# **What is space radiation?**

Radiation may be defined as energy in transit in the form of high-speed particles and electromagnetic waves. Electromagnetic radiation is very common in our everyday lives in the form visible light, radio and television waves, and microwaves. Radiation is divided into two categories - ionizing radiation and non-ionizing radiation.

Ionizing radiation is radiation with sufficient energy to remove electrons from the orbits of atoms resulting in charged particles, and it is this type of radiation that is evaluated for purposes of radiation protection. Examples of ionizing radiation include gamma rays, protons, and neutrons. Ionizing radiation is different from ion formation that occurs in ordinary chemical reactions, such as the generation of table salt from sodium and chlorine. In such a reaction, only the outermost electron is removed to form a positively charged ion. With ionizing radiation, if the energy is sufficient, electrons other than those in the outermost orbits can be released; this process renders the atom very unstable, and these ions are very chemically reactive.

* Non-ionizing radiation is radiation without sufficient energy to remove electrons from their orbits. Examples are microwaves, radio waves, and visible light.

**Space radiation** consists primarily of ionizing radiation which exists in the form of high-energy, charged particles. There are three naturally occurring sources of space radiation: trapped radiation, galactic cosmic radiation (GCR), and solar particle events (SPE).

**Trapped Radiation**

|  |
| --- |
| Bar Magnet Iron filings aligned around a simple bar magnet. |

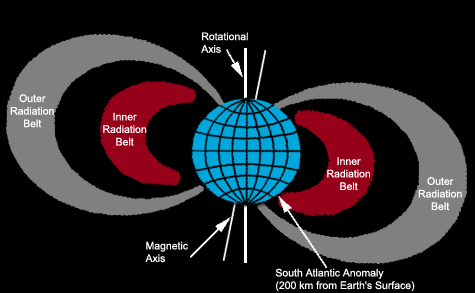
The rotation of the Earth's molten iron core creates electric currents that produce magnetic field lines around the Earth similar to those associated with an ordinary bar magnet. This magnetic field extends several thousand kilometers out from the surface of the Earth. The Sun produces a constant stream of particles which billow out into space and travel at almost 1 million miles per hour. This stream of particles, called the solar wind, varies in intensity with the amount of surface activity on the Sun. The solar wind contains ions from almost every element in the periodic table; however, it consists primarily of protons and electrons. The charged particles of the solar wind cannot easily penetrate the Earth's magnetic field.

|  |
| --- |
| Earth's Compressed Magnetosphere An artist's rendition showing the influence of the solar wind on the Earth's magnetic field. Note how the magnetic field lines are compressed on the sun-facing side and elongated on the opposite side. |

The interaction of the particles and the magnetic field forms a shock front around which the particles are deflected like water around the bow of a ship. The solar wind compresses and confines the magnetic field on the side toward the Sun and stretches it out into a long tail on the night side. The cavity formed by this process is called the "magnetosphere". This cavity shelters the surface of the Earth from constant bombardment by charged particles.

|  |
| --- |
|  |

Not all of the particles are deflected by the magnetosphere, however, and some become trapped in the Earth's magnetic field. The particles are contained in one of two doughnut-shaped magnetic rings surrounding the Earth called the Van Allen radiation belts. The inner belt contains a fairly stable population of protons with energies exceeding 10 MeV (*mega electron volts*). The outer belt contains mainly electrons with energies up to 10 MeV. The charged particles which compose the belts circulate along the Earth's magnetic lines of force. These lines of force extend from the area above the equator to the North pole, to the South Pole, and then circle back to the Equator.

   Except for the Apollo missions, NASA's manned spaceflight missions have stayed well below the altitude of the Van Allen belts. However, a part of the inner Van Allen belt dips down to about 200 km into the upper region of the atmosphere over the southern Atlantic Ocean off the coast of Brazil. This region is known as the South Atlantic Anomaly. The dip results from the fact that the magnetic axis of the Earth is tilted approximately 11 degrees from the spin axis, and the center of the magnetic field is offset from the geographical center of the Earth by 280 miles. The largest fraction of the radiation exposure received during spaceflight missions has resulted from passage through the South Atlantic Anomaly. Low inclination flights typically traverse a portion of the South Atlantic Anomaly six or seven times a day.

|  |
| --- |
| South Atlantic Anomaly and Van Allen Belts |

**Galactic Cosmic Radiation (GCR)**

Galactic cosmic radiation originates outside the solar system. It consists of ionized atoms ranging from a single proton up to an uranium nucleus. The flux (*rate of flow*) levels of these particles is very low. However, since they travel very close to the speed of light, and because some of them are composed of very heavy elements such as iron, they produce intense ionization as they pass through matter.

   For the most part, the Earth's magnetic field provides shielding for spacecraft from galactic cosmic radiation. However, cosmic rays have free access over the polar regions where the magnetic field lines are open to interplanetary space.

**Solar Particle Events (SPE)**

Solar particle events are injections of energetic electrons, protons, alpha particles, and heavier particles into interplanetary space. These particles are accelerated to near relativistic speeds by the interplanetary shock waves which precede fast coronal mass ejections and which exist in the vicinity of solar flare sites. The most energetic particles arrive at Earth within tens of minutes of the event on the Sun, while the lower-energy population arrives over the course of a day. They temporarily enhance the radiation in interplanetary space around the magnetosphere, and they may penetrate to low altitudes in the polar regions.

|  |
| --- |
| Solar Cycle Collage of x-ray images of the Sun between 1991 and 1995 at 120-day intervals, showing the evolution in the appearance of the Sun in these emissions from active to quiet times. (From Lockheed-Martin Solar and Astrophysics Laboratory). |

   The Sun's activity is characterized by an 11-year cycle that can be divided into four inactive years (solar minimum) and seven active years (solar maximum). Changes in electromagnetic radiation, particles, and magnetic fields arriving from the Sun have a significant influence on the space surrounding the Earth. Events such as solar flares and coronal mass ejections, which increase during solar maximum, give rise to solar particle events and geomagnetic storms at the Earth. Other features on the Sun, including sunspots (*areas of concentrated magnetic fields*), coronal holes (*open magnetic field lines which allow a continuous outflow of high-velocity solar wind*), and prominences (*quiescent clouds of solar material held above the solar surface by magnetic fields*), also contribute to the overall dynamic of the Sun-Earth interaction.

|  |
| --- |
| Solar Flare Solar Flare |

Solar flares are characterized by a highly concentrated, explosive release of energy, usually in the form of X-rays. In just several minutes, flares may heat material to many millions of degrees and release as much energy as a billion megatons of TNT. Groups of sunspots, especially those with complex magnetic field configurations, are often the sites of solar flares which may last from several hours to a few days. Most flares do not pose a threat to spacecraft either because they are too small to inject a significant number of solar particles into the magnetosphere, or because they occur at a place on the Sun where transfer of particles to Earth along interplanetary magnetic field lines is unfavorable. The solar flare X-rays generally have a relatively low flux and are usually not a concern to the spacecraft or its crew.

|  |
| --- |
|  |

Some of the most dramatic space weather effects occur in association with coronal mass ejections (CMEs). These are huge bubbles of plasma (*ionized atomic matter with high kinetic energy*) threaded with magnetic field lines that are ejected from the Sun's corona (*outer atmosphere*). A large CME can contain a billion tons of matter that can be accelerated to several million miles per hour. CMEs are often associated with solar flares and prominence eruptions, but they can occur in the absence of either of these processes. Near solar maximum, the Sun produces about three CMEs per day, whereas near solar minimum, it produces about one every five days. The faster CMEs have outward speeds considerably greater than that of the normal solar wind, and they produce large shock waves in the solar wind as they plow through it. Some of the solar wind ions are accelerated by the shock wave, and they become a source of intense and long-lasting energetic particle enhancements in interplanetary space.

The movement of the shock waves associated with CMEs and solar flares can give rise to magnetic storms, which are triggered by the collision of fast-flowing particles from the Sun with the magnetic field surrounding the Earth. Depending on the conditions, such collisions inject energetic ions and electrons deep into the terrestrial magnetosphere and create an electric current, called a "ring current", that circulates around the Earth. The magnetic field generated by the ring current perturbs the Earth's main magnetic field, allowing particles to reach previously unattainable altitudes and inclinations. Such storms are accompanied by enhanced displays of the Aurora Borealis (northern hemisphere) and Aurora Australis (southern hemisphere). These lights are created by collisions between the particles and atmospheric gases. The collisions raise the energy levels of oxygen and nitrogen atoms; as these excited atoms lose energy, they release some of it in the form of light.

Except for the Apollo missions to the Moon, NASA's manned spaceflight missions have taken place within the cocoon of the Earth's magnetosphere. Between the Apollo 16 and 17 missions, one of the largest solar proton events ever recorded occurred, and it produced radiation levels of sufficient energy for the astronauts outside of the Earth's magnetosphere to absorb lethal doses within 10 hours after the start of the event. It is indeed fortunate that the timing of this event did not coincide with one of the Apollo missions.

As NASA ponders the feasibility of sending manned spaceflight missions back to the Moon or to other planets, radiation protection for crew members remains one of the key technological issues which must be resolved.