Martian Regolith as Space Radiation Shielding

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Abstract

In current Mars scenario descriptions, an entire mission is estimated to take 500–1000 days round trip with a 100–600 day stay time on the surface. To maintain radiation dose levels below permissible limits, dose estimates must be determined for the entire mission length. With extended crew durations anticipated on Mars, the characterization of the radiation environment on the surface becomes a critical aspect of mission planning.

The most harmful free-space radiation is due to high energy galactic cosmic rays (GCR) and solar flare protons. The carbon dioxide atmosphere of Mars has been estimated to provide a sufficient amount of shielding from these radiative fluxes to help maintain incurred doses below permissible limits.[1,2] However, Mars exploration crews are likely to incur a substantial dose while in transit to Mars that will reduce the allowable dose that can be received while on the surface. Therefore, additional shielding may be necessary to maintain short-term dose levels below limits or to help maintain career dose levels as low as possible. By utilizing local resources, such as Martian regolith, shielding materials can be provided without excessive launch weight requirements from Earth. The scope of this synopsis and of Ref. 3 focuses on presenting our estimates of surface radiation doses received due to the transport and attenuation of galactic cosmic rays and February 1956 solar flare protons through the Martian atmosphere and through additional shielding provided by Martian regolith.

Contents

In a previous study, doses were determined for crew members on the surface of Mars with their only protection being the carbon dioxide atmosphere.[1,2] In this study, as in Ref. 1, dose estimates were predicted using a standard GCR flux-energy distribution for the minimum of solar activity and the February 1956 flare event fluence at 1 a.u. The February 1956 flare, having a relatively large number of high-energy particles, was selected for further analysis because of its potential to deliver the largest dose at moderate shield thicknesses[1] (25–50 g/cm^2). For the radiative transport through the atmosphere, the Committee on Space Research low-density model of the atmosphere was considered.[4] The spherical geometry of the atmosphere was also considered, in that the amount of protection provided increases with increasing zenith angles. This protection can be described in terms of an absorber amount or g/cm^2 of material, which can be converted to a linear thickness by dividing by density. On the surface (0 km) at a zenith angle of 0 deg, the atmosphere provides 16.0 g/cm^2 of carbon dioxide protection, increasing to 59.6 g/cm^2 at 75 deg. At a surface elevation of 8 km at a zenith angle of 0 deg, the atmosphere provides 7.5 g/cm^2 protection, increasing to 27.8 g/cm^2 at 75 deg. The unshielded integrated dose equivalent results are shown in Table 1. A total yearly skin and blood forming organ (BFO) dose may be conservatively estimated as the sum of the annual GCR dose equivalent and the dose equivalent due to one large flare. At the surface (0 km), such a dose equivalent is estimated to be 21.8 rem/yr for the BFO and 24.2 rem/yr for the skin.

For high-energy radiation, the dose delivered to the vital organ, referred to here as the blood forming organ dose, is the most important with regard to latent carcinogenic effects. In this analysis, the BFO doses are computed as the dose at a 5-cm depth in human tissue. The dosimetric quantity which relates physical dose to biological risk is the dose equivalent and is evaluated by incorporating energy-dependent quality factors as recommended by the International Commission on Radiological Protection.[5]

The maximum dose equivalent limits for U.S. astronauts are recommended by the National Council on Radiation Protection.[6] The 30-day skin and BFO limits are presently 150 and 25 rem, respectively. The annual limit for skin and BFO are 300 and 50 rem, respectively. The total career limit for the skin is 600 rem, and total career BFO dose limits vary between 100 and 400 rem, depending upon age and gender. The dose equivalents from Table 1 are below these established limits. However, if a crew member has already received a substantial dose during the mission or during his career, additional shielding may be desirable.

The regolith model selected for shield calculations is based on the chemistry of the Viking 1 Lander site.[4] The compounds selected and their normalized weight percentages are 58.2% SiO_2, 23.7% Fe_2O_3, 10.8% MgO, and 7.3% CaO. The bulk density of the regolith site is approximately 1.0–1.8 g/cm^3.[4]

The NASA Langley Research Center nucleon and heavy-ion transport computer codes are used to predict the propagation and interaction of the free-space nucleons and heavy ions through the Martian atmosphere and then through various thicknesses of regolith.[7,8] Salient features of these codes have been described in the previous study.[1]

In Ref. 1, these codes were used to describe the propagation of the free-space GCR and solar flare protons through the carbon dioxide atmosphere to the Martian surface. The resulting flux spectra at 0 and 8 km surface elevations were used as input conditions for the regolith shield calculations. The calculated particle flux vs energy distributions in the regolith were then used to determine the dose equivalent at specified locations in the shield media.

Table 1 Unshielded integrated dose equivalent for the COSPAR low-density atmosphere model

Incident radiation		Integrated dose (rem) at an altitude of 0 km	8 km
Annual galactic cosmic ray	Skin	13.2	18.9
	BFO	11.9	15.8
Solar flare event 2/56	Skin	11.0	16.2
	BFO	9.9	13.6

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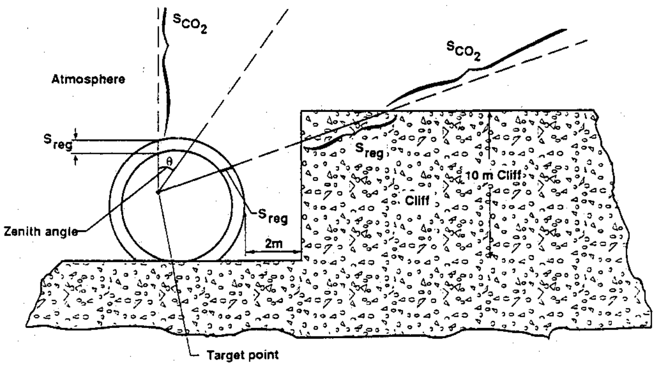

Fig. 1 Sample slant path distances (S) through carbon dioxide followed by Martian regolith evaluated at a specific target point.

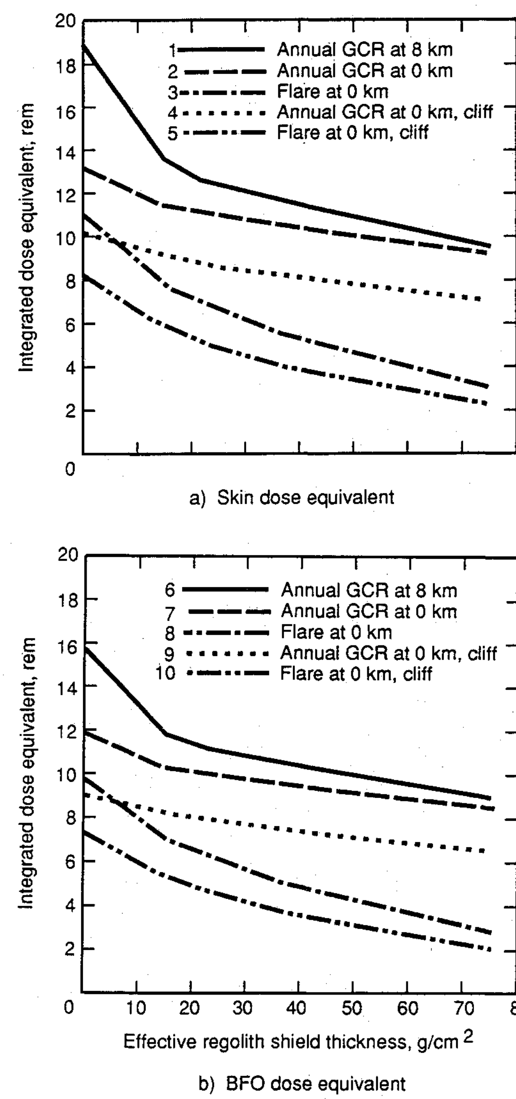

Fig. 2 Maximum dose equivalent in the central cross-sectional plane of the module as a function of effective regolith shield thickness.

One Martian habitat is described as a Space Station derived module 8.2 m in length and 4.45 m in diameter. The cylindrical module is assumed to be lengthwise on the surface, with various thicknesses of Martian regolith surrounding it. Another configuration assumes the module is near a cliff.

When propagation data for GCR and solar flare protons are applied to a specific habitat geometry, the doses at various points within the habitat can be estimated. The dose contribution attributed to particles arriving from a given direction is determined by the amount of CO_2 traversed, and then by the shield thickness encountered along its straight line path to a specified target point (see Fig. 1). The directional dose is then numerically integrated over all solid angles about the target point to determine the total dose at that point.

A series of dose calculations are performed for various regolith thicknesses covering the module. The largest integrated dose equivalent in a vertical plane through the center of the cylinder is plotted vs an effective regolith thickness in Fig. 2. As seen in the figure, the regolith does not provide much additional protection from the GCR or the flare event than that already provided by the atmosphere. The slope of each curve is relatively flat after 20 g/cm^2, with most of the skin and BFO dose reductions occurring in approximately the first 20 g/cm^2. For 22.5 g/cm^2 of regolith protection, the annual BFO dose equivalent due to GCR is reduced from 11.9 to 10.0 rem/yr at 0 km (curve 7, Fig. 2), and from 15.8 to 11.2 rem/yr at an elevation of 8 km (curve 6). For 22.5 g/cm^2 of regolith, the BFO dose equivalent due to the solar flare is reduced from 9.9 to 6.3 rem/event at 0 km (curve 8). The cliff further reduces the BFO dose equivalent by approximately 2–2.5 rem for both the GCR (curves 7, 9) and the February 1956 flare (curves 8, 10) at 0 km. The shielding provided by the cliff and atmosphere alone result in a BFO dose equivalent of 9.1 rem/yr due to GCR (curve 9) and 7.4 rem/event due to the February 1956 event (curve 10).

This analysis has shown that moderate thicknesses of Martian regolith do not provide substantial additional protection to that already provided by the carbon dioxide atmosphere, and that a logical alternative to massive shielding efforts may be to take advantage of local terrain features. If regolith is used as shielding material, the largest reduction in dose equivalent occurs in approximately the first 20 g/cm^2 (or approximately 15 cm, assuming a regolith density of 1.5 g/cm^3). Thus, if additional protection using Martian regolith is desired, a shield thickness on the order of 15–20 cm is recommended. If additional protection using 15 cm of Martian regolith is provided at an altitude of 0 km, the annual skin and blood forming organ dose equivalent (due to GCR and the February 1956 event) will be reduced from 24 to 18 rem/yr and from 22 to 16 rem/yr, respectively.

References

[1]Simonsen, L. C., Nealy, J. E., Townsend, L. W., and Wilson, J. W., "Radiation Exposure for Manned Mars Surface Missions," NASA TP-2979, March 1990.

[2]Simonsen, L. C., Nealy, J. E., Townsend, L. W., and Wilson, J. W., "Space Radiation Dose Estimates on the Surface of Mars," *Journal of Spacecraft and Rockets,* Vol. 27, No. 4, pp. 353–354.

[3]Simonsen, L. C., Nealy, J. E., Townsend, L. W., and Wilson, J. W., "Space Radiation Shielding for a Martian Habitat," SAE Paper 901346, 20th International Conf. on Environmental Systems, Williamsburg, VA, July 9–12, 1990.

[4]Smith, R. E., and West, G. S., "Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development," 1982 Rev., Vol. I, NASA TM-82478, 1983.

[5]"Recommendations of the International Commission on Radiological Protection," ICRP Pub. 26, Pergamon Press, New York, Jan. 1977.

[6]Fry, R. J., and Nachtwey, D. S., "Radiation Protection Guidelines for Space Missions," *Health Physics,* Vol. 55, No. 2, 1988, pp. 159–164.

[7]Wilson, J. W., et al., "BRYNTRN: A Baryon Transport Model," NASA TP-2887, March 1989.

[8]Townsend, L. W., Nealy, J. E., Wilson, J. W., and Simonsen, L. C., "Estimates of Galactic Cosmic Ray Shielding Requirements During Solar Minimum," NASA TM-4167, Feb. 1990.

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