2-1-2013

The CRaTER Special Issue of Space Weather: Building the observational foundation to deduce biological effects of space radiation

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Recommended Citation
Schwadron, N. A., S. Smith, and H. E. Spence (2013), The CRaTER Special Issue of Space Weather: Building the observational foundation to deduce biological effects of space radiation,Space Weather, 11, 47–48, doi:10.1002/swe.20026.

SPACE WEATHER, VOL. 11, 47–48, doi:10.1002/swe.20026, 2013

The CRaTER Special Issue of *Space Weather*: Building the observational foundation to deduce biological effects of space radiation

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Received 18 December 2012; accepted 12 January 2013; published 26 February 2013.

Citation: Schwadron, N. A., S. Smith, and H. E. Spence (2013), The CRaTER Special Issue of *Space Weather*: Building the observational foundation to deduce biological effects of space radiation, *Space Weather*, *11*, 47–48, doi:10.1002/swe.20026.

[1] The United States is preparing for exploration beyond low-Earth Orbit (LEO). However, the space radiation environment poses significant risks. The radiation hazard is potentially severe but not sufficiently well characterized to determine if long missions outside LEO can be accomplished with acceptable risk [*Cucinotta et al*., 2001; *Schwadron et al*., 2010; *Cucinotta et al*., 2010]. Radiation hazards may be over- or under-stated through incomplete characterization in terms of net quantities such as accumulated dose. Time-dependent characterization often changes acute risk estimates [*NCRP*, 1989; *Cucinotta*, 1999; *Cucinotta et al*., 2000; *George et al*., 2002]. For example, events with *high accumulated doses* but sufficiently *low dose rates* (<30 rad/h) pose significantly *reduced* risks. Protons, heavy ions, and neutrons all contribute significantly to the radiation hazard. However, each form of radiation presents different biological effectiveness. As a result, quality factors and radiation-specific weighting factors are needed to assess biological effectiveness of different forms of radiation [e.g., *NCRP 116*, 1993] (Figure 1). More complete characterization must account for time-dependent radiation effects according to organ type, primary and secondary radiation composition, and acute effects (vomiting, sickness, and, at high exposures, death) versus chronic effects (such as cancer).

[2] For heavy ions and protons, there are considerable advantages of providing a direct measurement of the linear energy transfer (LET) spectra behind shielding material. LET is the mean energy absorbed locally, per unit path length, when a charged particle traverses material. A LET spectrometer measures the amount of energy deposited in a detector of some known thickness and material property as a high-energy particle passes through it, usually without stopping. While LET spectrometers do not (necessarily) resolve mass, LET measurements

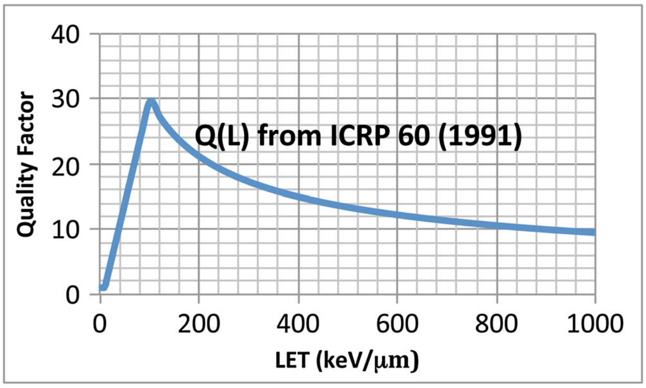

Figure 1. Quality factors are directly linked to linear energy transfer (LET). By directly measuring LET, the CRaTER instrument is able to provide a direct connection between measurements and biological impact via the quality factor.

do include all the species, with the possible exception of neutrons that are relevant to the energy deposited behind a known amount of spacecraft shielding. The Cosmic Ray Telescope for the Effects of Radiation (CRaTER; *Spence et al*. [2010]) is the first instrument of its kind to provide the needed ground truth measurements of LET spectra that provide the direct and critically needed link between biological effectiveness to the radiation environment. With CRaTER observations, we can now directly break down the observed spectrum of radiation into its constituent heavy ion components and through biologically based quality factors that provide not only doses and dose rates but also dose-equivalents, associated rates, and even organ doses. This special section details CRaTER measurements and efforts to validate models based on these foundation-building observations:

- The deep-space galactic cosmic ray linear energy transfer spectrum at solar minimum.
- Measurements of galactic cosmic ray shielding with the CRaTER Instrument.

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- The ionizing-radiation environment near the lunar surface during the recent deep solar minimum.
- Primary and secondary ion contributions to LET spectra measured by CRaTER Instrument on LRO.
- The newly discovered lunar energetic proton albedo.
- Characterization of the radiation environments of the Moon during three major solar events in 2012.

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