Dose from Van Allen belts, GCR, SEP and on Mars**
- **Comparison with dose limits for astronauts careers**
- **Both without and with 27.8 g/cm2 Al Shielding**

NASA three mission profiles

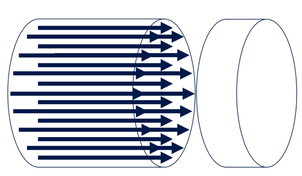


Comparison with RAD/MSL measurements

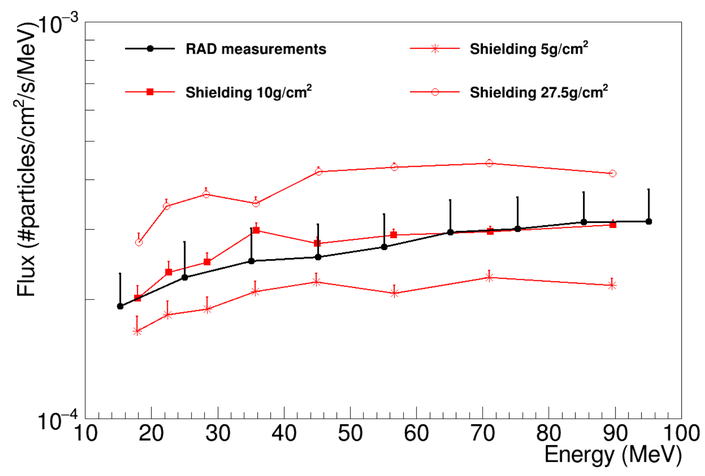
RAD: Radiation Assessment Detector ➔ particle detector on board Curiosity rover of MSL (Mars Science Laboratory)

Measured protons and other particles from:

- **GCR during Earth to Mars cruise phase**
- **Mars surface stay.**

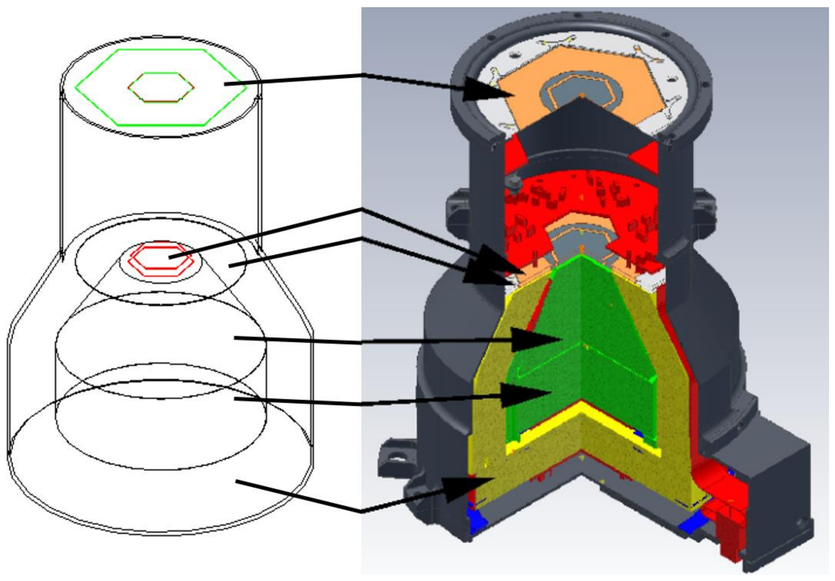


Total absorbed dose rates		
SPENVIS spectrum	RAD measurements	Deviation
June 30, 2012	June 11 - July 14, 2012	
12.27 µGy/day	12.01 µGy/day	2%



B. Ehresmann et al., "Charged particle spectra measured during the transit to mars with the mars science laboratory radiation assessment detector (MSL/RAD)", Life Sci. Space Res., no. 10, pp. 29-37, 2016

RAD/MSL Geant4 detailed simulations



Before:

- **Dose calculation with the ICRU sphere using spectra from SPENVIS for Earth exit and return, transit to Mars and Mars surface stay**
- **Geant4 simulation with just an Aluminium slab and expanded and aligned field to try to determine the shielding thickness that better reproduces results measured for RAD during transit to Mars: 10 g/cm2**

Now:

- **Detailed Geant4 simulation of RAD/MSL to validate published results for measured spectra**
- **Replicate previous spectra and obtained new spectra during transit and on Mars' surface**
- **Use published spectra results to re-do previous simulations using 2 phantoms:**
  - **ICRU sphere**
  - **new ICRP reference (detailed) anthropomorphic models**