The space radiation environment: an introduction. Schimmerling W.
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The Space Radiation Environment: An Introduction

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The components of space radiation that are of concern are the high-energy, charged nuclei of elements from hydrogen (protons) to iron (high-energy nuclei with charges greater than 2 are also referred to as "**HZE particles**". These particles are part of the **Galactic Cosmic Ray (GCR) background** radiation that permeates interplanetary space. As shown in Figure D. 1(a), the fraction of GCR constituted by the

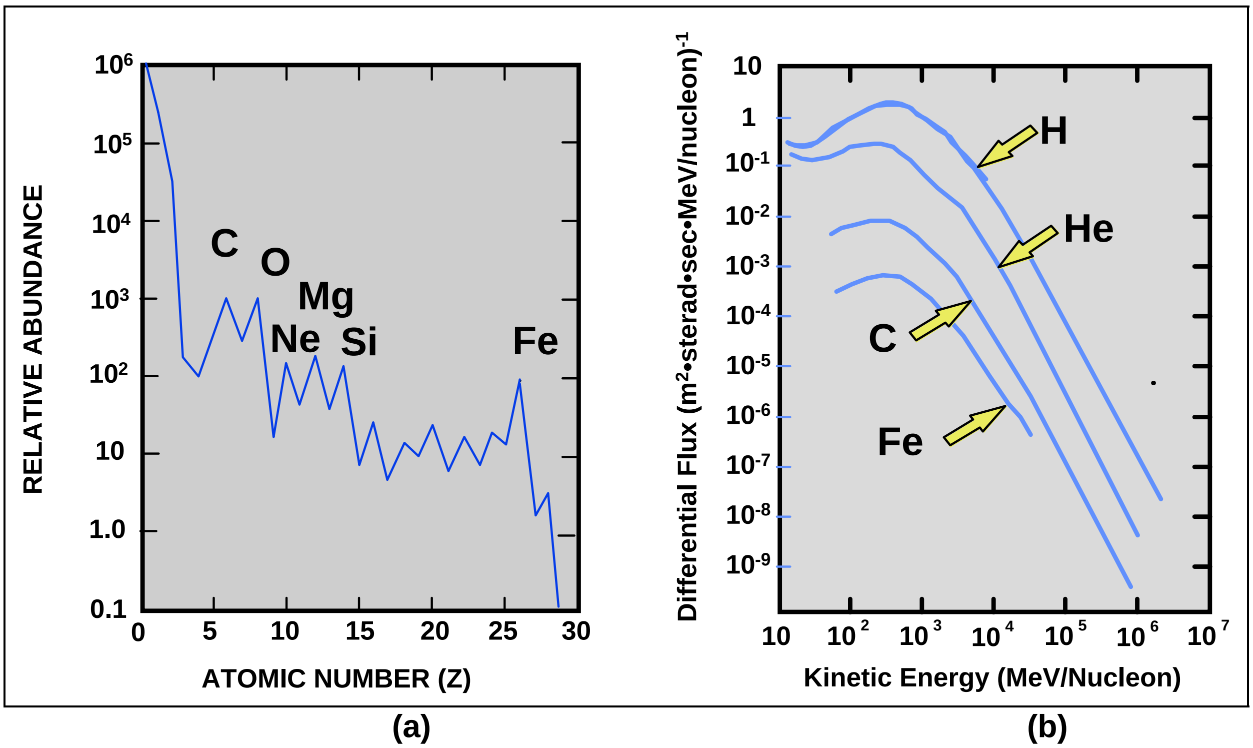

Figure D. 1. Abundances (a) and energy spectra (b) of GCR.

nuclei of elements heavier than helium is very small; approximately, GCR consist of 85% protons, 14% helium, and 1% heavier particles. As seen in Figure D. 2(b), showing the distribution in energy of several important HZE nuclei, these particles have very high energies, sufficient to penetrate many centimeters of tissue or other materials. In addition, the HZE nuclei are highly charged and, therefore, very densely ionizing. As a consequence, even though the number of HZE particles is relatively small, they have a significant biological impact that is comparable to that of protons.

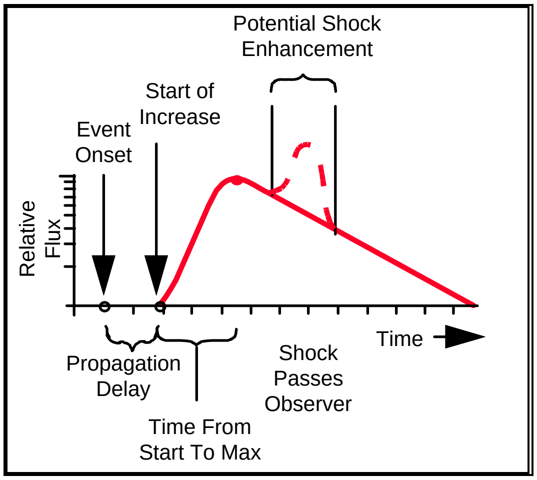

Figure D. 2. Time course of a Solar Particle Event.

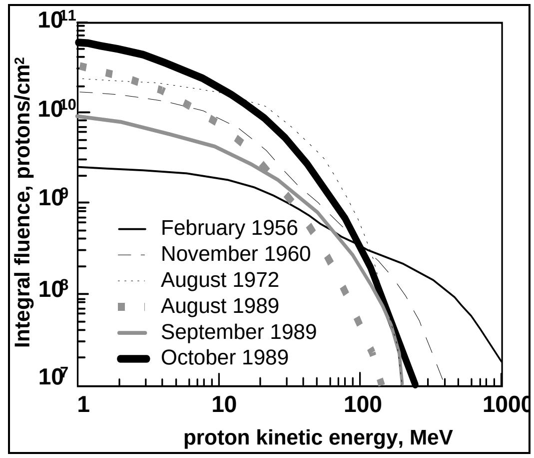

Figure D. 3. Distribution in energy of proton fluxes for major past SPEs (free space)

Solar disturbances occasionally cause much larger fluxes of particles, mainly high energy protons; these are known as Solar Particle Events (SPE). Peak flux during an SPE may be two to five orders of magnitude greater than background, within hours of the event onset, as shown in Figure D. 2. Periods of enhanced flux may last for days, with successive peaks due to multiple events and enhancements during shock passage (Figure D. 3), indicating that different physical processes are involved. However, the number of protons with energies in the region of several hundred MeV is significant in all cases.

An illustration of the contribution of different components of space radiation outside the Earth magnetic field is shown in Figure D. 4. This figure shows the calculated relative contribution of different groups of particles to the **dose equivalent** (cf. Appendix B for definition of quantities) behind 3 g/cm^2 of aluminum (slightly more than 1 cm thickness). The left-hand side shows that protons account for almost all of the SPE radiation, and the right-hand side shows that this is no longer true for GCR, where HZE particles account for most of the radiation risk.

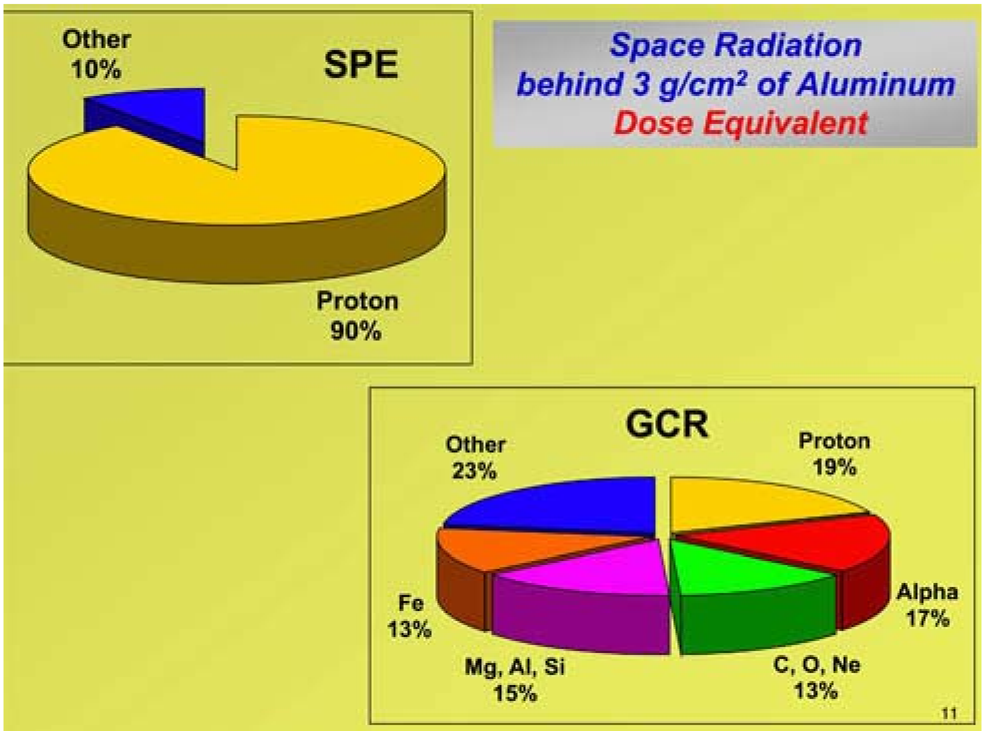

Figure D. 4. Relative contribution of different components of space radiation to dose equivalent

Protons and electrons of sufficiently low energy can be captured by the Earth's magnetic field, schematically indicated in Figure D. 5, as an equivalent bar magnet. In reality, the magnetic field is more complicated. Its shape is also distorted by the Sun, so that the magnetic field on the day side is compressed and the magnetic field on the night side is pushed away. Charged particles entering the Earth's magnetic field from space are turned from their path as they traverse the magnetic field lines. If their energy is sufficiently low, they are trapped into the **Van Allen belts** (Figure D. 6). These trapped radiation belts surround the Earth at altitudes that depend on the Earth magnetic field. The belts consist of protons (inner belt) and electrons (inner and outer belt), spiraling along magnetic field lines from pole to pole. Near the poles, the trapped radiation belts extend almost down to the surface.

The Earth's magnetic field is offset and tilted from the Earth's axis of rotation. Thus, the radiation belts, centered on the magnetic field, are also not centered on the Earth axis of rotation. The region where the radiation belts are closest to the Earth's surface, near

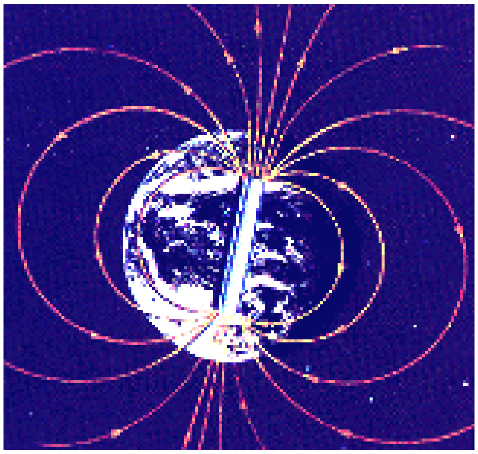

Figure D. 5. The Earth as a magnet showing field lines.

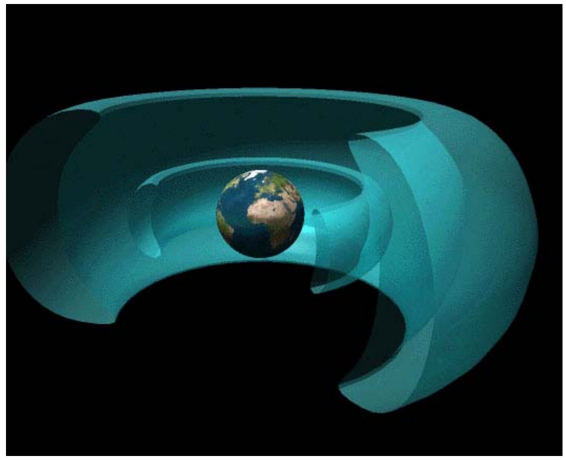

Figure D. 6. The Van Allen belts.

the coast of Brazil, is called the **South Atlantic Anomaly** (SAA), schematically shown in the inset of Figure D. 7. The trapped radiation belts are not static: their altitude distribution and intensity are greatly dependent on solar activity, with hourly, daily and seasonal changes. Over geological times, the magnetic field of the Earth has been known to change and reverse itself. The measured long term drift in the position of the SAA provides continuing evidence of active Earth magnetism. As shown in Figure D. 7, proton fluxes at energies of 100s of MeV, as measured on the Mir space station during solar minimum, can still be significant.

The magnetic field of the Earth allows only the fastest, most energetic particles to penetrate deep into the atmosphere, and the thick atmosphere provides so much material that most of the incident radiation interacts before it can reach the surface of the Earth. Thus, space radiation is the source of many of the cosmogenic nuclides, such as ^{14}C. At the surface of the Earth, only the most energetic, lightest products of the nuclear interactions of GCR with the atmosphere, mainly µ-mesons, are still present. This is the radiation background present everywhere on Earth.

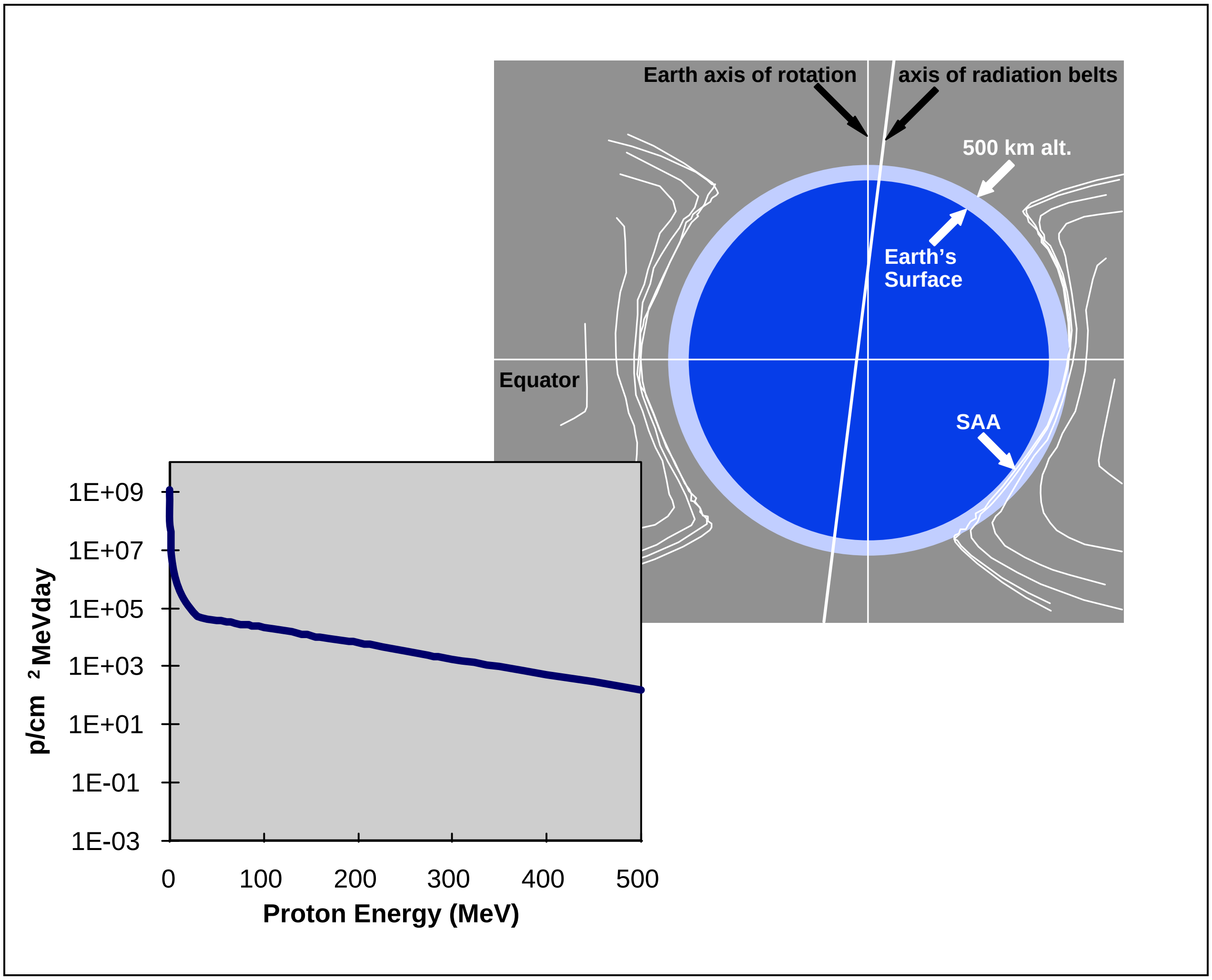

Figure D. 7. Energy distribution of trapped protons and South Atlantic Anomaly.

Higher in the atmosphere, at altitudes used by commercial aircraft, radiation is more intense, and the most hazardous secondary radiation is high energy neutrons emitted by GCR interactions with the atmosphere. The intensity of the radiation increases with altitude. At high altitude, large fluxes of high-energy protons from SPE can cause radiation levels to exceed those permissible for aircraft passengers or crew. For this reason, radiation levels on high-altitude aircraft must be monitored and aircraft may be required to descend to safer altitudes during an SPE.

The Space Shuttle and Space Station will be located in low Earth orbit (LEO), beyond the protection of the atmosphere, but still within the protection of the magnetic field. In these orbits, the radiation risk will be due to GCR particles too energetic to be significantly deflected by the magnetic field, and to trapped radiation belt protons. When the orbit of a spacecraft intersects the SAA, radiation intensity can increase by an order of magnitude. For this reason, extravehicular activity (EVA) should be avoided whenever a spacecraft is about to traverse the SAA. Even in the interior of a spacecraft, exposures could exceed radiation limits during a large SPE.

Under such circumstances, crews may be directed to limit activities to the most highly shielded area of the spacecraft, for use as a “storm shelter”.

Beyond the Earth’s magnetic field, crews are exposed directly to GCR radiation and to SPE radiation. Spacecraft or planetary habitats thus require their own measures to avoid radiation overexposures. The most fundamental measures that can be taken are to ensure that spacecraft and habitat materials are configured to provide maximum radiation shielding effectiveness; that a “storm shelter” is available; and that monitoring for SPE provide sufficient warning to crew members involved in EVA. Other measures are possible, but require a knowledge of biology that is not at present available.