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Overview of active methods for shielding spacecraft from energetic space radiation

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Abstract

During the 1960's and into the early 1970's, investigations were conducted related to the feasibility of using active radiation shielding methods, such as afforded by electromagnetic fields, as alternatives to passive, bulk material shielding to attenuate space radiations. These active concepts fall into four categories: (1) electrostatic fields; (2) plasma shields; (3) confined magnetic fields; and (4) unconfined magnetic fields. In nearly all of these investigations, consideration was given only to shielding against protons or electrons, or both. During the 1980's and 1990's there were additional studies related to proton shielding and some new studies regarding the efficacy of using active methods to shield from the high energy heavy ion (HZE particle) component of the galactic cosmic ray spectrum. In this overview, each concept category is reviewed and its applicability and limitations for the various types of space radiations are described. Recommendations for future research on this topic are made.

KEYWORDS: Space radiation, Active shielding, HZE particles, solar particle events.

1. Introduction

Since the early 1960's investigations of the feasibility of using active methods, such as electromagnetic fields or plasmas, to shield spacecraft from hazardous space radiation, especially high energy protons and electrons, have been undertaken with the intention of reducing the weight penalties associated with the use of bulk material shielding for manned spacecraft. These active concepts include the use of electrostatic fields, plasmas, confined magnetic fields and unconfined magnetic fields. In nearly all cases, the major focus of the proposed methods has been to shield against space electrons and protons, especially those associated with energetic solar particle events. Except for a few studies, no consideration was given to shielding against the high-energy, heavy-ions (HZE particles) present in the galactic cosmic ray (GCR) spectrum. A comprehensive listing of nearly all publications related to active shielding of spacecraft can be found in Sussingham, Watkins and Cocks [1]. In the present work each category of active shielding is briefly discussed and its applicability and limitations for the deep space radiation environment (both solar and GCR) presented. Some recommendations for future research are made.

2. Active shielding methods

2.1. *Electrostatic Fields*

Except for a study by Townsend [2] that investigated shielding of GCR iron nuclei, previous electrostatic shielding studies were limited to protons from solar and galactic cosmic rays and protons and electrons in the Van Allen belts. In ref. [2] it was demonstrated that electrostatic shields are unsuitable for GCR shielding since the required electrostatic potentials exceed the state of the art by over an order of magnitude. In addition, electrical breakdown considerations limit the minimum physical size of the shield configuration to dimensions on the order of hundreds of meters.

2.2. *Plasma Shielding*

Early studies of plasma radiation shielding focused on protecting against energetic solar protons emitted during large solar particle events (SPE) [3]. The concept involves a large electrostatic field to repel positively charged particles. Since this potential surface would attract and accelerate space electrons to very high energies, a lower intensity magnetic field is used to control a cloud of free electrons, which deflect the incoming electrons. Although the simplified analysis of ref. [3] suggests that there may be substantial weight savings associated with its use as protection from an energetic SPE, the technological challenges are many including achieving electrostatic potentials on the spacecraft surface exceeding 200,000kV, possible instabilities in the plasma cloud due to collisions, etc., and the huge magnetic field energy (12 MJ) stored in the plasma. Since the basic mechanism for deflecting positively charged ions is an electrostatic field, the plasma shield is not feasible as an HZE particle shield.

2.3. *Confined Magnetic Field*

Confined magnetic field configurations usually involve the use of concentric spheres or some similar arrangement to limit the spatial extent of the magnetic field to some limited finite region of space around the spacecraft. One such proposed design [4], involving superconducting wires configured so as to produce a uniform magnetic field in a restricted volume surrounding a spherical spacecraft yielded a weight advantage of nearly 20% for complete shielding against 200 MeV protons, such as might be encountered from an SPE during a manned mission to Mars. A subsequent analysis of the efficacy of such a shield for both GCR and SPE particles (August 1972 SPE assumed) demonstrated that the confined magnetic field was effective as an SPE shield, but was nearly useless as a GCR shield [5]. Additional analyses in ref. [5] indicated that proper selection of materials could result in lower combined exposures from SPE and GCR for passive bulk shielding having the same total mass as that needed to generate and support the magnetic shield configuration.

2.4. *Unconfined Magnetic Field*

Unconfined magnetic field shield configurations typically involve a cylindrical or toroidal-shaped spacecraft having a dipole-like magnetic field, usually generated by passing current through coils or the spacecraft skin. One such design [6], intended as a space colony, considered GCR protection in the analysis and resulted in a shield having a mass in excess of 1 million tons and a diameter in excess of 100 meters. The analysis, however, assumed that GCR radiation exposures had to be reduced to dose equivalent levels comparable to those experienced by the general population on Earth. Most analyses, however, involve protection only against SPE protons, including a recent proposal by Spillantini and collaborators [7]. Although many of these designs may afford protection from a large SPE, none will provide protection from the substantial chronic background of the biologically damaging GCR spectrum, especially the HZE component.

3. Summary and recommendations

Very few analyses of the efficacy of active shielding methods for protecting spacecraft crews consider the total spectrum (GCR and SPE) likely to be encountered on a deep space mission. Nearly all analyses have focused solely on SPE protons, thereby ignoring the biologically damaging GCR spectrum. To be seriously considered as a method of protecting spacecraft crews, protection against ALL significant sources of space radiation must be provided. It is not sufficient to consider only SPE protons and ignore the GCR. None of the active shielding methods proposed to date appear to offer a weight savings over bulk material shielding when considering the entire deep space environment, especially the HZE component of the GCR. Of the four general methods for active shielding, electrostatic fields, plasma shields, and confined magnetic can probably be dismissed as candidates for further investigation since the physics underlying their designs makes them inadequate as a GCR shield. Since the Earth's magnetic field is clearly an effective GCR shield, unconfined magnetic fields warrant further investigation. Such investigations must include the real radiation environments expected in deep space (SPE *and* GCR), which consist of particles ranging from protons through iron nuclei with energies up to several GeV per nucleon. It is not sufficient to choose one particle type and energy for the analysis. Although it is not necessary to deflect all of these particles, estimates of the shield effectiveness must include serious calculations of the biological risks from those that do penetrate the shield. Dose and dose equivalent comparisons between active and passive shields should include detailed transport analyses that consider secondary particle production mechanisms. Simple estimates of shield mass requirements based upon range-energy relations are not adequate for choosing between alternative shield configurations.

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