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Review

A review of instruments and methods for dosimetry in space

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Abstract

Instruments and methods recently used for space radiation dosimetry are reviewed for the purposes of comparison and reference. Passive detection methods mentioned include track-etch, luminescent, nuclear emulsion, and metal foil detectors. These can provide a reliable source of data for all types of radiation, but often require processing that cannot occur in space. Experimental methods of LET determination using TLDs, such as the high temperature peak ratio (HTR) method, are also discussed. Portable readout passive detectors including Pille, MOSFET, and bubble detector systems provide a novel alternative to traditional passive detectors, but research is more limited and their widespread use has yet to be established. Active detectors including DOSTEL, CPDS, RRMD-III, TEPC, R-16, BBND, and the Liulin series are examined for technical details. These instruments allow the determination of dose in real-time, and some can determine LET of incident particles by measuring energy deposition over a known path-length, but size and power consumption limit their practical use for dosimetry. Improved neutron dosimetry and development of a small active or portable readout personnel dosimeter capable of accurate LET determination are important steps for managing the effects of long-term exposure to the space radiation environment.

Keywords: Space; Cosmic; Radiation; Dosimeters; Detectors

Contents

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1. Introduction

Quantification of radiation dose to astronauts is difficult due to the complexity of the space radiation environment. Galactic cosmic rays (GCR) originating from cosmic events outside of the solar system contribute about half of the total effective dose received by astronauts in low-Earth orbit (LEO). The majority of the remaining dose is due to protons trapped within the Earth's magnetosphere. Secondary particles such as albedo neutrons reflecting from the Earth's atmosphere can also contribute a small dose, but this is often neglected. Perhaps most importantly, solar particle events (SPE) can deliver potentially lethal doses of radiation to astronauts traveling outside of the relative safety of Earth's magnetosphere, though these events are generally short-lived and comparatively rare (Benton and Benton, 2001). For astronauts within low-Earth orbit, these four sources all contribute to an immensely complex radiation field which varies as the spacecraft changes altitude and inclination, or passes through the South Atlantic Anomaly (SAA) where the inner proton belt intersects with the path of orbiting spacecraft. Secondary particles produced by scatter events within spacecraft increase complexity even further as the contents and orientation of the spacecraft changes.

Astronauts traveling in low-Earth orbit, such as onboard the space station, receive mean dose equivalents generally not exceeding 650 μSv/day (0.237 Sv/yr) (Benton and Benton, 2001). During deep space travel, astronauts will be subject only to galactic cosmic rays and rare solar particle events, but will receive much higher doses without the protection afforded by the Earth's magnetosphere. Little data is available for such an environment, but mean annual dose equivalents of around 0.5 Sv could be expected from GCR without contribution from SPE (Simonsen et al., 2000; Ballarini et al., 2006). Blood-forming-organ dose equivalent limits for astronauts within LEO are established by the NCRP Report No. 98 at 0.50 Sv/yr, with a sliding scale for total career dose dependent upon age and gender. The units for this limit were modified by NCRP Report No. 132, though the quantities remain essentially equivalent. The biological effects of GCR are still being studied and the NCRP requires more understanding before establishing dose limits for deep space travel.

While astronauts within low-Earth orbit are unlikely to exceed current dose limits, it is clear that future missions to the Moon and Mars may result in doses that approach or exceed recommendations. As such, the determination of dose requires instruments with great accuracy and sensitivity to the space radiation environment. In particular, it is critical to determine the linear energy transfer (LET) of incident radiation to make an accurate determination of equivalent dose. Simple measurements of absorbed dose do not account for the added biological harm of high LET radiation. Additional constraints include minimization of cost, weight, size, and power consumption due to the logistical challenges presented by space travel. Many instruments and techniques have been developed internationally by a variety of agencies, universities, and companies. This article provides a review of many of those devices, both passive and active, used in the determination of risk to astronauts from the space radiation environment.

2. Passive dosimetry

High-Z, high-energy (HZE) particles incident upon the hull and contents of spacecraft create a broad spectrum of secondary radiation that varies widely throughout the vessel. It is therefore necessary to quantify dose throughout the spacecraft and to each astronaut, rather than rely on single-point measurements. This requirement of widespread dosimetry lends itself to the use of passive detection methods that are small, economical, and can operate with no demands to the limited supply of electricity during space missions (see Tables 1 and 3).