countermeasures are employed. Also, as is done with radiation exposure, some acceptable level of bone loss should be established. A requirement that bone mass be maintained at one-G levels may be too strict, if good-quality bone can be recovered after the flight. An active research program on the International Space Station could provide the information on countermeasures and bone recovery that would help clear the way for a Mars trip. Also, if bone loss cannot be prevented safely or effectively, the option of using artificial gravity throughout the trip is also available.

THE ENVIRONMENT OF INTERPLANETARY SPACE

The main radiation risks on a Mars mission are solar flares and galactic cosmic radiation. Solar flares, or solar particle events, send out high-energy protons that can deliver extremely high radiation doses. On Earth and on Mars, the planet provides some protection, but in space the crew, if unprotected, could receive substantial radiation doses.

Galactic cosmic radiation is the background radiation in space. Although cosmic rays hit the Earth regularly, the magnetic field of the Earth provides some shielding. On Mars, some shielding will again be available from the planet. This shielding is absent in interplanetary space. While the energy of the protons in solar flares is measured in millions of electron volts, the energy of the particles in galactic cosmic rays can be in the giga electron volt range.

Radiation exposure in space is a concern for the same reason that it is a concern for medical or atomic workers—radiation sickness and an increased risk of cancer. A high dose can kill, and low chronic exposures may lead to an increased cancer risk. Although this increased risk is a concern, at present the estimated increased risk of cancer from radiation in space (1-2%) seems small compared to the other risks inherent in a trip to Mars.

SOLAR FLARES

The author James Michener, in his novel *Space*, outlines what might have happened if Apollo astronauts had been out on the Moon, when radiation from a solar flare arrived. They would have received fatal doses of radiation. Fortunately, during a Mars trip, adequate shielding can be provided to protect against solar particle events, and the crew could be provided with a “storm shelter;” a small area with extra shielding, to shelter them during very high radiation periods. On Mars, the planet's atmosphere and surface provide good shielding from solar flares. What is needed, however, is the ability to predict solar particle events. If the crew were performing an EVA while in transit, they would need enough time to get inside the vehicle and head for the storm shelter before the storm arrived. The capability to predict solar flares 8 hours before the spacecraft encounters the radiation has been identified as a high priority research area by the U.S. National Research Council [9].

GALACTIC COSMIC RADIATION

Solar particle events are a concern because of the high levels of radiation they can impart over a short period of time. Galactic cosmic radiation is an issue for a different reason; it provides a constant low level exposure to radiation. The characteristics of this radiation also differ from the x-rays and gamma rays that are usually of interest here on Earth in medicine or atomic energy work. Instead of just electrons or protons, galactic cosmic radiation contains heavy ions, such as iron nuclei, that can cause significant damage in tissue [7]. These particles are more damaging to tissues than other radiation (such as x-rays or gamma rays), and so are probably more likely to produce biologic effects such as cancer.

The problem has been that research with these high-energy particles requires special facilities and the estimates of the biologic effectiveness of these particles are based on only a few studies. A recent report from the U.S. Committee on Space Biology and Medicine notes that only one systematic study of cancer induction from high energy particles has been conducted (using the mouse Hardener gland) [2, 9]. These estimates are critical for setting exposure limits. The exposure limits are what determine how the spacecraft will be shielded and slight changes in the estimates can have a major impact on the mass and design of the spacecraft.

BIOLOGIC DOSIMETRY

As mentioned above, not all radiation produces the same biological effects. Most standard dosimeters only measure the amount of radiation, but not the actual biological effects. On a recent Mir flight, chromosomal aberrations were measured before and after the flight to get an actual biological readout of the effects of the radiation [12]. With this approach the actual biologic effects of the radiation are being measured, and this provides a more useful estimate of exposure. If these methods could be improved and used on the Space Station, more reliable estimates of the biological effects of space radiation could be obtained.

CHEMOPREVENTION

Each individual who is exposed to increased levels of ionizing radiation runs a statistical risk of developing cancer. Currently, the approach to reducing the risk of radiation-induced cancer is to set an exposure limit based on available estimates. The primary way to minimize cancer risk is to minimize exposure. Current Mars designs, however, cannot bring radiation levels to match what the crew would experience on Earth. Recent research demonstrates that some drugs can minimize radiation damage by acting as free radical scavengers.