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Space Radiation and its effects on environment: Conceptual Study

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ABSTRACT

Space travel has advanced significantly over the last six decades with astronauts spending up to 6 months at the International Space Station. Nonetheless, the living environment while in outer space is extremely challenging to astronauts. In particular, exposure to space radiation represents a serious potential long-term threat to the health of astronauts because the amount of radiation exposure accumulates during their time in space. Therefore, health risks associated with exposure to space radiation are an important topic in space travel, and characterizing space radiation in detail is essential for improving the safety of space missions. In this paper, we have discussed space radiation environment and in brief present and future endeavours that exposure to various space radiation environments and how it can be reduced.

Keywords: Space Radiation, Environment, Characteristics, Classification

INTRODUCTION

Thespace radiation environment is a complex field comprised primarily of charged particles spanning energies over many orders of magnitude. The principal sources of these particles are galactic cosmic rays, the Sun and the trapped radiation belts around the earth. Superimposed on a steady influx of cosmic rays and a steady outward flux of low-energy solar wind are short-term ejections of higher energy particles from the Sun. Space radiation is different from the kinds of radiation we experience on Earth, such as X-rays or gamma rays. Space radiation is comprised of atoms in which electrons have been stripped away as the atom accelerated in interstellar space to speeds approaching the speed of light-eventually, only the nucleus of the atom remains. Space radiation is made up of three kinds of radiation: particles trapped in the Earth's magnetic field; particles shot into space during flares (solar particle events); and galactic cosmic rays, which are high-energy protons and heavy ions from outside our solar system. All of these kinds of space radiation represent ionizing radiation. Shreya et.al mentions a climate change, how space technology is used for climate change. Satellite, navigation,telecommunication, etc. systems are helpful tools used for studying the climate change condition [21].

Compared to the terrestrial surface, space represents a hostile environment, characterized by the combination of microgravity, and a peculiar radiative environment, which could lead to severe health issues for astronaut crews engaged in long-term missions. Among these factors, exposure to radiation dominated by particle shots and Galactic cosmic rays of extremely high energy is of special concern [1, 2]. Efficient shielding of such radiation is very difficult, considering the mass constraints which spaceships need to respect. Radiation is a form of energy that is emitted or transmitted in the form of rays, electromagnetic waves, and/or particles. In some cases, radiation can be seen (visible light) or felt (infrared radiation), while other forms like x-rays and gamma rays are not visible and can only be observed directly or indirectly with special equipment. Although radiation can have negative affects both on biological and mechanical systems, it can also be carefully used to learn more about each of those systems.

METHOD

Space radiation is distinct from common terrestrial forms of radiation. Our magnetosphere protects us from significant exposure to radiation from the sun and from space. Radiation that is emitted from the sun is comprised of fluctuating levels of high-energy protons. Space radiation consists of low levels of heavy charged particles. High-energy protons and charged particles can damage both shielding materials and biological systems. The amount of space radiation is typically low, but the effects are cumulative.

Environment of Space Radiation

a) Radiation Environment in Low-Earth Orbits (LEO)

Ionizing radiation (IR) sources in the ISS orbits (altitude: 300 to 400 km; orbital inclination: 51.6°) include the three primary radiation sources (galactic cosmic rays (GCRs), which range widely from protons to Fe-ions, solar particle events (SPEs), and electrons and protons trapped in the Van Allen Belts (TPs)) outside the spacecraft. These combine to produce a complex radiation environment in and around the ISS, and the complexity of this radiation is dependent on the solar cycle, altitude, and shielding of each module of the ISS. Space radiation environments include fast neutrons with a wide energy range beyond several tens of (MeV) Mega electron-volt.

Characteristics of Space Radiation Environment in LEO

- A high contribution from high-linear energy transfer (LET) radiation that have a high-quality factor (QF) up to 30.
- Dose rates have values that are a few hundred times greater than those on the ground.
- The directional distribution of space radiation is nearly isotropic.
- Radiation effects occur under μG. Space radiation for LET greater than several keV/μm causes more serious damage to living things than low-LET radiation.

b) Radiation Environment Beyond LEO (Deep Space, the Moon and Mars)

The space radiation environment differs in and beyond LEO, including the surface of the Moon, Mars, deep space, and their comparisons. In deep space outside Earth's protective magnetic field, HZE (high-energy, heavy-ion) charged particles of GCRs and solar energetic particles (SEPs) strongly affect the dosimetry of astronauts. Space radiation doses change drastically because of the varying intensity and peak amplitude of SEP events in and near the Moon and Mars environments, where a protective magnetic field is almost completely absent.

c) Solar Ultraviolet (UV) Radiation

UV is part of the natural energy produced by the sun. UV radiation has electromagnetic radiation wavelengths from 10 nm to 400 nm, which are shorter than visible light (400–700 nm) but longer than X-ray. UV radiation reaches the Earth surface. UV radiation is classified into three regions based on their effects on biological processes: UV-C (<280nm), UV-B (280-315nm), and UV-A (315-400nm). UV-C which is a highly energetic wavelength is eliminated by the stratospheric ozone layer and is not encountered by plants. Both UV-B and UV-A radiations reach the surface of the Earth. The environment of space is characterized by low gravity, temperature oscillation, short-wavelength solar UV radiation, and complex cosmic IR. In particular, space is showered by a variety of different types of radiation, and thus, astronauts are exposed to a considerably large amount of space radiation.

Different Kinds of Radiation

Ionizing (high energy)

Ionizing radiation consists of particles or photons that have enough energy to ionize an atom or molecule by completely removing an electron from its orbit, thus creating a more positively charged atom. Examples of ionizing radiation include alpha particles (a helium atom nucleus moving at very high speeds), beta particles (a high-speed electron or positron), gamma rays, x-rays, and galactic cosmic radiation (GCR).

Non-Ionizing (low energy)

Less energetic non-ionizing radiation does not have enough energy to remove electrons from the material it traverses. Examples of non-ionizing radiation include radio frequencies, microwaves, infrared, visible light, and ultraviolet light.

Difference between Ionizing and Non-Ionizing

Non-ionizing radiation is damaging, but it can easily be shielded out of an environment as is done for UV radiation. Ionizing radiation, however, is much more difficult to avoid. Ionizing radiation has the ability to move through substances and alter them as it passes through. When this happens, it ionizes (changes the charge of) the atoms in the surrounding material with which it interacts. Ionizing radiation is like an atomic-scale cannonball that blasts through material, leaving significant damage behind. More damage can also be created by secondary particles that are propelled into motion by the primary radiation particle. The particles associated with ionizing radiation are categorized into three main groups relating to the source of the radiation: trapped radiation belt particles (Van Allen Belts), cosmic rays, and solar flare particles.

Interaction of Radiation with Materials

The manner in which radiation interacts with solid material depends on the type, kinetic energy, mass, and charge state of the incoming particle and the mass, atomic number, and density of the target material. In this section, we discuss the manner in which the different types of radiation interact with materials.

a. Ionization Effects

Ionization of the target material occurs for photons, electrons, protons, and energetic heavy ions. Photon interactions are not a primary concern for satellites in the natural space environment. However, we include photon interactions in this discussion because of their importance in hardness assurance testing. Most laboratory sources used to simulate total-dose space environment effects emit either low-energy x rays or high-energy gamma rays.

b. Photon Effects

Photons interact with material through three different processes, namely the photoelectric (or fluorescent) effect, the Compton Effect, and pair production. For each of these processes, the primary result of the interaction is the creation of energetic secondary electrons. Low-energy photons interact with material predominantly through the photoelectric effect.

c. Electron-Hole Pair Generation

High-energy electrons (secondary electrons generated by photon interactions or electrons present in the environment) and protons can ionize atoms, generating electron-hole pairs. As long as the energies of the electrons and holes generated are higher than the minimum energy required creating an electron-hole pair, they can in turn generate additional electron-hole pairs. In this manner, a single, high enough energy incident photon, electron, or proton can create thousands or even millions of electron-hole pairs.

d. Dose Enhancement

One additional factor that must be taken into account in determining the total number of electron-hole pairs generated in a material is dose enhancement. Dose enhancement arises when an incident particle travels through two adjacent materials with different atomic masses. Close to the interface of two materials, charge particle equilibrium is not maintained. Charge particle equilibrium is defined as the condition where the total energy carried out of a given mass element by electrons is equal to the energy carried into it by electrons.

Galactic Cosmic Radiation (GCR)

Galactic Cosmic Radiation, or GCR, comes from outside the solar system but primarily from within our Milky Way galaxy. In general, GCR is composed of the nuclei of atoms that have had their surrounding electrons stripped away and are traveling at nearly the speed of light. The GCR permeates interplanetary space and is comprised of roughly 85% hydrogen (protons), 14% helium, and about 1% high-energy and highly charged ions called HZE particles. An HZE is a heavy ion having an atomic number greater than that of helium and having high kinetic energy. GCR is extremely damaging to materials and biology. In general, we are largely shielded from GCR on Earth because of our planet’s atmosphere and magnetic field, whereas the Moon is not shielded from GCR because it lacks a global magnetic field and atmosphere. GCR are heavy, high-energy ions of elements that have had all their electrons stripped away as they journeyed through the galaxy at nearly the speed of light.

They can cause the ionization of atoms as they pass through matter and can pass practically unimpeded through a typical spacecraft or the skin of an astronaut. The GCR are a dominant source of radiation that must be dealt with aboard current spacecraft and future space missions within our solar system.

Trapped Radiation Belts

Radiation belts are the regions of high concentration of energetic electrons and protons trapped within the Earth's magnetosphere. There are two distinct belts of toroidal shape surrounding the Earth where high energy charged particles are trapped in the geomagnetic field. The inner radiation belt (IRB), located between about 1.1 to 2 Earth radii, consists of electrons with energies up to 10 MeV and protons with energies up to ~700 MeV. The outer radiation belt (ORB) starts from about 4 Earth radii and extends to about 9-10 Earth radii in the anti-sun direction. The outer belt consists mostly of electrons whose energy is below 10 MeV.

Solar Energetic Particles (SEP)

The SEP are mainly produced by solar flares, caused by sporadic eruptions of the chromosphere of the Sun. High fluxes of charged particles (mostly protons, electrons and helium and heavier ions) with energies up to several GeV are emitted by processes of acceleration outside the Sun. It is now generally understood that SEP events arise from coronal mass ejections (CME) from active regions of the solar surface. The CME propagates through interplanetary space carrying along with it the local surface magnetic field frozen into the ejected mass.

Radiation Damage in Living Organisms

Space radiation can penetrate habitats, spacecraft, equipment, spacesuits, and even astronauts themselves. The interaction of ionizing radiation with living organisms can lead to harmful health consequences such as tissue damage, cancer, and cataracts in space and on Earth. The underlying cause of many of these effects is damage to deoxyribonucleic acid (DNA). The degree of biological damage caused by ionizing radiation depends on many factors such as radiation dose, dose rate, type of radiation, the part of the body exposed, age, and health.

Effects of Space Radiation

The energy that ionizing radiation loses as it travels through a material or living issues is absorbed by that material or living tissue. The ionization of water and other cell components can damage DNA molecules near the path the particle takes- a direct effect of which is breaks in DNA strands including clusters of breaks near one another; breaks that are not easily repaired by cells. Such DNA break clusters are much less frequent, or do not occur at all, when cells are exposed to the types of radiation found on Earth. Because it can disrupt an atom, space radiation also can produce more particles, including neurons, when it strikes a spacecraft or an astronaut inside a spacecraft- this is called a secondary effect.

Measure to Reduce These Effects

There are a number of proposed solutions to mitigate space-related problems encountered before landing on journeys to Mars and beyond. Some of the suggested solutions related to MG (Microgravity). The simplest way to create artificial gravity is through centrifugal artificial gravity using centrifugal force. The gravity (g) created by centrifugal force can be calculated with the formula, $g = \omega 2 \times r$, where ω is the angular velocity and r is the radius of the circle travelled. For a person subjected to centrifugal force, the gravitational force applied along the head-to-foot axis (Gz) is not uniform like the Earth's gravitational force. The strength of the Gz force varies according to the distance of the body parts from the center. To avoid these adverse effects of centrifugal artificial gravity systems, linear artificial gravity systems (Turbo-lift) are also being designed. After understanding the effect of artificial gravity on human physiology, the necessary dose and duration of artificial gravity therapies should be calculated.

Another alternative method is to apply lower body negative pressure (LBNP). The LBNP suit is designed to be worn over the lower abdomen and legs at regular intervals while in space to redirect blood into the lower body through negative pressure. It is observed that applying 25 mmHg of negative pressure to the lower extremities reversed the increases in intraocular and intracranial pressure induced by simulated MG (HDT). Another method employed to reduce the effects of MG-induced cephalad fluid shift is vasoconstrictive cuffs. Similar to LBNP, their aim is to reduce venous return from the legs to the heart.

CONCLUSION

The space radiation environment is a complex mixture of radiation species dominated by highly-penetrating charged particles from the Sun and sources outside the solar system. Their energy spectrum and abundances are modified by interplanetary magnetic fields, long-term solar activity and punctuated by short-term solar particle events. From the properties of charged particles and the composition of the environment associated with conceptual missions and vehicles, transport codes model the radiation fields that would be experienced by astronauts during different missions. In this paper, we have discussed the environment of space radiation followed by a variety of simulated space radiation environments.

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