High energy astrophysical hazards for habitability

P. Ubertini, M. Piersanti, M. Laurenza, and P. Diego

INAF – IAPS, Rome, Italy.
Introduction

• The health risks to astronauts from space radiation are a major problem for space exploration, perhaps representing a limiting factor on the maximum mission length under current risk acceptance levels.

• The main sources of radiation in space are the galactic cosmic rays (GCR) and solar particle events (SPE).

• The GCR consist of high-energy protons, helium nuclei, and heavy nuclei with energies extending to more than 10 GeV/amu (long –term changes)

• SPEs are largely protons with energies up to a few hundred MeV with a small helium and heavy ion component (short and long term changes).
• The energy spectrum of each source determines their range in shielding material and the human body.

• The amount of radiation received by astronauts depends on several factors including position in the solar cycle, and mission duration.

Mattia et al., 2016

Typical Energy Spectra

NASA – ACE Brochure
Career dose limits for space personnel quoted in NASA Technical Standard 2007 for year, are

- 52 cSv for a 25 year old male;
- 37 cSv for a 25 year old female;
- 72 cSv for a 35 year old male;
- 55 cSv for a 35 year old female.

Cruise phase exposures to SEPs

Would have delivered to unshielded crews blood forming organs (BFO) doses of 411, 110 and 62 cSv during three large SEP events (August, 1972; November, 1960, and February, 1956 Simonsen et al. (1990))

The dose level to be incurred over a year in interplanetary space near Earth, approaches the dose limits defined for 25 year old personnel (Schwadron et al. (2010))
2029 - Mission to Mars
• In this work we evaluated the GCR and SEP contribution to the «radiation health risk» during an hypothetical manned Mars mission in the next solar maximum (2029).
• In order to determine the dose rate, we calculated:
  1. The radiation sources and effects from both the Solar particle fluxes and GCR;
  2. The Radiation sources and effects from long term - Solar particle fluence;
  3. The Ionizing dose;
  4. The linear energy transfer (LET);
  5. The equivalent Dose Rate.
Mission Definition

- We set a Mission to Mars lasted for 400 days;
- We set the launching on 01/01/2029, corresponding to the next Solar Maximum;

- **Table 2:** Early scenarios for manned Mars exploration (McKenna-Lawlor et al., 2012)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Duration (Days)</th>
<th>Deep Space (Days)</th>
<th>Surface stay (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars swingby</td>
<td>600</td>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>Mars Short surface stay</td>
<td>430</td>
<td>400</td>
<td>30</td>
</tr>
<tr>
<td>Mars Long surface stay</td>
<td>1000</td>
<td>400</td>
<td>600</td>
</tr>
</tbody>
</table>
Radiation sources and effects
Solar particle fluxes.

- We used the Xapsos et al. (2000) model;
- The ion range is from Hydrogen to Iron;
- We assume to be in the worst possible case: October 1989 flare-flux composition-like;
- Short term proton flux;
- Short term ion flux.
Radiation sources and effects
GCR Spectra.

- We used the ISO standard 15390 model for the mission epoch;
- The ion range is from Hydrogen to Iron;
- We assume to be in the worst possible case: October 1989 flare-flux composition-like;
- We take into account GCR + fully ionized anomalous component (M=2);
- Ions Spectrum.
Radiation sources and effects

Long term - Solar particle fluence.

- We used the ESP Psychic model with 95% confidence level;
- The ion range is from Hydrogen to Iron;
- We assume to be in the worst possible case: October 1989 flare-flux composition-like;
- Long term proton flux;
- Long term ion flux.
Radiation sources and effects

Shielded flux: MFLUX.

• We choose a shielding composed by 3.705 mm Aluminium from solar protons;

• We obtained a proton orbit averaged flux.
Radiation sources and effects
Ionizing dose: parameters.

• We used the Shieldose-2 model;
• We choose a Aluminium sphere geometry 20 layers (1 mm thick each)
• Target material at the center of the sphere: Silicon.
Short Term LET spectra

• For the chosen geometry, we obtained the LET spectra;
• By using the Benton et al. (2010) relation, we obtained the LET spectra in H₂O;
• The Dose rate is obtained by using the Benton and Benton (2001) relation:

\[
\text{Dose rate} = 4\pi \times 1.6 \times 10^{-9} \times LET_{H₂O}
\]

• We obtained the following dose rate for SEP and GCR for the whole interplanetary part of the mission:

<table>
<thead>
<tr>
<th></th>
<th>SEP Long Term</th>
<th>SEP Short Term</th>
<th>CGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose rate</td>
<td>203 cSv</td>
<td>72 cSv</td>
<td>31.2 cSv/d</td>
</tr>
</tbody>
</table>
Summary and Conclusions

• We evaluated the GCR and SEP contribution to the «radiation health risk» during an hypothetical manned Mars mission in the next solar maximum (2029);
• The values of SEP energy obtained are in agreement with results obtained by Cane et al. (1986), McKenna-Lawlor et al. (2012), Townsend et al. (2006) and Laurenza et al. (2009);
• As expected the SEP energy peak is around 30 MeV (Laurenza et al., 2009);
• Es expected, the GCR effect represents the principal hazard for manned interplanetary missions also during a solar maximum period (SM);
• The long term SEP effect (203 cSv) during a SM period, despite being lower than GCR, is higher than the dose limit (72 cSv) for space personnel quoted by NASA (2007);
• The long term SEP effect represents an additional hazard for manned interplanetary missions that cannot be neglected especially during a SM period;
• Interestingly, a dramatic event like October 1989 flare-flux (short temp SEP) can produce by itself an equivalent dose rate of 72 cSv, addressing a further health safety issue.
Thank you for your attention