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Special Information Topic Issue

SICSA OUTREACH
Sasakawa International Center for Space Architecture

Space Radiation Health Hazards: Assessing and Mitigating the Risks

Hazardous ionizing radiation levels pose a serious occupational health risk for astronauts on long-duration missions. Natural sources include colossal energy-releasing events on the surface of the Sun and throughout the vast expanses of our galaxy. Man-made devices such as nuclear power generators can also contribute to the spacefarer's radiation environment.

Extended exposure to penetrating types of radiation, even at relatively low levels, can induce cancers to appear many years later. Even short exposure to a very high radiation level, accompanying a massive solar flare for example, can cause serious injury or death within days or hours.

Unfortunately, no known economical strategies can fully match radiation protection benefits that are afforded by our Earth's magnetic field and atmosphere. Practical considerations are likely to mandate that some level of added health risk for space travelers is inescapable.

How much added risk of space radiation-related illness is acceptable? Some recent NASA guidelines address this question. What approaches can be applied to meet these guidelines? This issue highlights influences and possibilities.

The content of this issue draws extensively upon the research and experience of Dr. Stuart Nachtwey, the principal radiological health officer at the NASA Johnson Space Center. We are grateful for his valuable contributions.

Solar Flare Observed on *Skylab*
NASA Photo

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SICSA is grateful to Jay B. Weidler, Senior Vice President for Space Operations, Brown & Root U.S.A., Inc. and to Ralph B. Harp, Jr., Vice President, Adams and Porter International, Inc. for obtaining donations from their organizations to publish this issue.

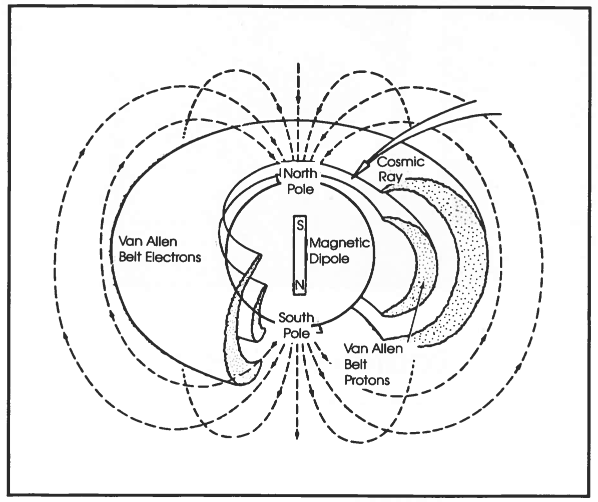
Space Radiation Environments

Natural radiation environments in space consist primarily of high speed protons and electrons in the solar wind, cosmic rays from outer space and the Sun, and energetic particles captured by the Earth's geomagnetic field forming the Van Allen Belts. We are protected from most of this radiation on the ground by the Earth's atmosphere and magnetic field. In space and on lunar/planetary surfaces however, people must rely upon habitat walls and other barriers for essential shielding.

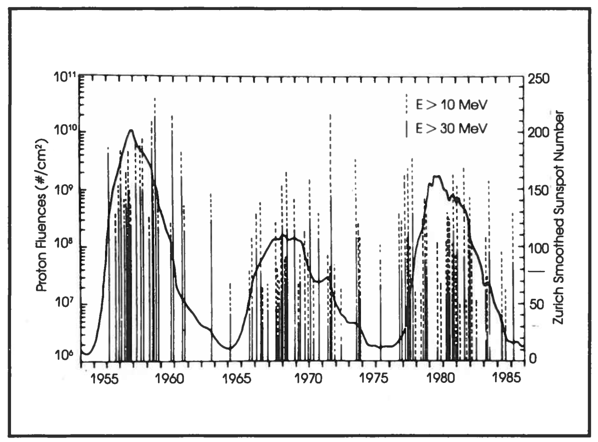
Trapped protons comprise the predominant radiation source within the inner zone of the Van Allen Belts. The most intense region of the inner zone is called the "South Atlantic Anomaly" between Africa and South America. Here, orbits of spiraling protons reach closest to Earth. The outer belt, on the other hand, is made up primarily of electrons. The total intensity in this region is about an order of magnitude greater than in the inner zone.

Beyond the Van Allen Belts, space voyagers will encounter an environment dominated by galactic cosmic radiation consisting of particles which originated outside the Solar System during cataclysmic events such as supernova explosions. Particle energies are typically extremely high, measured in some instances up to 10^{20} electron volts (eV). The galactic cosmic rays (GCR) consist mainly of protons, with smaller contributions of helium and heavier ions such as iron. Although GCRs have very low flux density, their high energy allows them to easily penetrate passive shields causing concern for long-term missions.

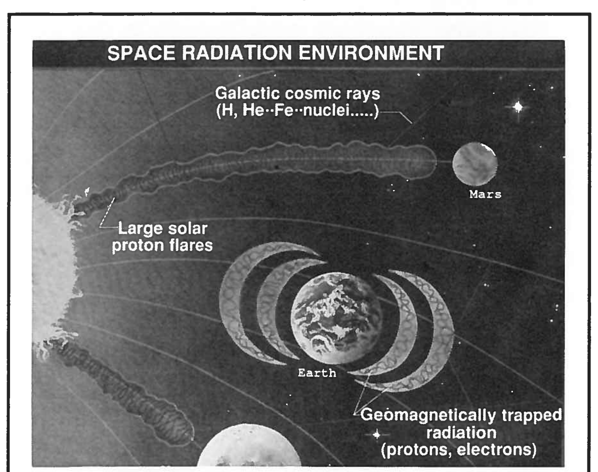
Large solar flares can produce solar particle events (SPE) which raise radiation levels to intensities that could be lethal to humans. A polar orbit inside the Earth's magnetosphere is a particularly hazardous region because the Earth's magnetic field over the north and south poles dips downward. Solar particle events change in frequency during 11 year cycles, reaching a maximum during the periods before and after sunspot maximum. Most events last about an hour. Massive, highly lethal occurrences are relatively rare, but last hours or even days.



Earth's Magnetic Field
A. Nicogossian, NASA and J. Parker, Biotechnology, Inc.



Sunspot Activity vs. Solar Flare Proton Flux
D.S. Nachtwey, NASA Johnson Space Center



Space Radiation Environment
NASA Photo

Types	Chg. (Z)	Q	Locations
X-Rays	0	1.0	Radiation belts, solar radiation and in the secondaries made by nuclear reactions
Gamma Rays	0	1.0	
Electrons			Radiation belts
1.0 MeV	1	1.0	
0.1 MeV	1	1.0	
Protons			Cosmic rays, inner radiation belts, solar cosmic rays
100 MeV	1	1-2.0	
1.5 MeV	1	8.5	
0.1 MeV	1	10.0	
Neutrons			Produced by nuclear interaction; found near the planets, the Sun and other matter
0.05 eV (thermal)	0	2.8	
.0001 MeV	0	2.2	
.005 MeV	0	2.4	
.02 MeV	0	5.0	
.5 MeV	0	10.2	
1.0 MeV	0	10.5	
10.0 MeV	0	6.4	
Alpha Particles			Cosmic rays
5.0 MeV	2	15.0	
1.0 MeV	2	20.0	
Heavy Primaries	≥3	See Text	Cosmic rays

Ionizing Radiation in Space
R.D. Johnson and C. Holbrow (NASA SP-413); NASA-STD-3000

The degree of damage to organisms from various ionizing radiation types are reflected by values associated with particle energy (MeV), charge (Z) and Quality factor (Q). High-Z and high-energy particles associated with galactic cosmic rays are of particular concern in planning exploratory missions beyond the magnetosphere. Alpha particles are the nuclei of helium atoms which have had all their electrons stripped away, leaving two protons and two neutrons.

Ionizing Radiation Characteristics

An atom has been ionized when one or more electrons is stripped away, such as from a collision with a speeding proton. Injury to living organisms occurs when high energy protons, cosmic rays, x-rays, or gamma rays penetrate and split apart cell molecules. This can kill or damage the cell. In addition, particles passing through an obstruction such as spacecraft walls can ionize atoms within those walls, creating another hazard called secondary radiation.

Heavy cosmic ray particles such as the nuclei of carbon, oxygen and iron atoms do the most damage because they carry greater positive electrical charges than protons, causing more ionization within the cells. A single heavy cosmic ray particle can kill a cell. Protons, however, do the most overall damage because there are so many of them. They comprise the substance of most cosmic rays.

Since galactic cosmic rays are far more penetrating than other types of radiation they are extremely difficult to shield against. Even a relatively moderate energy cosmic ray proton or alpha particle (<1 GeV/nucleon) can pass through more than one meter of aluminum. In the unlikely event that shielding were to be provided capable of stopping all primary nuclei, secondary particles such as neutrons, pions and recoil nuclei would still be emitted, drastically limiting the shielding's health benefits to the crew.

A solar particle event from a large solar flare produces very high ionizing radiation doses over periods that sometimes last a few hours or several days. A major solar particle event could expose astronauts in free space to life-threatening dose levels in a few hours.

Shielding against the protons from a solar particle event is more feasible than is the case with galactic cosmic rays because energy levels are much lower. As is explained later in this issue, there are many approaches to providing this shielding, ranging from man-made materials to utilizing in-situ resources.

Dose Measurements/Standards

The extent to which ionizing radiation causes biological damage depends partly on the amount of energy absorbed (dose). However, the same dose from different types of radiation produces different amounts of damage. For example, a given dose of galactic cosmic ray heavy ions is judged to be about 20 times more effective in producing cancer-causing damage than is the same dose of high energy protons.

The relative biological effectiveness of different radiations is accounted for by multiplying the dose (expressed in rad or Gray, the SI unit) by a quality factor, Q, set by the International Commission on Radiological Protection (ICRP). The result of Dose times Q is the dose-equivalent expressed in rem or in sievert (Sv), the SI unit. One Sv equals 100 rem (1 mSv=.0001 Sv=.1 rem).

NASA has a radiation protection program for astronauts that limits the amount of radiation received deep in the body to what is judged to be an acceptable level. To preclude any mission impact, the dose-equivalent to the deep organs (5 cm) is limited to 25 rem in a 30-day period.

The allowable career limit, which depends on the age at the beginning of exposure and on the sex of the subject, ranges from 100 to 400 rem (see table on Ionizing Radiation Exposure Limits). A 30 to 40 year old beginning astronaut will have a career limit between 200 and 275 rem. The 50 rem annual limit ensures that the career dose will be spread out over a protracted period.

There are conceivable situations, such as during extravehicular activity (EVA) in the trapped electron belts, where the dose to the eye or to the skin could be very high without the deep dose limit being approached. In these situations, ancillary standards for the eye and skin have been set.

Adherence to the limits requires that potential doses from extraordinarily large solar particle events (SPE) be avoided by some means, e.g., a heavily shielded "storm shelter" to be incorporated into the design of spacecraft or base.

Legal Requirements for NASA

- *Provide a risk limitation system.*
- *Reduce exposure to as low as reasonably achievable.*
- *Evaluate risks vs. gains.*
- *Apprise space workers of risks.*

In Addition, NASA...

- *Supports research to understand risks.*
- *Projects doses for each mission.*
- *Verifies doses for each mission.*
- *Monitors mission doses in real time.*

Radiation Health Considerations
D.S. Nachtwey, NASA Johnson Space Center

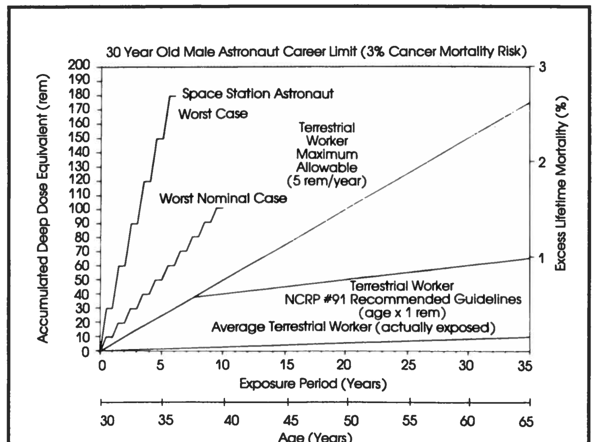
Depth	BFO (5 cm)	Eye (0.3 cm)	Skin (0.01 cm)
30 days	25 rem	100 rem	150 rem
Annual	50	200	300
Career	100-400*	400	600

These limits are recommended to NASA by the National Council on Radiation Protection and Measurements (NCRP) subject to approval by the NASA Administrator, expected in 1989.

**Career depth dose-equivalents are based upon a max. 3% lifetime excess risk of cancer mortality. Total dose-equivalent yielding this risk depends on sex and age at the start of exposure. The career dose-equivalent limit is nearly equal to:*

200 + 7.5 (age-30) rem, males, up to 400 rem max.
200 + 7.5 (age-38) rem, females, up to 400 rem max.

Ionizing Radiation Exposure Limits
D.S. Nachtwey, NASA Johnson Space Center



Excess Mortality Risks
D.S. Nachtwey, NASA Johnson Space Center

From Life on Earth	***Exposure***
• *Transcontinental round trip by jet*	*0.004 rem*
• *Chest x-ray (lung dose)*	*0.010 rem*
• *Living one year in Houston*	*0.100 rem*
• *Living one year in Denver*	*0.200 rem*
• *Xeromammography (breast dose)*	*0.383 rem*
• *Barium enema (intestine dose)*	*0.875 rem*
• *Living one year in Kerala India*	*1.300 rem*
• *Max. allowable radiation worker/yr*	*5.000 rem*
Manned Spaceflight	
• *Skylab 3, 84 days (blood forming organs)*	*7.94 rem*
(eye lens)	*12.83 rem*
(skin)	*17.85 rem*
• *Max. allowable space worker/yr*	*50.00 rem*

Radiation Dose Examples
D.S. Nachtwey, NASA Johnson Space Center

Effect in Healthy Adults	***Acute Dose***
• *Blood count changes common*	*50 rad*
• *Vomiting, "effective threshold"*	*100 rad*
• *Mortality, "effective threshold"*	*150 rad*
• *LD_{50} minimal medical treatment*	*320-360 rad*
• *LD_{50} supportive medical treatment*	*480-540 rad*
• *LD_{50} bone marrow/blood stem cell transplant*	*1000 rad*
Effects on Reproductive Systems	
• *50% temporary sperm count reduction*	*15 rad*
• *100% sperm loss lasting a few months*	*100 rad*
• *Male sterility lasting 3 or more years (if subject survived high dose)*	*600 rad*
• *Possible menopause in 40 yr.-old woman*	*300 rad*
• *Possible temporary menstrual suppression in 20 yr.-old woman.*	*300 rad*

Ionizing Radiation Effects
D.S. Nachtwey*, NASA Johnson Space Center

*The information in this table was compiled by Dr. Victor P. Bond (Brookhaven National Laboratory) for NCRP Report 98. Values for vomiting and mortality are derived from data presented by Evans et. al in "Health Effects Model for Nuclear Power Plant Accident Consequences Model" NUREG/CR-4214 SAND 85-7185, U.S.G.P.O., Washington DC.

Space work and travel embodies broadly recognized dangers. Even prior to the Challenger *disaster, the Society of Actuaries listed being an astronaut as the first of "nine worst jobs for staying alive in." Others, presented in order of greatest danger are hydroplane driver, race car driver, aerial performer without net, boxer, lumber worker, skin diver/helmet diver, power line worker, and steeple climber.*

Radiation Health Effects

Living organisms on Earth are continuously exposed to very low radiation levels from a wide range of natural and man-made sources. This condition does not usually present an insurmountable problem because new cells are produced to replace damaged ones at prolific rates. When exposure to high radiation doses destroys a large number of cells in a short time, however, the natural repair process can be disrupted, overwhelmed or altered. Such circumstances are particularly serious when those cells are located in vital areas such as blood forming organs (BFO) and the gastrointestinal tract.

Some parts of the body are more vulnerable to radiation damage than others. The skin and eyes, for example, are accessible (but less susceptible) to a wide range of energy particles with limited penetration capabilities. Certain deeper locations, including bone marrow, lungs, pancreas and liver, are of great concern due to their criticality and susceptibility to cancer.

Women face added risks stemming from breast cancer. In addition, there are unanswered questions about potential damage to the reproductive processes. As indicated by the table to the left, a large exposure of radiation (300 rem) to a woman may induce menopause or otherwise adversely affect her reproductive system.

Overt human reactions to radiation exposure can be immediate or delayed. Near-term manifestations can include nausea, vomiting, decreased white blood cells, diarrhea, fever, hemorrhage, and death. Delayed effects include cancer and birth defects in progeny or miscarriages.

Since some people are more prone to cancer than others, astronaut crew selection based upon family history, age, and perhaps even sex might be prudent for long-duration missions. Selection of older candidates with low previous cumulative lifetime radiation doses could also reduce risks of premature deaths due to cancers. In any event, crew awareness of all potential risks is essential.

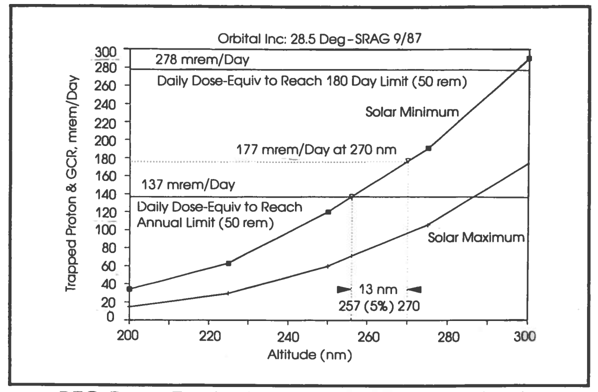
Earth-Orbiting Spacecraft

For Earth-orbiting spacecraft, the altitude of the vehicle and inclination of the orbit are important determinants of radiation dose rates. Low-Earth orbit (LEO) spacecraft receive substantial shielding benefits from the Earth's magnetic field. This geomagnetic shielding effect lessens with higher altitudes, disappearing at approximately six Earth radii (geosynchronous orbit) and beyond.

Space Station Freedom's LEO, 28.5° inclination orbit will carry the spacecraft through the South Atlantic Anomaly which will expose crews to ionizing proton radiation in excess of Earth levels. This added dose of about 0.1 rem per day is equivalent to receiving approximately 10 chest x-rays in one day. The Soviet *Mir* space station's 52° orbit passes through the South Atlantic Anomaly more rapidly resulting in lower radiation doses.

Ionizing radiation doses would be higher without spacecraft cabin walls that provide some shielding from particles in LEO. In higher orbits populated by an abundance of high energy cosmic rays, the cabin walls are much less effective barriers. Secondary radiation produced when a primary cosmic ray strikes and ionizes the metal material (typically aluminum) of which the wall is made will readily penetrate into the cabin. It will scatter numerous times, multiplying its destructive potential. Ionizing effects of electrons that populate the outer radiation belt and areas beyond are also a major concern. They contribute to radiation levels in geosynchronous orbit (GEO) which are about 3 orders of magnitude worse than in LEO.

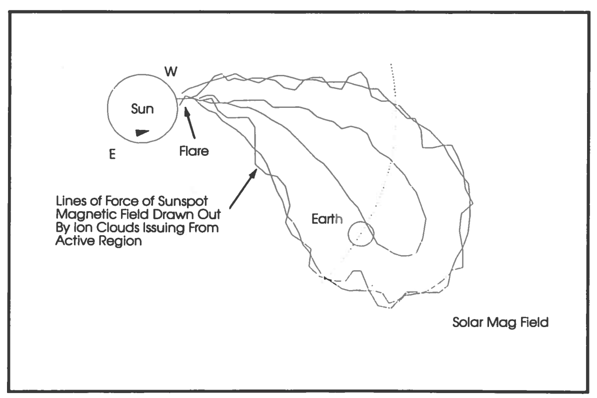
The potential that a crew will be exposed to a major solar particle event (SPE) such as the large proton storm recorded by satellite instruments in August 1972, increases in probability as missions increase in number and length. Although there is less penetration by SPE particles relative to GCRs due to their lower energies, their high flux density makes them very dangerous. Solar energetic particles also produce secondaries which build up in shielding materials.



BFO Dose Equivalent as Related to Altitude
(Assumes 205 mil. aluminum common module)
D.S. Nachtwey, NASA Johnson Space Center

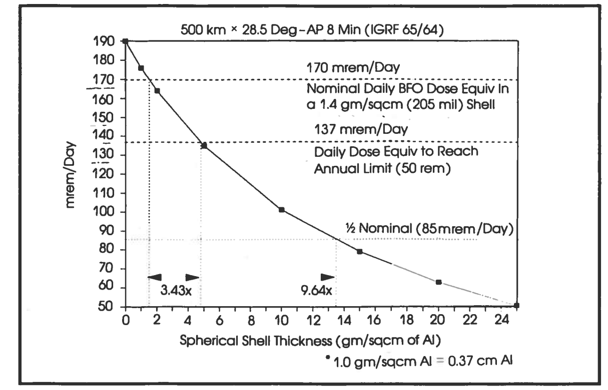
Mission Orbit	Radiation Source	Days	Dose Equiv. (mSv)	
			Bone Marrow	Skin
28.5° inclination	South Atlantic Anomaly and GCRs for all missions	90	98	200
57° inclination		90	82	203
90° inclination		90	73	163

LEO Space Station Dose Estimates
(Assumes 1.0 g/cm² aluminum shielding and 450 km altitude)
W. Atwell, Rockwell International, and A. Hardy, NASA JSC



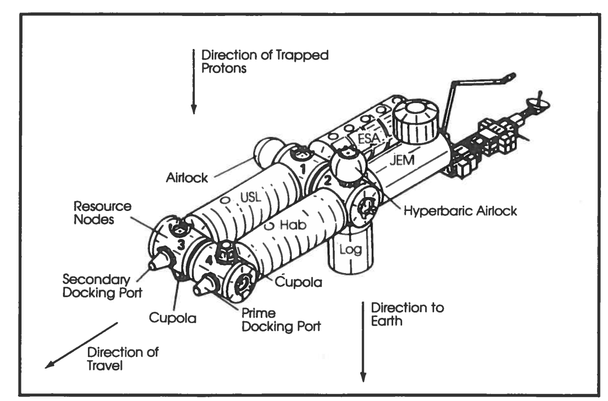
Solar Flare/Solar Particle Event
D.S. Nachtwey, NASA Johnson Space Center

Solar particle events (SPEs) are intermittent proton storms that accompany intense solar flares. While solar flares occur with changing frequency throughout 11 year cycles, they are common events that correlate with sunspot activity. Anomalously large flares producing lethal particle fluxes, however, are relatively rare, occuring only a few days per decade. We currently cannot accurately predict the intensity or occurrence of SPEs very far in advance of their happening.



Modeled Depth Doses vs. Shell Thickness
D.S. Nachtwey, NASA Johnson Space Center

Aluminum is commonly used for the construction of LEO spacecraft pressure shells because of its relatively light weight and moderate cost. Alternative materials may possibly be substituted or added to provide improved GCR and SPE radiation protection for spacecraft operating outside the Earth's magnetosphere. Tanks placed inside the shell walls containing water or other substances could be used to provide additional shielding. In all cases, allowable shell thickness and mass will be severely limited by overall payload launch and orbit transfer constraints.



Radiation Exposure Relative to Orientation
D.S. Nachtwey, NASA Johnson Space Center

Space Station Freedom's *surfaces that will be exposed to the greatest trapped proton radiation are those which are least shielded by the Earth or various elements of the spacecraft. One way to decrease cumulative crew doses is to locate sleeping quarters in the most protected areas. If this is not practical, it may be desirable to periodically rotate individuals between sleeping quarters located in higher and lower protection locations to more equitably balance exposures.*

As previously noted, a crew's exposure and vulnerability to dangers associated with ionizing radiation is influenced by mission length; orbit altitude and inclination; age, health, and predispositions to cancers; and timing with regard to levels of solar activity at the time. Crews on space shuttle missions lasting a few days have typically been exposed to less than 0.5 rad, which is well within acceptable limits.

An astronaut crew in free space (above the Earth's protective magnetic field) at the time of a major solar particle event (SPE) would fare much worse however. The anomalously large SPE in August 1972 would have led to about 135 rem to the blood forming organs inside a module which provides 2.0 g/cm² (.75 cm Al) of shielding. Such a dose would likely have produced decreases in white blood cells, nausea, and vomiting; however, it would not have been lethal. This could be reduced to an acceptable 14 rem with 20 g/cm² (7.5 cm Al) of shielding.

Planned 180 day missions onboard *Space Station Freedom* in its 270 nautical mile altitude orbit will fall well within NASA's 50 rem annual radiation limit based on a 3% excess cancer risk. Any plan to duplicate a Soviet cosmonaut year-long mission during solar minimum, however, would most likely exceed this level. While legal problems might be overcome by dropping the orbit altitude by 13 nautical miles, health benefits to be gained by such an approach are uncertain since there is no clear value below which radiation exposure is "safe".

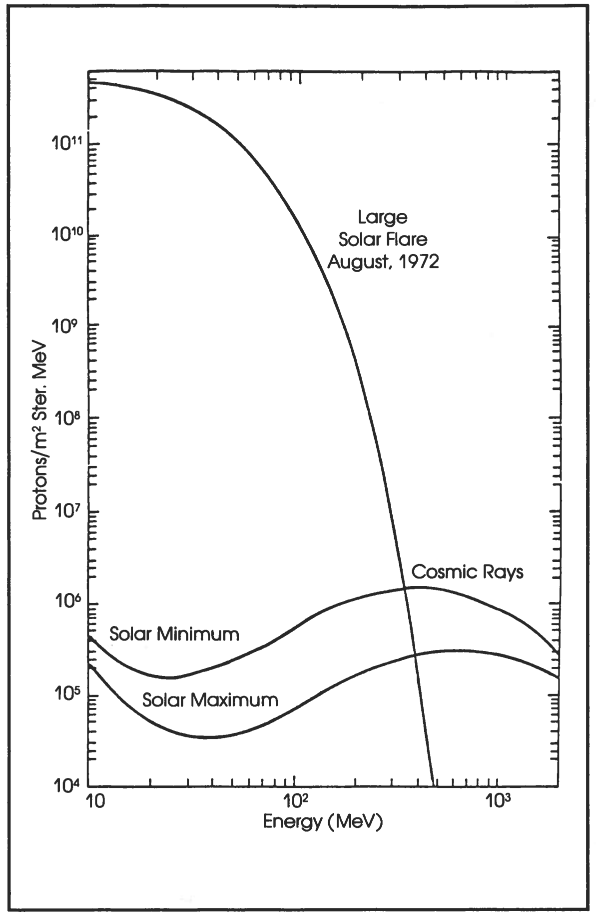
There may never be true "career" astronauts in the traditional context of long-term, continuous professional livelihood. A 30 year-old male on his first 180 day mission could only look forward to 5 more similar tours of duty before exceeding the 200 rem career radiation limit set for his age group and sex. A 30 year-old female on her first mission could expect only 3 more before reaching her 140 rem limit. A 50 year-old male beginning a new career as an astronaut might spend up to a total of 5 years in space before reaching his 350 rem limit.

Voyages to Mars and Other Planets

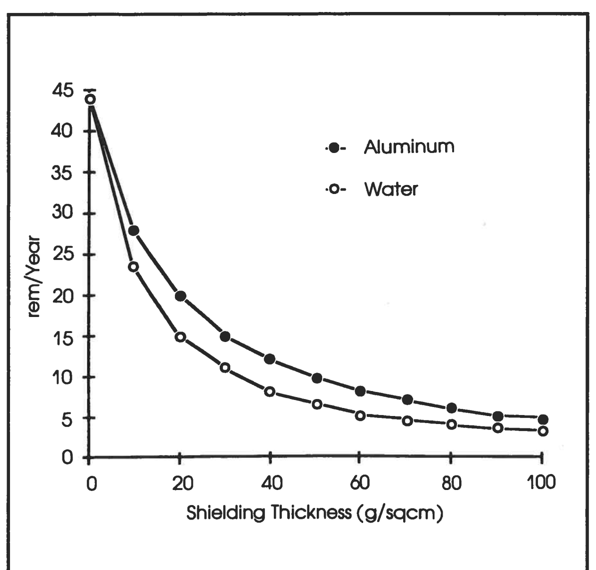
Crews on missions to Mars and other distant locations will encounter radiation exposure at least two orders of magnitude greater than has been experienced on previous space flights. While the general dose rates will be comparable to levels Apollo astronauts received on lunar missions, flight durations will be much longer. Missions to Mars and back will probably require 2 years or more. Many prominent scientific experts envision human space expeditions lasting many years, decades or even generations. Realization of such possibilities will depend upon our ability to much more fully understand the nature of space radiation, its effects upon health, and effective ways to mitigate the dangers.

Travel to other planets will mean traversing the Van Allen Belts where trapped particles present a significant hazard. In addition, the crew will be bombarded by the relatively constant galactic cosmic rays (GCRs). Since we currently lack a sound basis for developing a reliable quality factor for GCRs there is disagreement among researchers about appropriate dosage limits. Important questions have to do with the biological effects of GCRs and how to translate the number and intensity of particle encounters to rem. Estimates of their damage ranges from 1-20 times the effects of similar x-ray doses.

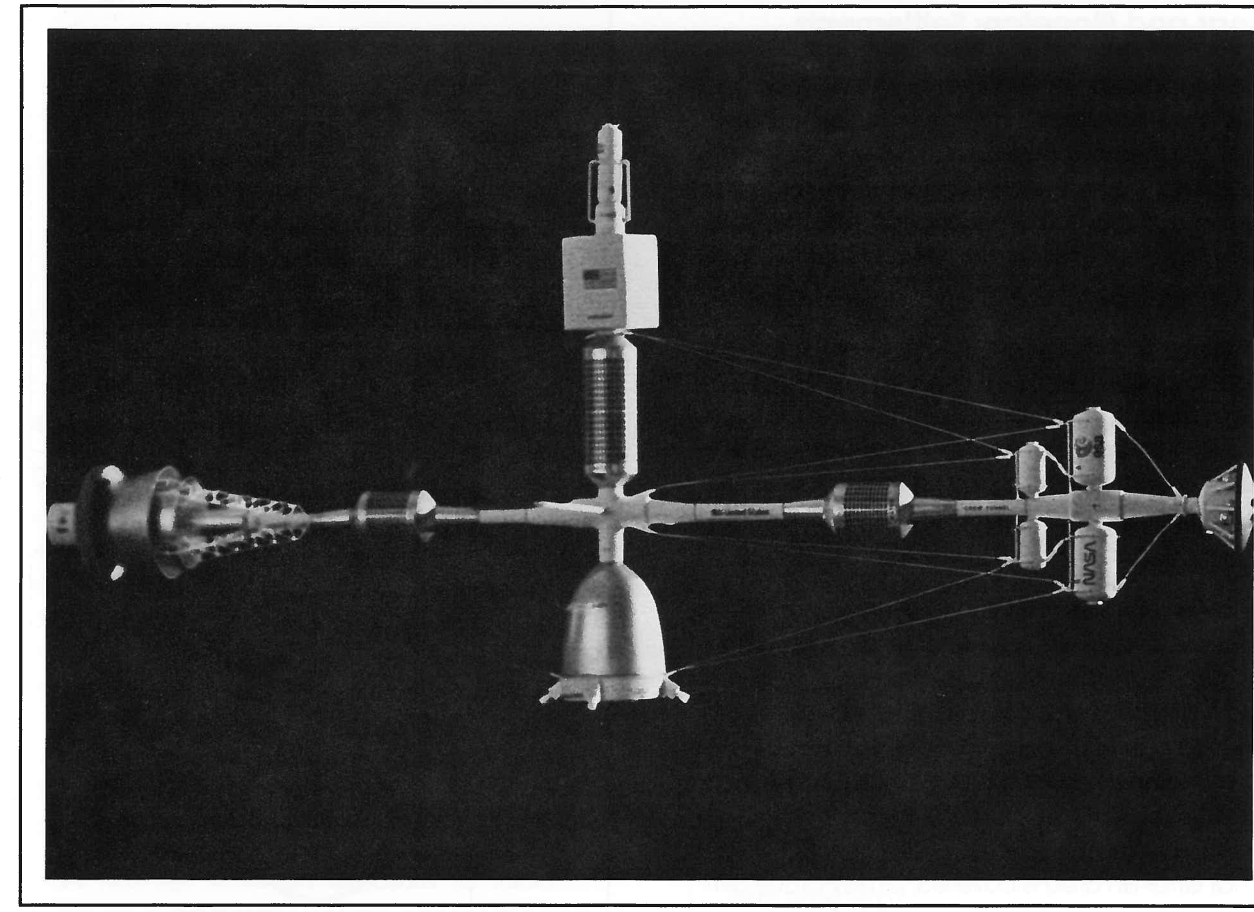
Astronauts on a two to three year-long planetary voyage will also face a finite risk of exposure to a large solar proton storm. The probability of such an event will be influenced by mission timing with respect to the Sun's 11 year cycles of activity. Given our rudimentary scientific knowledge of SPE causes, forecasting to offer an early warning of imminence or to predict intensity is currently not possible. After a SPE is detected, however, instrumentation can determine if high energy protons have been blown into space. This allows astronauts between 20 minutes and 3 hours to reach the most shielded area inside the spacecraft, depending on how far from the Sun they are. Provision of an onboard solar flare detection system and storm shelter is strongly advised.



Proton Energy Spectrum
J.R. Letaw, R. Silberberg, C.H. Tsao
Naval Research Laboratory, Washington, D.C.



GCR Primary Dose Shielding-Alum. vs. Water
J.R. Letaw and S. Clearwater, 1986.



SICSA Manned Mars Vehicle Concept
Design and Model by Sean Nolan

Mission	Radiation Source	Days	Dose (mSv)
Sortie to GEO[a] Long. 160° W, 2 g/cm² Al	Van Allen Belts GCRs	15	56
Lunar Mission 4 g/cm² Al	Van Allen Belts GCRs	90	74 1000
Mars Mission	Van Allen Belts GCRs, SPE[b] and Power Sources	1095	1800

a Geosynchronous
b Potential Solar Particle Event

Radiation Dose Estimates for Space Missions Beyond the Magnetosphere
R.J.M. Fry, Biology Division, Oak Ridge Nat'l Laboratory and
D.S. Nachtwey, NASA Johnson Space Center

Note: These estimates are more speculative than those presented on page 6 for LEO.

Radiation Countermeasures

Shielding Around Habitable Areas

- *Use of thick, dense spacecraft walls.*
- *Water tanks and stowage inside walls.*
- *Thick soil layer over surface habitats.*

Operationally Minimize Crew Exposure

- *Restrict and rotate extravehicular activity.*
- *Limit mission lengths and number of tours.*
- *Operate LEO space stations at lowest practical altitudes.*

Carefully Screen Crew Candidates

- *Select people who are low cancer risks.*
- *Use older crews with low lifetime doses.*

Lunar and Planetary Settlements

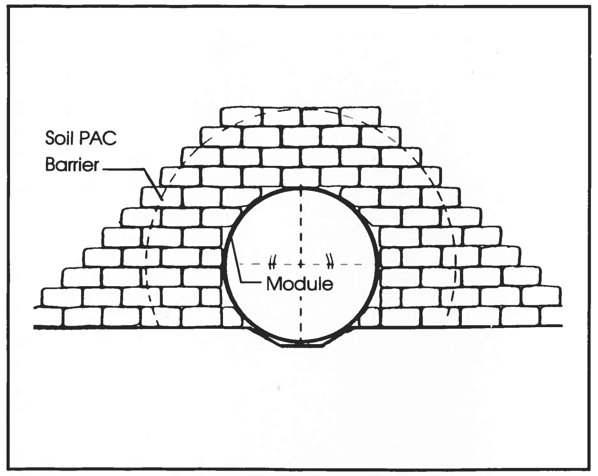
Ionizing radiation environments on the Moon and Mars pose perplexing obstacles to the achievement of future colonization. Unlike our planet, the Moon has no radiation absorbing atmosphere, nor a magnetic field to deflect cosmic ray particles. Mars' thin carbon dioxide atmosphere and very weak magnetic field offer little protection.

A variety of habitat shielding concepts have been proposed to take advantage of natural geologic features and surface materials for protection. Key options include placing habitats in underground lava tubes, tunneling into crater walls, or covering the facilities with 50 centimeters or more of packed or bagged soil.

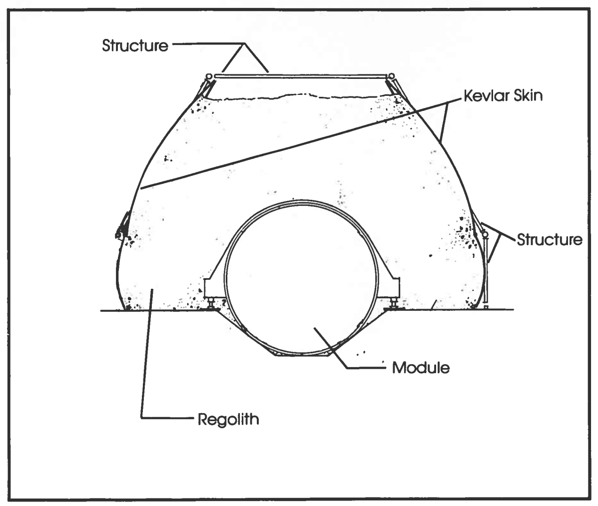
Reliance upon soil barriers for shielding entire complexes against large SPEs and GCRs will influence development in significant ways. Use of lava tubes, for example, will severely restrict site selection options. Tunneling, or material transfer to cover many modules will require large automated equipment systems to handle massive amounts of material. Another potential problem is that after an area is covered, it may prove difficult to position and connect additional modules nearby to accommodate evolutionary growth.

The annual skin dose from GCRs with 4 g/cm^2 shielding is estimated to be approximately 12 rem on the Mars surface and 18 rem on the Moon. Since these doses are under the 50 rem/year limit and shielding spawns secondary radiation, an option is to concentrate shielding around selected modules or "storm shelters" to protect inhabitants from massive solar particle events only. This approach is highly controversial, particularly since the effects of long-term exposure to GCRs are still unknown.

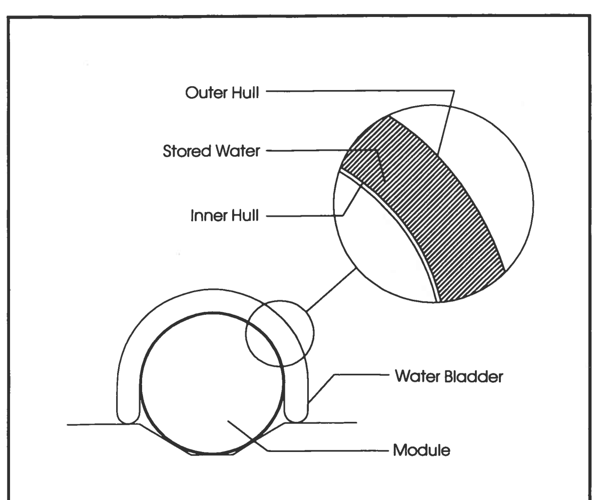
Protection from large SPEs can be accomplished by adding mass ($\geq$ 20 g/cm^2) to or within the walls of the emergency refuge. Aluminum, water, methane, plastic and boron or lithium hydrides are alternatives. The resulting mass poses problems, however, with a half-sphere aluminum shelter 2m in diameter exceeding 1.3 metric tons.



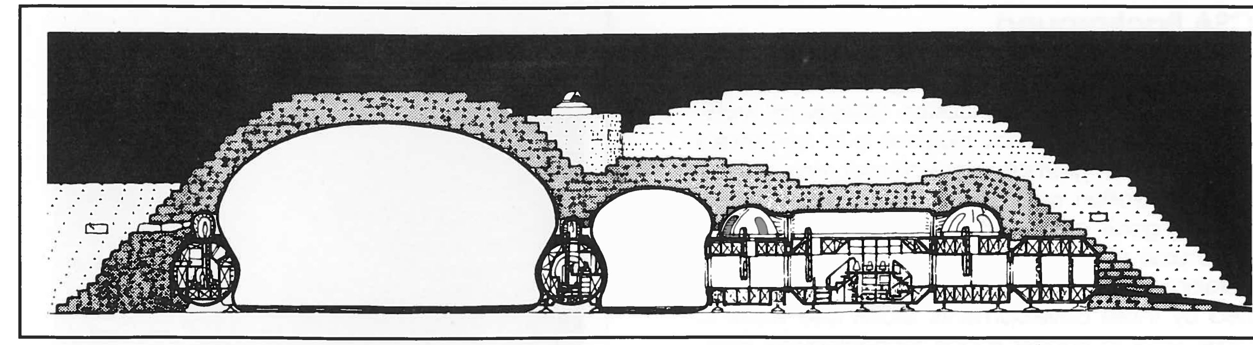
Soil Bags to Provide Shielding
SICSA Concept



Shielding Structure Containing Soil
SICSA Concept by J. Lorandos and E. Akhidime



Water to Supplement Shielding
SICSA Concept-Drawn by J. Lorandos



A massive quantity of soil would be required to adequately shield an entire settlement.

Summary Considerations

Health dangers associated with ionizing radiation on long-term missions beyond the Earth's surface pose serious and difficult problems warranting priority attention. The three primary natural radiation sources are the Van Allen Belts, intermittent and unpredictable solar particle events (SPE), and the low flux density, but highly energetic galactic cosmic rays (GCR) which continually bombard space from all directions. Man-made hazards, such as from nuclear power systems must also be considered.

NASA has set limits on exposure to radiation based on a 3% excess lifetime cancer mortality risk. These limits vary depending on age at first exposure and sex of the individual, with a maximum ceiling set at 50 rem/year and 400 rem in a total career.

Protecting future spacefarers from excessive radiation provides a strong technical challenge. Although the danger present in the Van Allen Belts is well known and can be minimized, radiation from GCRs and SPEs is more difficult to mitigate. This is partly due to the high degree of uncertainty of the biological effects from exposure to GCRs. In addition, the high energy characteristics of GCRs make shielding from them complex and of questionable value. Should overall shielding be required, lunar and planetary surface habitats may be protected using soil barriers. It is important to consider impacts of this approach upon site selection, equipment and operations requirements, and facility staging.

Damon, T. 1989. ***Introduction to space: The science of spaceflight.*** Malabar, FL: Orbit Book Company.

Fry, R.J.M., and D.S. Nachtwey. 1988. Radiation protection guidelines for space missions. ***Health Physics,*** vol. 55, no. 2, pp. 159-164.

Fry, R.J.M. 1986. ***Radiation effects in space.*** Paper presented at the 26th Plenary Meeting of the Committee on Space Research, Toulouse, Fr.

King, J.H. 1974. Solar proton fluences for 1977-1983 space missions. ***Journal of Spacecraft and Rockets,*** vol. 11, pp. 401-408.

Letaw, J.R. and S. Clearwater. 1986. ***Radiation shielding requirements on long-duration space missions.*** Severn Communications Corporation, Sevena Park, MD. SCC Report 86-02. Naval Research Laboratory Contract N000 14-85-C-2200.

Letaw, J.R., R. Silberberg, and C. H. Tsao. 1986. Natural radiation hazards on a manned Mars mission. In ***Manned Mars missions working group papers.*** NASA M002.

Nachtwey, D.S. 1982. ***Radiation exposure detection and protection.*** Paper presented at the 53rd Annual Scientific Meeting of the Aerospace Medical Association, Bal Harbour, FL, May.

National Council on Radiation Protection and Measurements (NCRP). 1989. ***Report no. 98: Guidance on radiation received in space activities.*** Bethesda: NCRP, July.

Nealy, J.E., J.W. Wilson, and L.W. Townsend. 1988. ***Solar-flare shielding with regolith at a lunar base site.*** NASA Technical Paper 2869.

Nealy, J.E., J.W. Wilson, and L.W. Townsend. 1989. ***Preliminary analyses of space radiation protection for lunar base surface systems.*** Paper presented at 19th Annual Intersociety Conference on Environmental Systems, San Diego, CA, July.

Nicogossian, A.E., and J.F. Parker. 1982. ***Space physiology and science.*** NASA SP-447.

Report on the RBE Committee to the International Commissions on Radiological Protection and on radiological units and measurements. 1986. ***Health Physics,*** vol. 9, pp. 357-386.

Silberberg, R., et al. 1985. Radiation transport of cosmic ray nuclei in lunar material and radiation doses. In ***Proceedings of lunar bases and space activities of the 21st century,*** ed. W.W. Mendell. Houston: Lunar and Planetary Institute.

Sinclair, W.K. 1988. Radiation safety standards: space hazards vs. terrestrial hazards. ***Advanced Space Research,*** vol. 3, pp. 151-159.

Related Information Sources

SICSA Background

SICSA is a nonprofit research, design and education entity of the University of Houston College of Architecture. The organization's purpose is to undertake programs which promote international responses to space exploration and development opportunities. Important goals are to advance peaceful and beneficial uses of space and space technology and to prepare professional designers for challenges posed by these developments. SICSA also works to explore ways to transfer space technology for Earth applicaitons.

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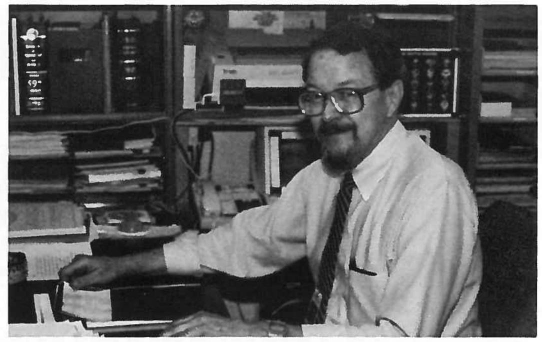

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This report expands upon information and views presented by Dr. Nachtwey and SICSA Director, Larry Bell, in a lecture at the International Space University (ISU), 1988 summer session held at the Massachussetts Institute of Technology.

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