Organ Dose Assessment and Evaluation of Cancer Risk on Mars Surface

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Organ specific fluence spectra and doses for large solar particle events (SPE) and galactic cosmic rays (GCR) at various levels of solar activity are simulated on the surface of Mars using the HZETRN/QMSFRG computer code and the 2010 version of the Badhwar and O’Neill GCR model. The NASA JSC propensity model of SPE fluence and occurrence is used to consider upper bounds on SPE fluence for increasing mission lengths. To account for the radiation transmission through the Mars atmosphere, a vertical distribution of Mars atmospheric thickness is calculated from the temperature and pressure data of Mars Global Surveyor. To describe the spherically distributed atmospheric distance on the Mars surface at each elevation, the directional cosine distribution is implemented. The resultant directional shielding by Mars atmosphere at each elevation is then coupled with vehicle and body shielding for organ dose estimates. Finally, cancer risks for astronauts exploring Mars can be assessed by applying the NASA Space Radiation Cancer Risk 2010 model with the resultant organ dose estimates. Variations of organ doses and cancer risk quantities on the surface of Mars, which are due to a 16-km elevation range between the Tharsis Montes and the Hellas impact basin, are visualized on the global topography of Mars measured by the Mars Orbiter Laser Altimeter. It is found that cancer incidence risks are about 2-fold higher than mortality risks with a disproportionate increase in skin and thyroid cancers for male and female astronauts and in breast cancer for female astronauts. The number of safe days, defined by the upper 95\% percent confidence level to be below cancer limits, on Mars is analyzed for several Mars mission design scenarios.

Key words: Space Radiation, Organ Dose, Cancer Risk, Mars Mission
**Introduction**

We discuss calculations of the median and 95th percentile cancer risks to humans on the surface of Mars for different solar conditions. The NASA Space Radiation Cancer Risk 2010 model is used to estimate gender and age specific cancer incidence and mortality risks for astronauts exploring Mars.

In the transport of particles through the Mars atmosphere, a vertical distribution of Mars atmosphere thickness is calculated from the temperature and pressure data of Mars Global Surveyor, and the directional cosine distribution is implemented to describe the spherically distributed atmospheric distance along the slant path at each elevation on Mars. The resultant directional shielding by Mars atmosphere at each elevation is coupled with vehicle and body shielding for organ dose estimates.

Astronaut cancer risks are mapped on the global topography of Mars, which was measured by the Mars Orbiter Laser Altimeter. Variation of cancer risk on the surface of Mars is due to a 16-km elevation range, and the large difference is obtained between the Tharsis Montes (Ascraeus, Pavonis, and Arsia) and the Hellas impact basin. The number of safe days on Mars to be below radiation limits at the 95th percent confidence level can be estimated for various Mission design scenarios.

**Approach for Organ Doses and Cancer Risk Estimates**

- Transport properties of the shielding materials and the astronaut’s body tissues using NASA BRYNTRN and HZETRN/QMSFRG code system.
- Spherical configuration of aluminum for the equivalent Mars Transfer Vehicle and Habitat.
- Computerized anatomical man (CAM) model for body shielding distribution at the sensitive organs of astronauts.
- New NASA quality factors for the organ dose and effective dose calculation.
- Cancer risks of 40-y male based on both US average and never-smoker populations using the NASA Space Radiation Cancer Risk 2010 model.

**Conclusions**

- The NASA radiation evaluation tool is very useful for exploration mission design studies, including understanding Mars topography and impacts on risks.
- Risks for a Never-Smoker population is much lower than those for the US average population.
- GCR is shown to dominate crew cancer risk for Mars missions and is the limiting factor for the protection of astronauts from radiation exposure for Mars missions.
- Mars landing sites will have only small effect on GCR risk.

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**Environmental Parameters for Space Radiation Simulation**

**Impact of SPE Spectral Variation and Mission Length**

<table>
<thead>
<tr>
<th>30-Month Mars Mission</th>
<th>Environmental parameters</th>
<th>Mission duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transits 12-month</td>
<td>Mars stay 12-month</td>
<td>30-month</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Transits 18-month</td>
</tr>
<tr>
<td></td>
<td>Transits 30-month</td>
<td>Mars stay 30-month</td>
</tr>
<tr>
<td>Median</td>
<td>2.78x10^8</td>
<td>2.03x10^8</td>
</tr>
<tr>
<td>95 percentile</td>
<td>2.16x10^10</td>
<td>7.50x10^10</td>
</tr>
</tbody>
</table>

**Risk of 40-y Males**

**Effective Dose of Males for 18-month on Mars 5 g/cm² Al Shielding**

**Expected Cancer Risk for 18-month on Mars Surface**

**Cancer Risk at Upper 95% CI for 18-month on Mars Surface**

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**30-month Mars Mission**

**Mars Orbiter Laser Altimeter (MOLA) Topography -Mars Global Surveyor-**

**US Average Population**

<table>
<thead>
<tr>
<th>Transit to/from Mars for 6-month each way</th>
<th>Mars surface stay for 18-month</th>
<th>Total for 30-month</th>
</tr>
</thead>
<tbody>
<tr>
<td>E, Sv REID(95% CI)</td>
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</tr>
<tr>
<td>0.17 0.68(0.23, 1.96)</td>
<td>0.37 1.44(0.50, 3.91)</td>
<td>0.71 2.80(0.90, 7.75)</td>
</tr>
</tbody>
</table>

**Never-Smoker Population**

<table>
<thead>
<tr>
<th>Transit to/from Mars for 6-month each way</th>
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<th>Total for 30-month</th>
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</tr>
<tr>
<td>0.17 0.53(0.18, 1.51)</td>
<td>0.37 1.20(0.39, 3.02)</td>
<td>0.71 2.18(0.68, 6.02)</td>
</tr>
</tbody>
</table>

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**Annual Effective Dose Comparison**

**Impact of SPE Spectral Variation and Mission Length**

- *1 SPE + GCR at Solar Maximum inside 20 g/cm² Al Mars Transfer Vehicle (MTV).
- ** GCR at Solar Minimum at the Mean Elevation of Mars Surface inside 5 g/cm² Al Habitat.