The Space Exploration Initiative represents a major evolution in scope when compared to any previous human spaceflight program. The Mercury program was designed primarily to demonstrate the feasibility of human spaceflight, and successive efforts have progressively expanded our understanding of human response to spaceflight.

Health maintenance and medical care will be crucial to the Space Exploration Initiative. Missions to the Moon and Mars will expose crew members to reduced gravity and to radiation, both potentially harmful. Human factors considerations are important for crew selection, interpersonal relationships, and human-machine interfaces. These and other factors must be reflected in the design of space vehicles and missions for human exploration.

Spaceflight Deconditioning

The experience from both the U.S. and Soviet programs has shown that zero gravity has profound and varied effects on human physiology, resulting in a broad range of responses that vary in nature according to the duration of exposure and use of countermeasures. This process of adaptive responses, termed "spaceflight deconditioning," can compromise mission objectives if not appropriately managed. The key physiological systems affected by extended exposure include:

The Cardiovascular System: This system undergoes a complex adaptation which includes both functional and structural changes. Primary operational concerns involve low blood pressure and abnormal heart rhythm.

The Musculoskeletal System: Bones and muscles lose mass in space. Bone loss also results in an increased risk of kidney stones and an increased risk of fracture in flight as well as post-flight.

The Neurological System: The neurological system undergoes an adaptation which results in a number of concerns. Space motion sickness can occur early in flight and can be a problem until the body adapts to zero gravity.

The Hematological, Immunological and Endocrine Systems: Anemia and immune system dysfunction need to be studied further to understand the long term medical implications. The human endocrine system, affected in a multitude of ways which could impact crew health, requires further study.

Extended exposure to zero gravity results in profound changes in human physiology. This must be understood in order to modify the course of spaceflight deconditioning and enable the delivery of medical care in space, since acute medical care decisions are often based on changes in underlying physiological indices.

Another concern is the effect of reduced gravity on a crew member

Space Shuttle Medical Evaluations

already deconditioned by exposure to zero gravity. The crew must have adequate physiological reserve to perform assigned duties.

The effects of deconditioning from extended stays on planetary surfaces also needs to be better understood to determine if there are any adverse effects on crew performance during long missions.

Space Radiation

The Space Exploration Initiative program requires understanding and management of space radiation hazards. A multidisciplinary radiation issues research program involving solar physics, nuclear physics, radiobiology, and probability risk assessment will have a major influence on spacecraft design, habitats and mission planning. Such a program should be able to qualitatively and quantitatively determine the energy, particle type, and reaction mechanism dependencies necessary for biological and mechanical space radiation risk assessment. Generation of additional physics data characterizing galactic cosmic radiation, solar particle events, and solar dynamics will enable the development of reliable predictive models of the radiation environment.

Uncertainties in these radiation effects on cells, tissue and small organisms could be reduced by simulations using the Bevalac at the Berkeley Radiation Laboratory or the Brookhaven Booster Facility. Radiation shielding requirements should be established with an interagency effort between NASA, the Department of Energy, and the Department of Defense. Ground and space-based facilities and programs must be started now to be in place and fully operational by 1995. An expanded ground based simulation program will be used as a basis for radiation environment and shielding models; however, space experiments will be needed for validation.

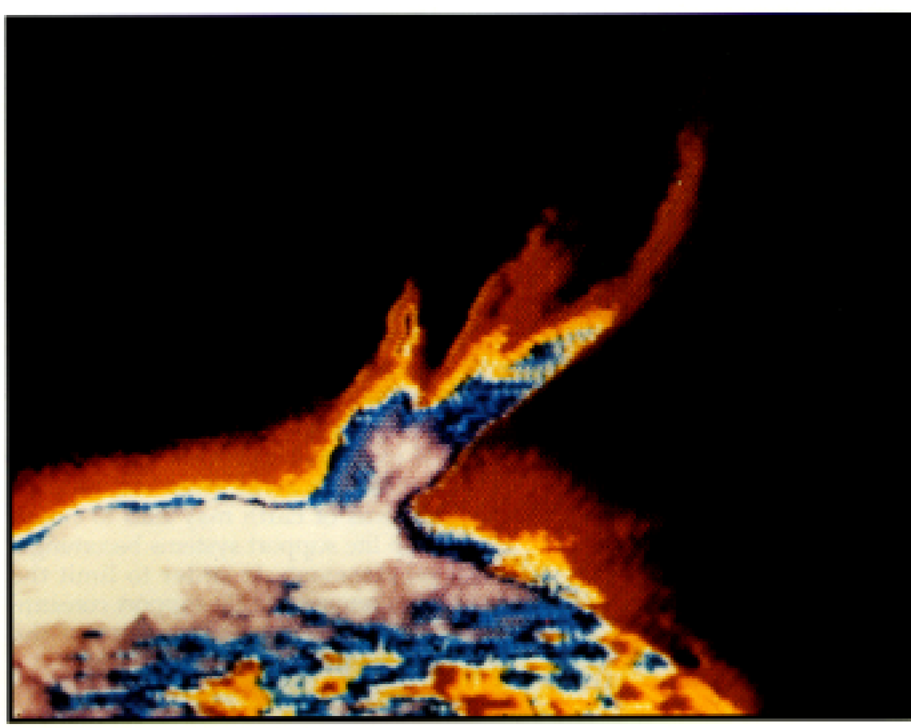
Medical Care

Within the U.S. space program, inflight medical illness has resulted only in minor mission impacts. In contrast, the Soviet space program, where missions are often lengthy, has been impacted by inflight medical contingencies. Their contingencies resulted in either a mission abort or replanning on several occasions. While predicting the likelihood of medical illness or injury inflight is difficult, it is reasonable to assume that medical contingencies will probably occur in the course of an ambitious and sustained exploration program.

The objective of inflight medical care is one of risk management. Crew health can be affected by a number of factors.

Given that crew illness or injury has the potential to impact mission objectives and crew productivity, an adequate medical care capability should be provided for all phases of the exploration program. Computer-

Solar Eruption Photographed from Skylab



based medical and compact diagnostic systems, extended life pharmaceuticals, blood substitutes (or freeze-dried blood) are needed for the Mars missions.

Life Support Systems

Conducting operations in space requires that provisions be made for protecting people from its hostile environment. Human physiology possesses a remarkable degree of adaptability, but humans can only survive in an environment characterized by rather narrow thermal and atmospheric limits. The materials needed to sustain life can either be brought from Earth or, with the right technology, created in place from wastes or in situ resources. This tradeoff between logistical resupply, regeneration and manufacturing is embodied by the concept of loop closure.

U.S. space programs to date have employed open loop system design, with no reuse of waste products. Wastes are stored for return to Earth or are vented overboard from the spacecraft. Initial efforts at partial water loop closure have been undertaken on the Soviet Mir station. However, further work on the type of closed loop systems critical to the success of the Initiative needs to be accomplished. Creation of closed loop life support systems based on regeneration of waste products represents a radical departure from the existing experience.

The cost of resupplying open loop life support systems for the conduct of extended duration missions or operations away from the support systems of Earth may lead to closed loop life support systems becoming a requirement. In order to limit the requirement for life support consumables, certain components of the waste stream must be recycled.

The basic subsystem functions traditionally included in life support include the following:

- Temperature and humidity control
- Atmosphere control and supply
- Atmosphere revitalization
- Water reclamation and management
- Waste processing
- Fire detection and suppression

These activities form the basis of the Environmental Control and Life Support System. Other life support functions which must be addressed include food supplies, system control, and local resource utilization.

The design of the Environmental Control and Life Support System is interrelated with a number of key operational considerations. Most important of these is the selection of the atmospheric parameters for exploration spacecraft and habitats. The selection of a hypobaric, normoxic atmosphere, such as utilized for Skylab (5 psi total pressure with an approximate 70/30% mixture of oxygen and nitrogen, respectively), allows the principal advantage of conducting extravehicular activities with minimal prebreathing. Another benefit of a lower operating pressure is reduced leakage rates.

The main drawback outside of unknown, long term physiological effects, is reduced cooling and heat dissipation. While a reduced pressure, oxygen-enriched atmosphere results in concentrations of oxygen which are equivalent to sea level atmosphere, the body is subject to a total pressure which is approximately one-third of that on Earth. Although the Skylab missions have demonstrated the feasibility of working in reduced pressure for up to 84 days, a number of physiological changes have been documented.

The physiological effects of living in hypobaric environments for extended periods of time are not known at present. While they do not appear to result in any gross disruption of physiological processes, the long term effects and the interaction with the effects of zero gravity exposure need to be characterized. The effects of extended hypobaric exposure should be studied as a component of a ground-based research program. Specialized facilities such as altitude chambers will be utilized for this research.

The development of life support systems with high efficiency and reliability represents the area of greatest technical emphasis in the life sciences area. A developmental program should focus on both subsystem and integrated system technologies, as well as a core research program to evaluate applicable physical-chemical processes.

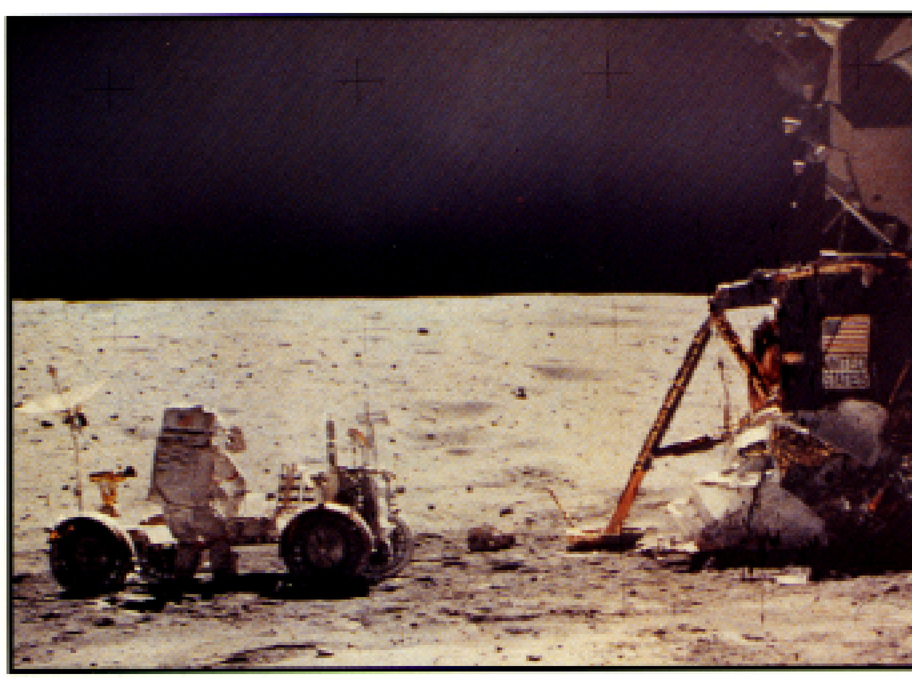
Human Factors

Human factors address the issues relevant to human interface with a variety of systems. In the past two decades, there has been an increasing awareness of the value of human factors in the design of work environments. The missions proposed in the exploration program would expose crew members to a unique combination of stresses and hazards for long periods of time. Effective integration of human factors considerations into mission design results in two primary accomplishments: a) the human would be physically and mentally able to do the tasks outlined, and b) all the systems, equipment, spacecraft, rovers, vehicles, tools, etc., will be designed so the tasks can be efficiently accomplished.

Specific human factors issues include:

- Habitat design, including usable volume and space allocation
- Human-machine interfaces
- Psychological and psychosocial considerations, such as crew selection, small group dynamics, provision for recreation and optimal crew size and mix
- Environmental and physical considerations such as lighting and ventilation

Astronaut Loading Equipment on Lunar Rover, Apollo XVI



Conclusions

Cumulative experience from both the U.S. and Soviet space programs has resulted in an initial characterization of the human response to spaceflight. Exploration missions present numerous challenges relative to previous programs.

Space Station Freedom can represent the transition within the U.S. space effort to a sustained presence in low Earth orbit. Planning for exploration missions has identified a space station as the primary zero gravity platform for conducting life sciences investigations. This orbital test bed would provide first generation capabilities, particularly spaceflight deconditioning countermeasures, the development of medical procedures and facilities, and the development of closed life support systems. The Report of the Advisory Committee on the Future of the U.S. Space Program recommended that "the justifying objectives of Space Station Freedom should be reduced to two: primarily life sciences, and secondarily microgravity experimentation." If this recommendation is implemented, then the space station would be utilized to resolve the life science issues critical to a Mars mission. However, program reviews in the past two years have resulted in restructuring and delaying the space station. These programmatic changes call into question the availability of life science data in a timely manner.

Missions to the Moon can be initiated without resolving many of the life science questions that must be resolved for the Mars mission. All of the architectures require lunar activity prior to initiating a piloted Mars mission. It is therefore logical to consider the concept of utilizing the Moon as a preparatory environment for a Mars mission to integrate a number of key life science and operational requirements. There is a compelling argument for the deployment of a first-generation Mars transfer vehicle (crew compartment) in lunar orbit. This zero gravity test bed would allow development and validation of key life support technologies and human factors design, and would function as a platform for conducting essential biomedical investigations into spaceflight deconditioning. Additional rationales for a Mars transfer vehicle in lunar orbit include validation of radiation shielding provisions developed for Mars excursions and conduct of radiobiological experiments to refine dose-effect models.

The use of the Mars transfer vehicle, in conjunction with a surface emplacement on the Moon, would allow mission-critical studies into the physiological effects of fractional Earth-normal gravitational exposures following extended zero gravity stays. This objective can be accomplished with a high degree of operational fidelity on the Moon, and the ready access to zero gravity or fractional gravity would permit a rapid accumulation of data. Simulations of Mars gravity on the lunar surface, using a weighted spacesuit, would allow refinement of gravity-response curves.

The Mars transfer vehicle would have a number of other key missions in addition to life science activities, including simulations of Mars missions complete with excursions to the Martian (lunar) surface and return, the use of an orbital platform for lunar or astronomical observations, and as a test bed for other essential Mars transfer vehicle subsystem development.

This approach, which integrates several key life science requirements with other exploration objectives, should take advantage of existing assets, specifically the Shuttle and the Soviet Mir space station, to initiate an early start on key life science issues. The Shuttle is an ideal platform for developing and testing zero gravity countermeasures and validating life support system hardware. An aggressive ground-based research effort will be a critical element, leveraging the effectiveness of inflight investigations.

The recent increase in joint U.S. and Soviet cooperation in the life sciences is an encouraging development. For the present, Mir represents the only extended duration spacecraft in operation, and access to Soviet crews for joint medical studies represents a tremendous windfall that adds to the existing knowledge base. This resource represents a timely start on key medical and physiological concerns and should be aggressively pursued.

Skylab Bicycle Ergometer