

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



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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 atmospheric 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.

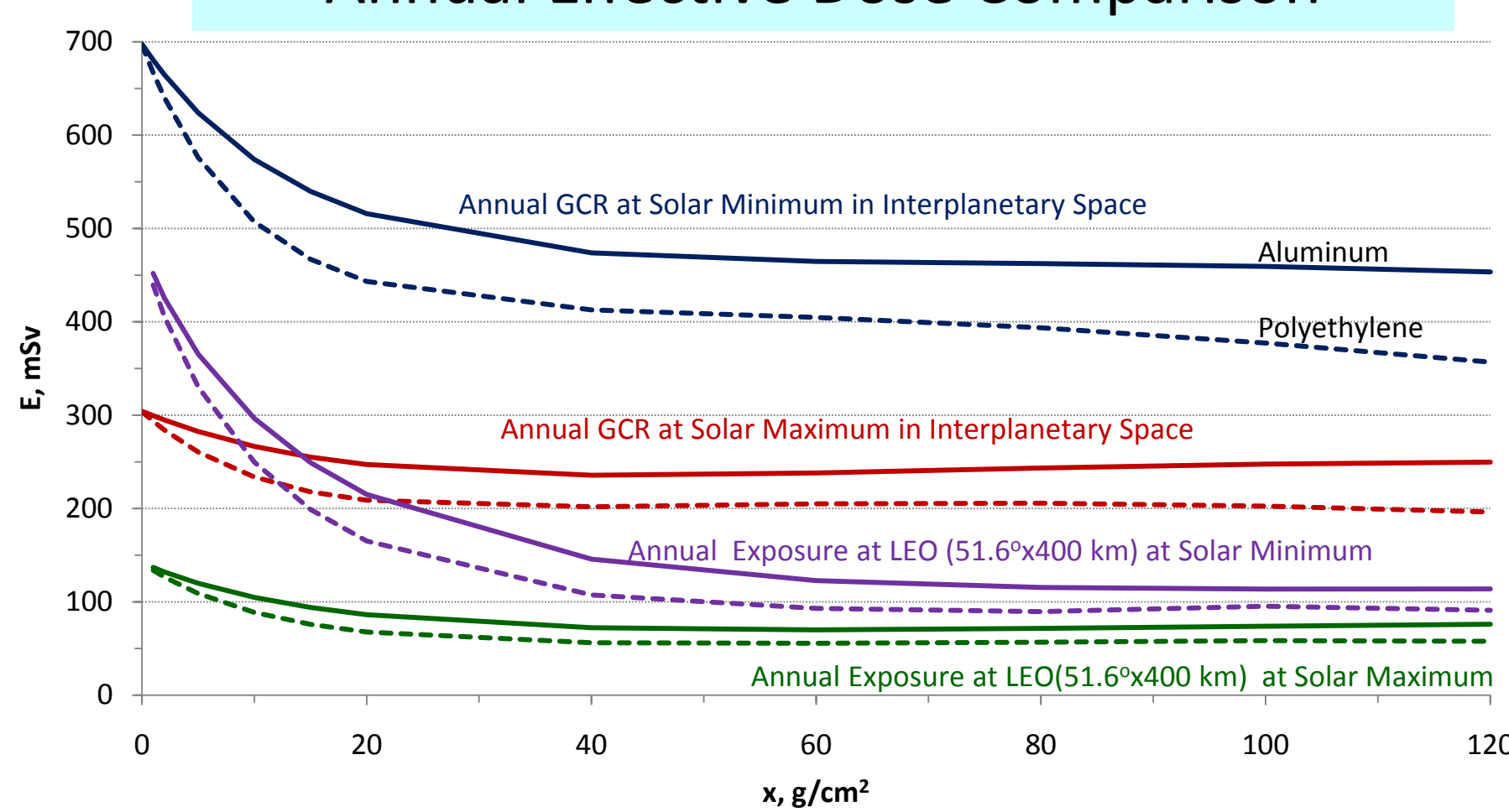
Approach for Organ Doses and Cancer Risk Estimates

- ❖ 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

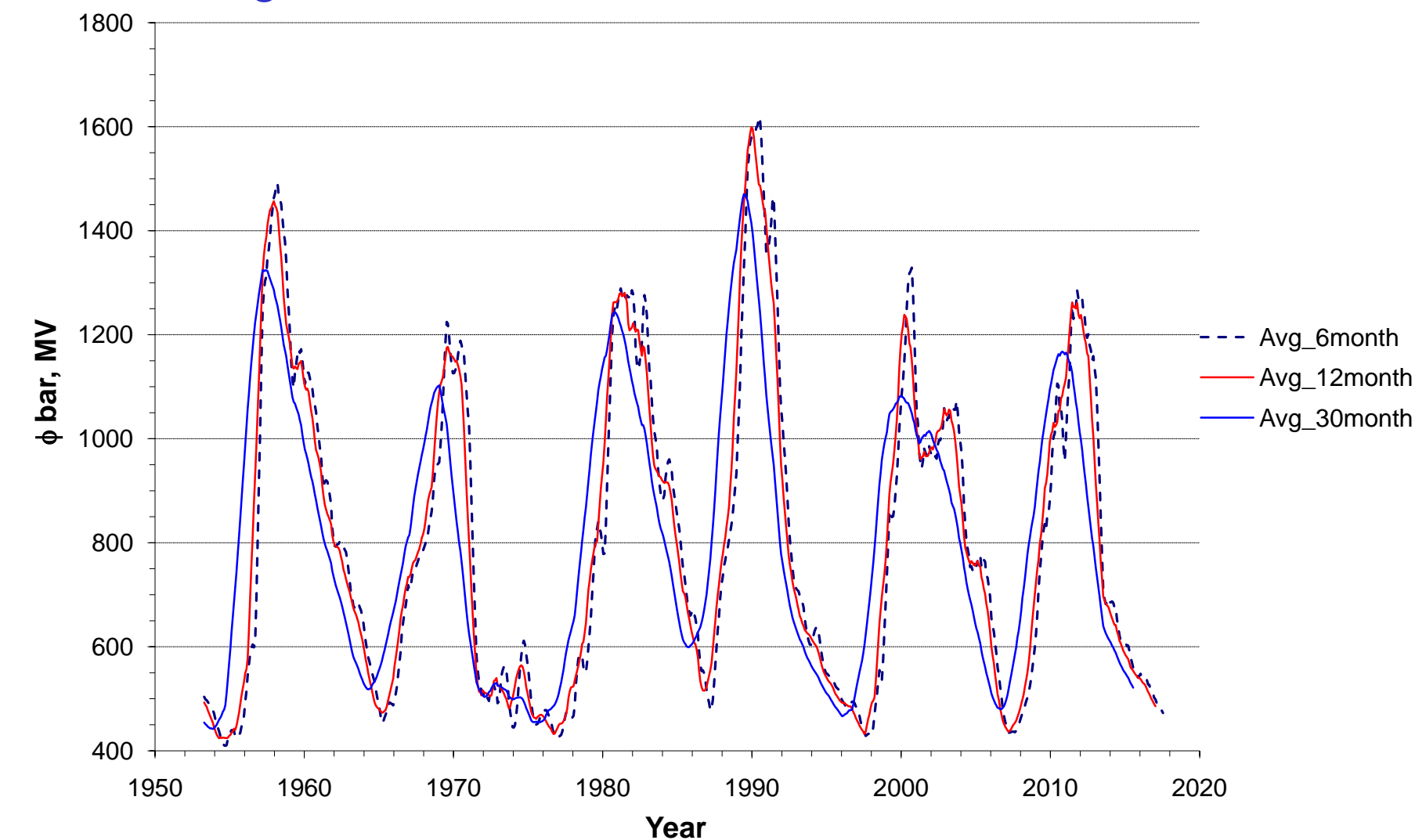
- ❖ The NASA radiation evaluation tool is very useful for exploration mission design studies, including understanding Mars topography and impacts on risks.
- ❖ Risks for a Never-Smoker population is much lower than those for the US average population.
- ❖ GCR is shown to dominate crew cancer risk for 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.

Annual Effective Dose Comparison



Environmental Parameters for Space Radiation Simulation

Average GCR Environment for a Given Mission Period

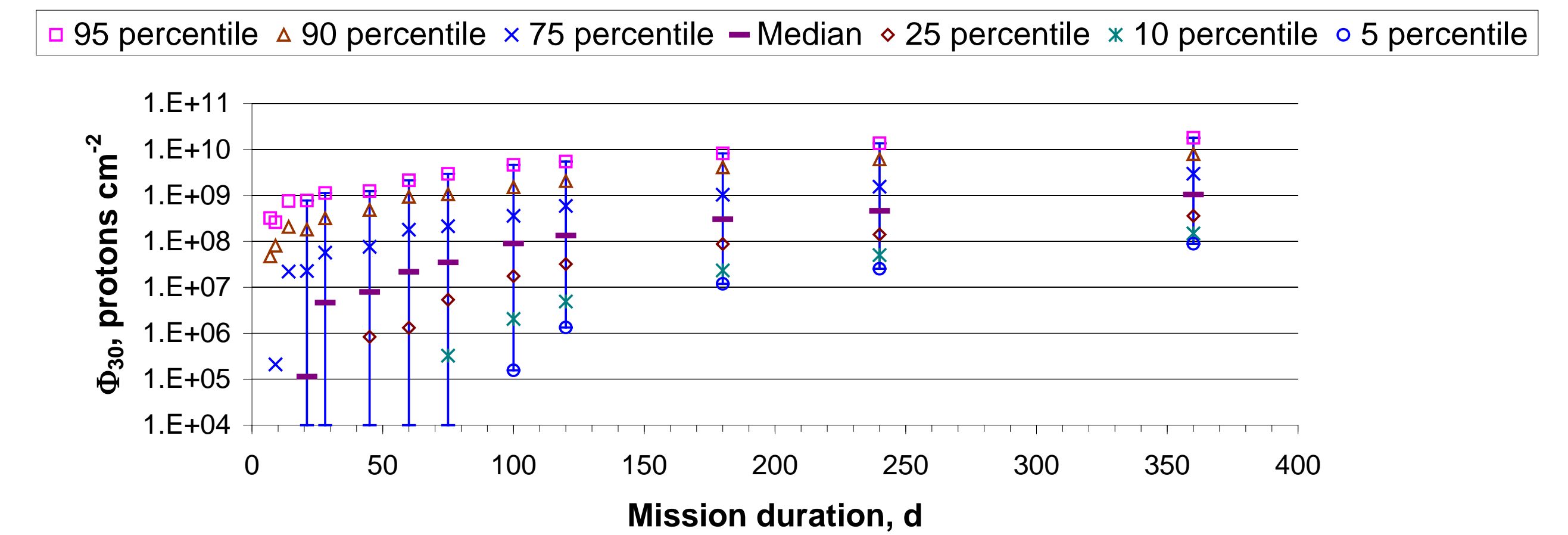


Vertical Distribution of Mars Atmospheric Properties*

Altitude, km	T, °C	p, kPa	ρ, g/cm ³	Atmospheric shielding thickness, g/cm ²	
				Low density model	High density model
8.0	-41.2	0.34	7.64×10 ⁻⁶	0.14	0.19
6.0	-37.0	0.41	8.98×10 ⁻⁶	3.16	4.34
4.0	-35.0	0.49	1.07×10 ⁻⁵	6.73	9.25
2.0	-33.0	0.58	1.27×10 ⁻⁵	10.97	15.08
0.0	-31.0	0.7	1.50×10 ⁻⁵	16.00	22.00
-2.0	-29.0	0.84	1.78×10 ⁻⁵	19.04	26.17
-4.0	-27.0	1.00	2.12×10 ⁻⁵	22.64	31.13
-6.0	-25.0	1.2	2.52×10 ⁻⁵	26.92	37.01
-8.0	-23.0	1.44	2.99×10 ⁻⁵	32.00	44.00

*Temperature and pressure data based on Mars Global Surveyor

Impact of SPE Spectral Variation and Mission Length

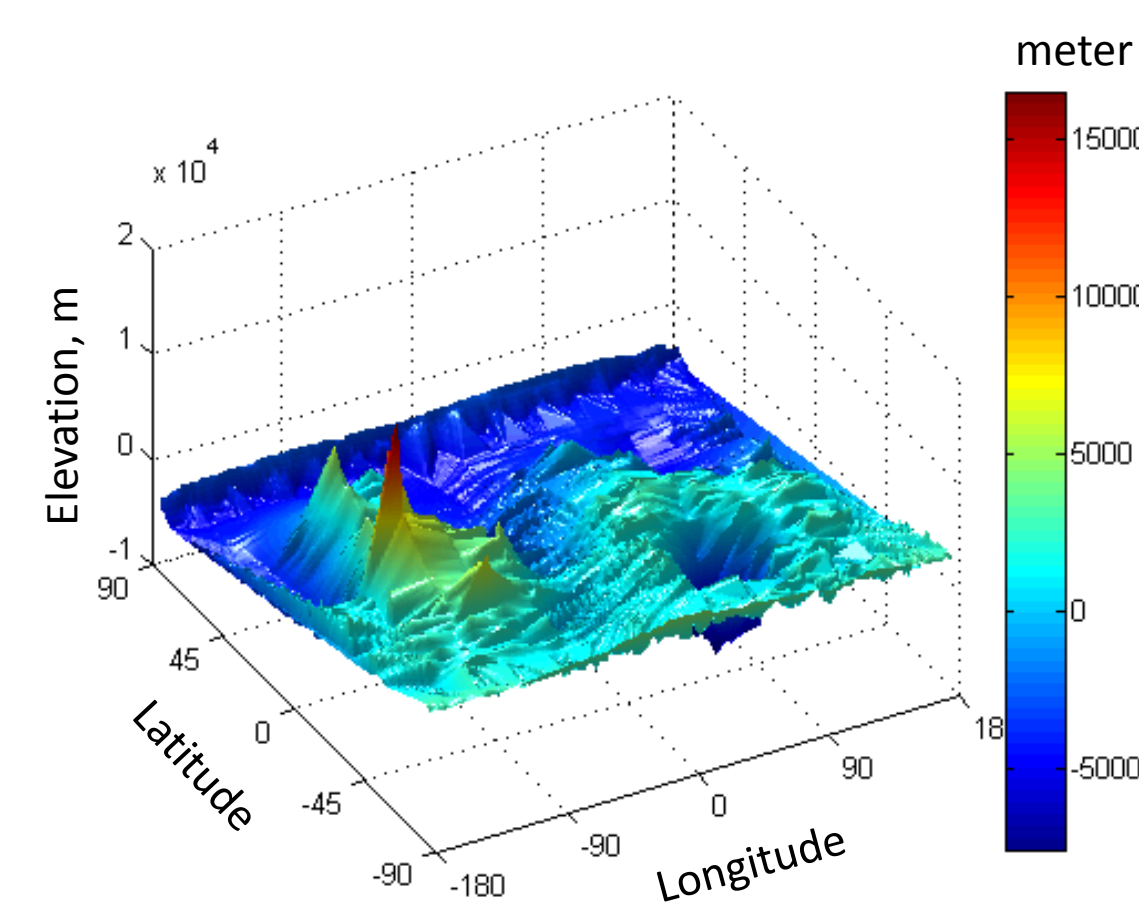


Environmental parameters		Mission duration				
		6-Month	12-Month	30-Month*		
GCR deceleration parameter (φ), MV	Solar minimum	428	428	428		
	Median solar activity	735	743	773		
	Solar maximum	1100	1100	1100		
SPE fluence (Φ ₃₀), p/cm ²	Median level	1.39×10 ⁸	9.74×10 ⁸	5.26×10 ⁹		
	August 1972 SPE	8.10×10 ⁹	8.10×10 ⁹	8.10×10 ⁹		
	95 percentile	1.08×10 ¹⁰	4.80×10 ¹⁰	1.35×10 ¹¹		
30-Month Mars Mission	Φ ₃₀ by each segment			Φ ₃₀ by fraction to 30-month mission		
	Transits	Mars stay	Total	Transits	Mars stay	Total
	12-month	18-month	30-month	12-month	18-month*	30-month
Median	2.78×10 ⁸	2.03×10 ⁹	2.34×10 ⁹	2.10×10 ⁹	3.16×10 ⁹	5.26×10 ⁹
95 percentile	2.16×10 ¹⁰	7.50×10 ¹⁰	9.66×10 ¹⁰	5.40×10 ¹⁰	8.10×10 ¹⁰	1.35×10 ¹¹

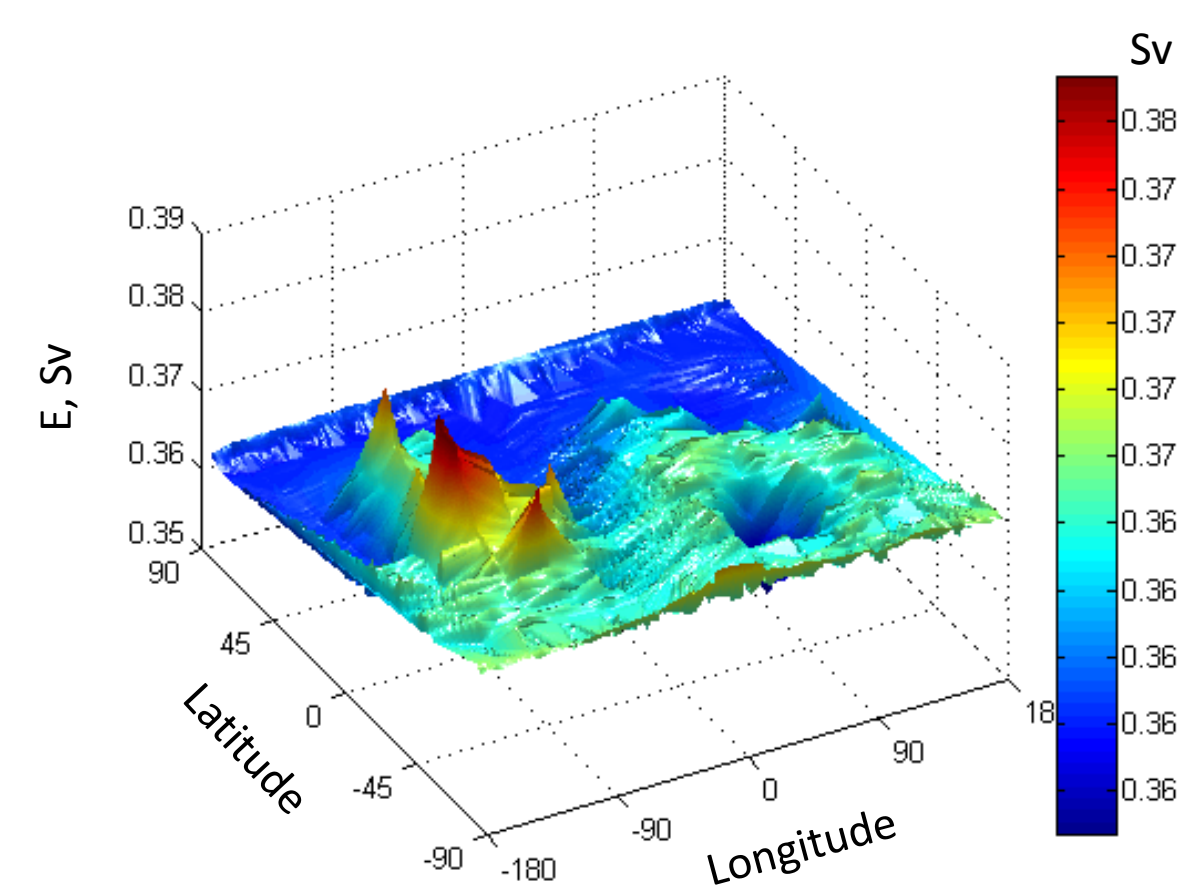
*Organ dose estimates using SPE fluences proportional to the simulated fluence of 30-month mission.

30-month Mars Mission

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



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

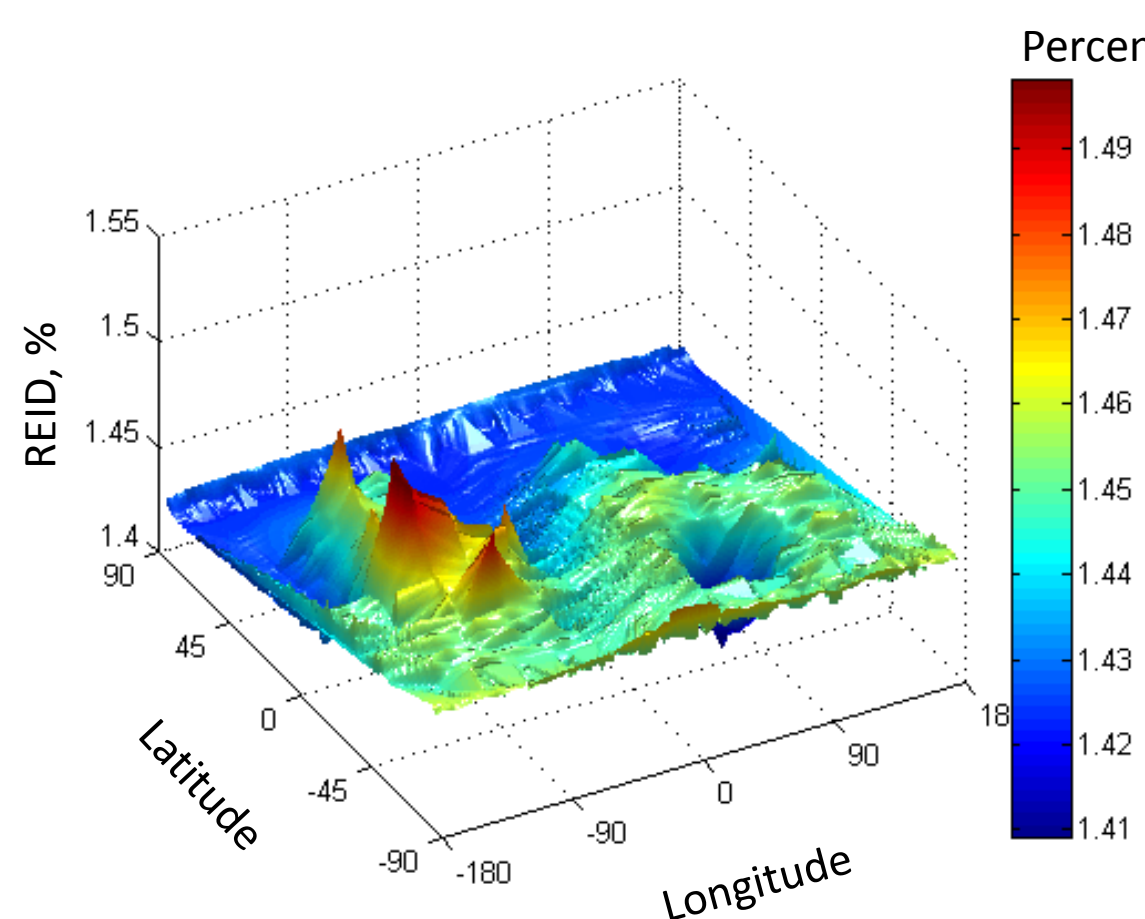


US Average Population

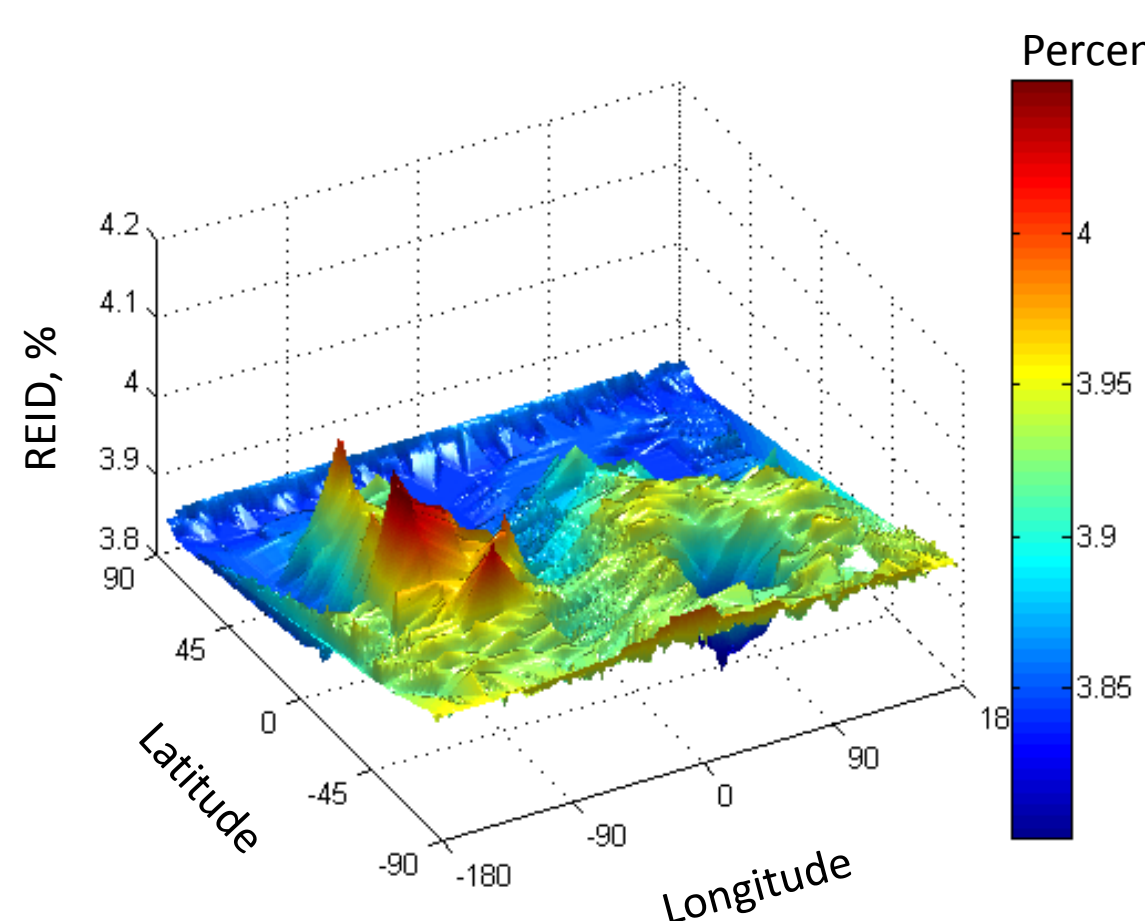
Transit to/from Mars for 6-month each way*		Mars surface stay for 18-month**		Total for 30-month	
E, Sv	REID[95% CI]	E, Sv	REID[95% CI]	E, Sv	REID[95% CI]
0.17	0.68[0.23, 1.96]	0.37	1.44[0.50, 3.91]	0.71	2.80[0.90, 7.75]

*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

Expected Cancer Risk for 18-month on Mars Surface



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



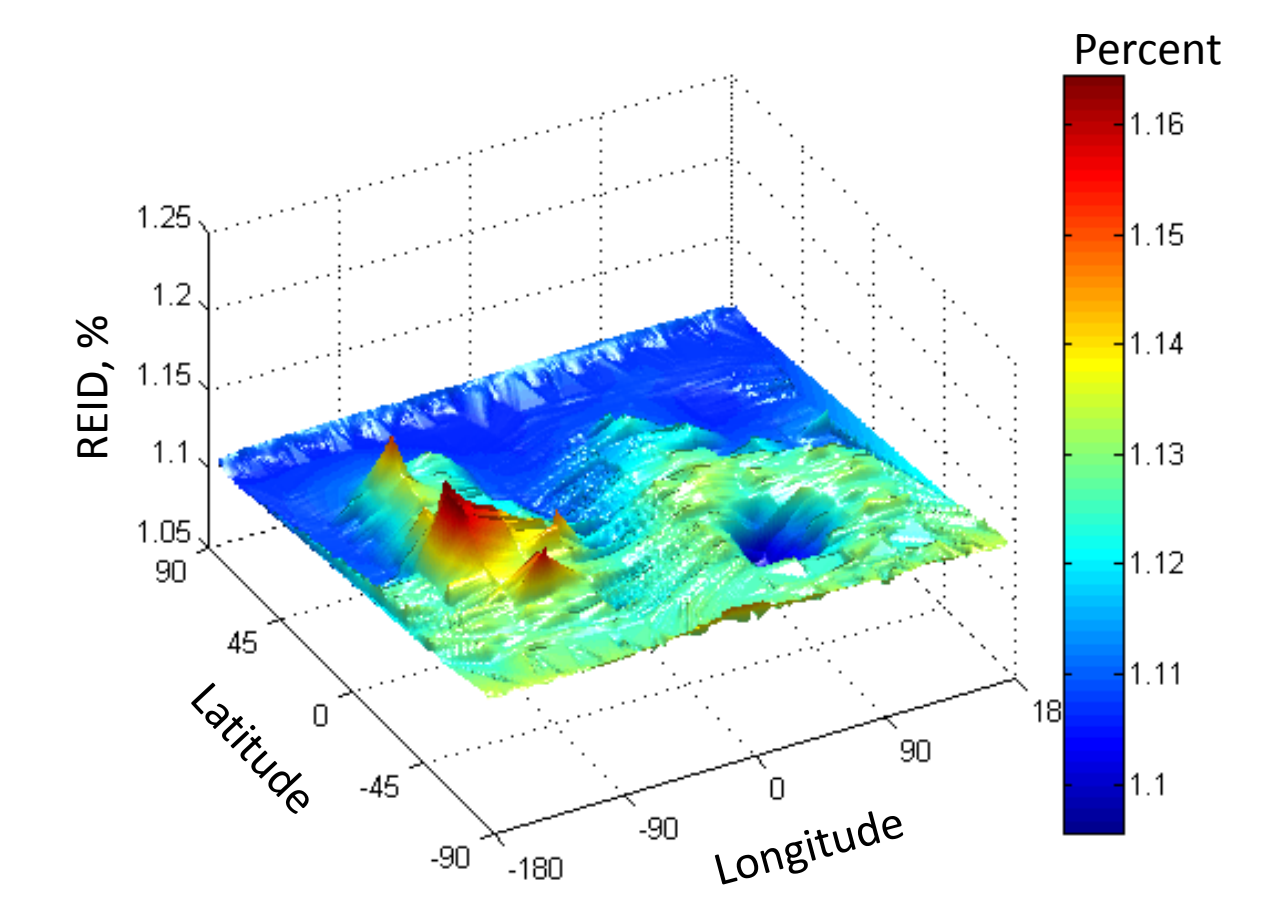
Risk of 40-y Males

Never-Smoker Population

Transit to/from Mars for 6-month each way*		Mars surface stay for 18-month**		Total for 30-month	
E, Sv	REID[95% CI]	E, Sv	REID[95% CI]	E, Sv	REID[95% CI]
0.17	0.53[0.18, 1.51]	0.37	1.12[0.39, 3.02]	0.71	2.18[0.68, 6.02]

*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

Expected Cancer Risk for 18-month on Mars Surface



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

